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RESEARCH ON THE DESIGN AND CONSTRUCTION OF A FILAMENT STORAGE SYSTEM FOR 3D PRINTERS

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ABSTRACT: This work aims to create a prototype of an automated filament spool handling system for 3D printers. This is a derivative of the classic storage system defined as ASRS (Automated storage-retrieval system). This type of system is already present in the industry for the automation of logistics processes in warehouses. The system has four major components: the transporter subsystem, the XZ positioning subsystem, the display control device (HMI) and the storage and measurement subsystem.

Keywords: ASRS, 3D Printer, Arduino

Introduction

In the era of advanced technology and continuous innovation, automation is becoming central to improving efficiency and performance in a wide range of industrial fields. In this context, the present paper proposes the development of a prototype of an automated system for handling filament spools intended for 3D printers. This system is an adaptation of the well-known ASRS (Automated Storage and Retrieval System) concept, already used in the industry to optimize logistics processes in warehouses.

Essentially, the project focuses on four major components, each with its own distinct and essential role in the functioning of the system as a whole. These components include the conveyor subsystem, which facilitates the efficient movement of filament spools within the system, the XZ positioning subsystem, responsible for precisely positioning the spools at various locations, the display controller, which provides the user interface and control over the entire system, and, not least the storage and measurement subsystem, which manages the proper storage of filament spools and provides stock and consumption information.

These components are made as stand-alone modules that have their own integrated micro-controller and communicate with the rest of the modules in the system. This allows for much easier further development.

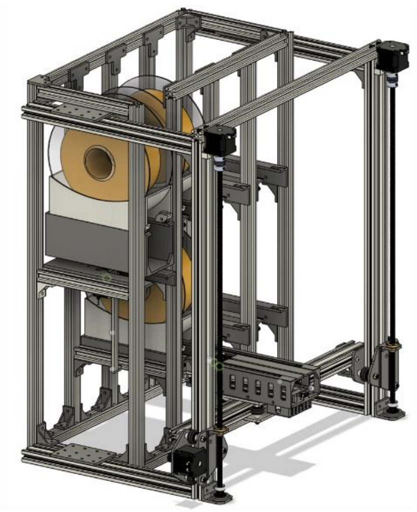

Fig. 1 Automated storage

Current stage

At the time of this article there was no similar system on the market. What does exist, however, are box-type handling systems, as presented in the paper "Automated storage and retrieval system" ([1], 2020) which exposes an automated storage system placed between two rows of shelves, a system similar to that found in larger-scale automated warehouses that work with full size euro pallets or boxes. Another similar paper, for which there is no written paper ([2], 2017), but which illustrates a similar system to the first paper, also manipulates miniature pallets.

General presentation of the work

The initial idea of the project was formulated to respond to the need of users in the field of 3D printing to efficiently manage and control their necessary raw materials.

The proposed system facilitates the organized storage of these materials, providing the user with accurate and up-to-date information about the stock level and diversity of available materials. In addition, the system opens the horizon to the generation of detailed statistics on material consumption and to ensuring business traceability, thus contributing to process optimization and decision-making within the production process.

Thus, the system is composed of four distinct subsystems:

- The transporter - has the role of handling the filaments between the storage area and other areas of the system.
- XZ positioning subsystem - takes care of the precise positioning of the conveyor at one of the slots or at the measuring area to facilitate the transfer of the spool.
- Display control device - represents the main interface between the system and the user, allowing them to transmit commands and use the system effectively.
- Storage and measurement subsystem - has the responsibility to store the filaments and measure their parameters to ensure an optimal and efficient production process.

Since the filament spools can have different shapes and sizes, it was chosen to standardize the product to be handled with the help of introducing a special support that is designed for efficient handling (Fig. 2).

It has two bearings that improve the movement of the support on the contact surfaces, but also an extension that helps the conveyor to confirm that it has reached the correct position and that it has touched the support.

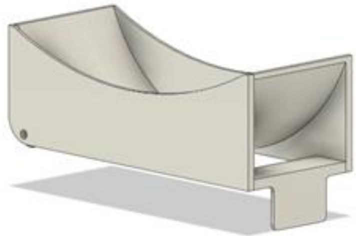

Fig. 2 Support for filament spool

The transporter

The transporter (Fig. 3) is the device responsible for the Y-axis manipulation of the rolls, more precisely with the placement or withdrawal of the rolls on/from the storage space.

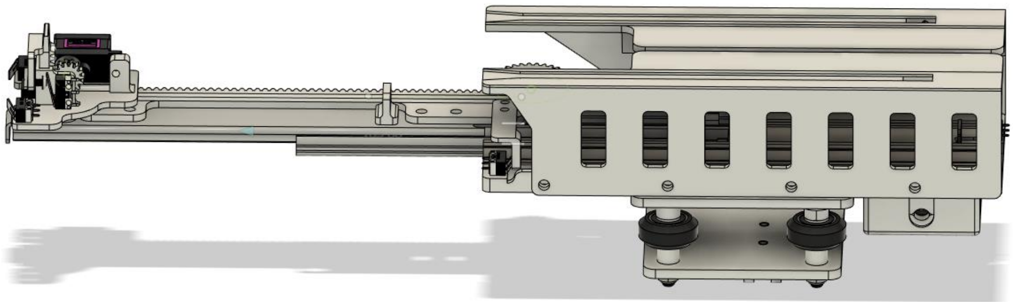

Fig. 3 Extended version of the transporter

It is designed to be able to extend so that it can reach the spool, and for this a rack and pinion mechanism is used together with a furniture slide with a linear guide role. A servomotor (S0025M) is used to move the extending system.

In order to make contact with the spool support, a system with a sort of pin that can raise is mounted on the extremity of the slide, with the help of a servo motor (MG90S) the pin is set in motion. Mounted in front of this system are two micro-switch type sensors connected in series to help the system accurately position itself relative to the spool holder. The control of the pin position is carried out with the help of two micro-switch sensors for the limits (lower and upper) of the pin. The top position can be adjusted with the adjustment screw.

For a correct positioning of the extension system, two micro-switch sensors are also used for the stroke ends. So that the conveyor can be moved and thus positioned at one of the storage spaces, it has four special beveled rollers. They slide on a metal profile with specially designed surfaces for the roller to run perfectly on them; this technology is called "v-slot"¬ and it is an innovative method of combining structural elements with linear guide elements. A 6mm wide transversal toothed belt known as GT2 is used to move the transporter, driven by a nema17 stepper motor.

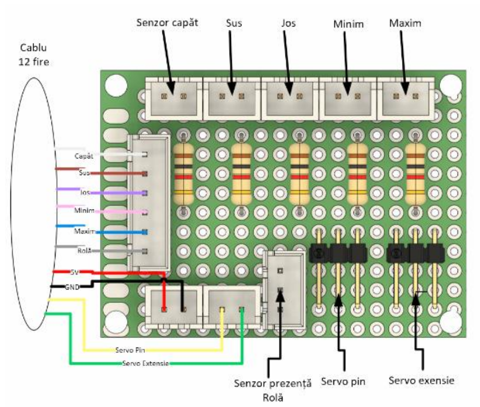

Fig. 4 Electronic prototyping board for extension

Since the transporter has many sensors and motors, and the control board is at a considerable distance, it was decided to make an electronic prototyping board (Fig. 4) and thus the number of wires needed for connections was reduced from 19 to 10. In this way so we can connect the transporter to the main Arduino board by means of a 12-wire cable with a diameter of 0.33mm. A 12-wire cable was chosen to prevent later modifications, improvements or additions. These limit switches have a similar mode of operation to touch buttons and in order for them to be interpreted correctly by the acquisition board they need a pull-up circuit which is done using a 1k or 10k resistor as shown in the schematic from Fig. 5.

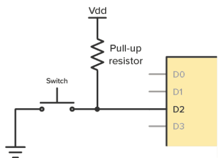

Fig. 5 *Pull-up* circuit **([3], 2021)**

Display control device (HMI)

The display screen is the interface through which the user can control the automated system, from here the operator can choose whether to add or retrieve a spool of filament from the warehouse, and the system will guide him through the steps he needs to follow in order to perform the selected operation.

In terms of hardware, the display screen consists of a 320x240 pixel tft touch screen, which has an ST7789 driver for the graphics part and an XPT2046 driver for the touch part. They are controlled by a Groudstudio carbon D4 development board with esp32 microprocessor and programmable in c++ language, Arduino. The development board is assembled on the back of the screen with the help of silicone in a well-established position, measured and marked with the help of a caliper. This further helped in the easier design of the case, which was later 3D printed. The electrical connections were made by hand, connecting the two components according to the diagram in Fig. . The SD card reader has also been replaced with one for micro SD to enhance the ergonomics of the design.

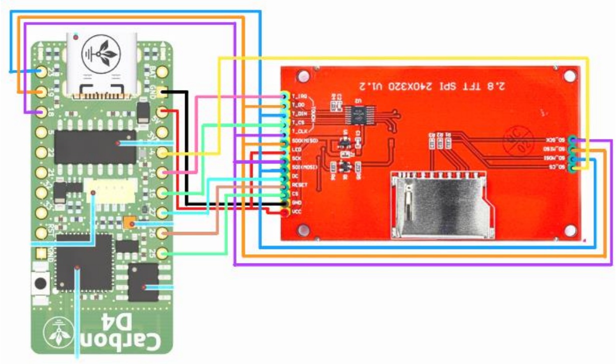

Fig. 6 Electric diagram of the display

The physical version of the prototype for the display screen is shown in Fig. 6 which illustrates how the components are connected on the back of the screen and Fig. 7 where you can see the main page of the screen from which you can select the two ways of using the screen.

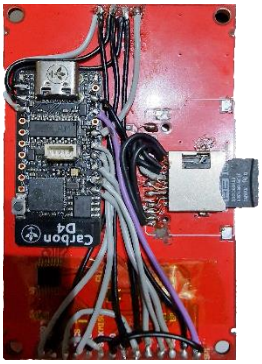

Fig. 6. The command circuit of the display

Fig. 7. Home Page

As for the software part, separate files were used for the various functions of the screen. An example of this is the file for each page or category of pages, which contains two types of functions: display function (responsible for making graphics for the page such as texts, images, shapes) and functionality function (responsible for interpreting screen taps and reacting accordingly). Navigating through the pages of the screen is easy, the design being minimalistic, and is shown in Fig. 8, in a narrow form.

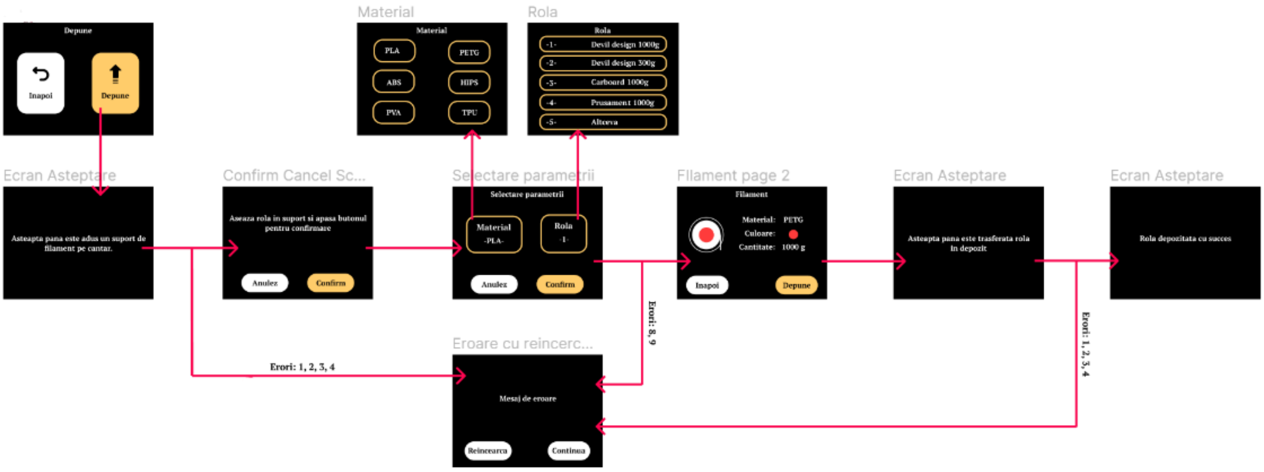

Fig. 8 Data-flow diagram of the system

Also, since the system contains two development boards, it is necessary to create a communication protocol, so a protocol of the form "XX-YY-ZNN" was used, where XX represents the board for which the message was communicated, YY the board that transmitted the message, Z message type: S- status, C-command, E-error, and NN the numerical code of the message (DI-MB-S01, means that the message S01 - "Operation completed successfully" was communicated by the motherboard "main board" - MB, for "display" screen - DI). The rule is that one of the boards sends a command type message, and the board that has to respond will send back only a status or error type message. This approach helps to make the system modular, which makes future improvements much easier because a large number of modules responsible for various functions can be introduced. These modules can be connected via the usb connector for programming, but also using the two communication pins RX and TX or D0 ¬and D1 of the Arduino development board. The communication rules can also be seen in Table 1.

Table 1 Communication rules

Commands	Description	Received message	Description
MB-DI-C01-06	Filament/palet command	DI-MB-S01/E..	Terminated with success/error
MB-DI-C11-16	Filament add	DI-MB-S01/E..	Terminated with success/error
MB-DI-C07	Collor interrogation	DI-MB-S02-0x0000/E	Succes-color
MB-DI-C08	Weight interrogation	DI-MB-S03-1000	Succes-weight
MB-DI-C09	Cancel mission	DI-MB-S01/E	Terminated with success/error
MB-DI-C19	Retry movement	DI-MB-S01/E	Terminated with success/error
MB-DI-C17	Raise the door	DI-MB-S01	-
MB-DI-C18	Lower the door	DI-MB-S01	-

Storage and measurement subsystem

The warehouse structure is made of 2020 aluminum profiles, assembled using 3D printed joints of various shapes. It is designed to accommodate 6 storage spaces for 3D filament spools, the area for inserting/removing the filament from storage, the area for measurements, but also the electronics and control part.

The measurement area (Fig. 9) consists of measuring filament color using a TCS34725 color sensor and filament mass using a force cell paired with an HX711 signal amplifier. The color measuring mechanism works similarly to the transporter extension system, using the rack-pinion mechanism, and to be able to limit the movement of the rack, the system has two end-of-stroke sensors of micro-switch type. The guide of the rack is made using a profiled hole on its shape.

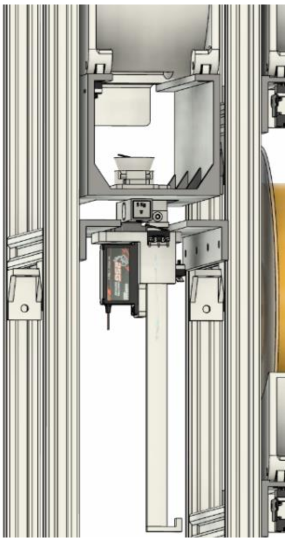

Fig. 9 Measuring system of the parameters of filament

The Cartesian XZ system (Fig. 10) is the mechanism responsible for the precise positioning of the conveyor at the space intended for filament storage. It works on principles similar to those used in the construction of Cartesian 3D printers, which use a screw-nut drive system for the Z axis, and a belt-pulley system for X and Y. The screw used is not an ordinary one, but a special one, having a trapezoidal thread section and 4 starts, with a step of 2mm. To eliminate the level difference between the two vertical guide columns, two parallel drive screws are used, they are driven by two nema17 stepper motors and synchronized with each other by means of a closed timing belt. An open belt drive mechanism is used for the X-axis, also driven by a nema17 stepper motor and held in tension by the tensioner.

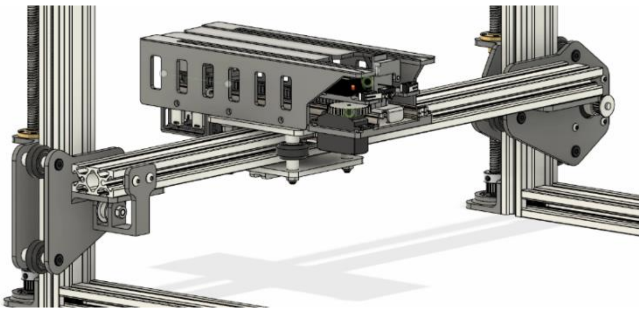

Fig. 10 The Cartesian positioning XZ system

Since the system has many sensors and motors, which are controlled by an Arduino nano controller, it was chosen to use SN74HC166N parallel-in serial-out integrated circuits that work by shifting registers and thus allow the parallel reading of several digital sensors using only 3 pins on the Arduino development board. These ICs can be connected in parallel to further increase the capacity. Considering the high number of digital sensors (19) the use of 3 such chips was chosen. The balance of these pins is detailed in Table 2.

Table 2 The list of inputs for shift-registers

Pin	Usage	Pin	Usage	Pin	Usage
1	Transp. Spool presence	9	Slot 3	17	Min Extend color
2	Transp. max	10	Slot 4	18	Max Extend color
3	Transp. min	11	Slot 5	19	Door closing sensor
4	Transp. down	12	Slot 6	20	
5	Transp. up	13	Scale zone pallet presence	21	
6	Transp. touch	14	Endstop X	22	
7	Slot 1	15	Endstop Z	23	
8	Slot 2	16	Spool touch (color)	24	

Conclusions

Thus, this paper presents an automated system for efficient filament storage for 3D printers, which provides a user-friendly and intuitive interface.

Own contributions include putting into a new form the well-known concepts, both automatic goods storage (ASRS), but also the classical mechanisms of 3D printer motion such as the screw-nut with trapezoidal section, the belt-pulley, the use timing belt. Another innovative idea used in this work is the shift-register concept, a concept explained in detail in the video on the YouTube channel "The Learning Circuit" ([4], 2020). Also, the modularity of the system is a plus of this prototype.

This system features many components modeled in CAD using *Autodesk's Fusion 360* 3D design software and 3D printed using *Artillery 3D*'s *Sidewinder X2* 3D printer.

As future improvements, the authors want to develop the following functionalities for this prototype:
- Wi-Fi connectivity to an MQTT server
- Realization of a web application for remote stock query
- Possibility to generate statistics about material consumption
- Internal temperature and humidity control to preserve material parameters

Bibliography

[1].Marlies Hoekstra and Maarten Schipper (2022), “Automate storage and retrieval system”, retrieved from https://www.hackster.io/453951/automated-storage-and-retrieval-system-2df0a8

[2].Nathan Koflanovich (2017), “Mini pallet ASRS cycle testing” retrieved from https://www.youtube.com/watch?v=ksVe7vame3Q&ab_channel=NathanKoflanovich

[3]. Øyvind Nydal Dahl (2021), „The Pull-Up Resistor: How it Works and Choosing a Value” retrieved from https://www.build-electronic-circuits.com/pull-up-resistor/

[4]. ariq Ahmad (2020), „How to Add Outputs to an Arduino Using a Shift Register – The Learning Circuit 77” retrieved from https://community.element14.com/challenges-projects/element14-presents/thelearningcircuit/w/documents/4986/how-to-add-outputs-to-an-arduino-using-a-shift-register----the-learning-circuit-77

DESIGN AND REALIZATION OF AN EXPERIMENTAL MODEL OF DELTA 3D PRINTER

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ABSTRACT: This paper presents the design and realization of an experimental model of a 3D Delta printer. The purpose of this work is to create a functional and ergonomic model, considering the weight of this model to be reduced, not ignoring factors such as its rigidity, accuracy and printing speed. I also opted for the use of components from the Bigtreetech series, as they are much better organized and easier to implement compared to the much more common components that include Arduino. Regarding the software of the system, I chose Klipper, it being much easier to implement on the electronics mentioned above.

KEYWORDS: Delta 3D *Printer*, Precision, Rigidity, Software, Fine-tuning, Adaptability, RepRap

1. Introduction

Over time, the term '3D printing' has become increasingly popular, currently having a wide range of applications, whether industrial, medical or decorative.

Several types of architectures have been developed in this industry, the most popular being CoreXY, Cartesian and Delta, the latter being chosen for the presented system. This type of architecture, Delta, was chosen in the construction of the system due to several factors:

- Provides greater accuracy of printed parts and models
- The quality of the surfaces of the printed models is much better
- Can be adapted much more easily to larger dimensions, while keeping a well-proportioned and efficient design
- Offers the possibility to customize elements such as the bed or the printhead

2. Current status

As I stated above, 3D printing technology became increasingly popular, appearing first as a futuristic concept between the 1950s and 1970s, then, making its appearance in 1987 with the first printer model, the SLA-1.

Currently, this technology has branched out, and is present not only in the field of plastics and copolymers (SLA, MSLA, SLS and FDM technologies), but also in the field of metallurgy (SLM, EBM, LMD, etc. technologies) and in the construction field.

Regarding, more precisely, the Delta architecture, on the market there are brands such as WASP or FLSUN (Figure 1) that are specialized in the construction of products of this kind, and, at the same time, enthusiasts or experts together build these customized machines and accessible to anyone, this kind of project being known as RepRap.

Fig.1 FLSUN V400

3. Stages of design and assembly of the physical components and implementation of the operating system

The goal of the project is to build a 3D Delta printer that will be able to print at considerably higher speeds (over 50-60 mm/s), and also to produce precise parts and with considerably better surface quality.

In this sense, in order to avoid the presence of surface defects, we chose for the extrusion system to be made in Bowden style, as can be seen in Figure 2. This implies that the entire extrusion system is found on the structure of the printer, thus making the effector to be lighter and at the same time, more compact.

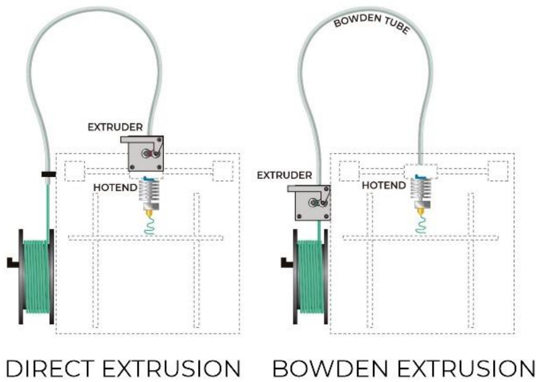

Fig.2 Direct extrusion and Bowden extrusion

The operating principle is slightly more complex because the axes are arranged differently from the Cartesian ones, which are more often seen in the world. Compared to Cartesian printerd, the axes of a Delta printer are positioned on the corners of a triangular base, the movement of the gantries being made along them. In addition to the movement made on the height of the axes, each set of arms moves independently, creating the horizontal movement of the print head, as can be seen in Figure 3.

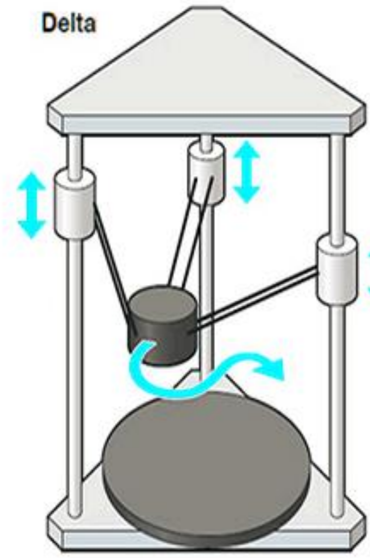

Fig.3 Operation diagram of a delta printer

Another important characteristic is the rigidity of the structure itself, as well as of the bed as a sub-assembly. This characteristic can be achieved especially if the right material is chosen, preferably ABS for 3D printed parts, and plates made of stainless-steel sheet, the latter having the ability to be good thermal conductors without showing deformations that can affect the printed models .

The design of the system was done in SolidWorks, and the 3D models of the accessories that are the electronics and the hot end were obtained from the manufacturers' support page. Aluminum extrusions, V-Slot type, 20x20 mm, respectively 20x40 mm, on lengths of 1 m for the columns and 250 mm for the sides of the structure were also used to make the structure.

The first step in designing the system was choosing the shape of the printer, choosing between the triangular or hexagonal version. While the triangular one can be more compact in shape, the hexagonal one is preferable, bringing an advantage by creating an enclosure that allows the use of a much larger printing space, according to Figure 4.

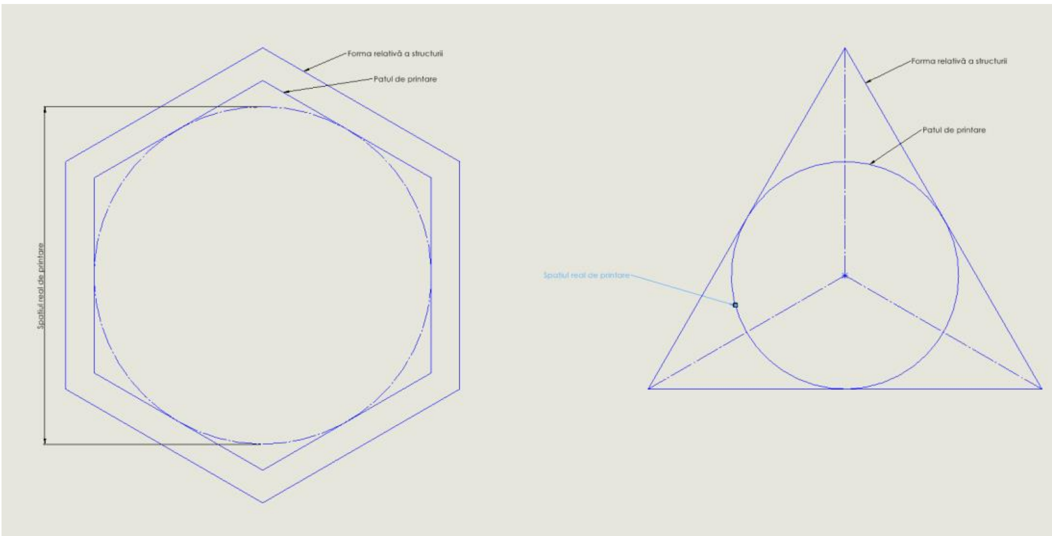

Fig.4 Relative comparison of the geometries of the printing spaces

Knowing these factors, the hexagonal shape was chosen. Thus, the main structure was made, along with that of the printing bed, according to Figures 5 and 6.

Fig.5 Main structure

Fig.6 Subassembly of the printing bed

Regarding the printing bed, I opted to making a whole sub-assembly (Figure 6.), considering that the elements that are heated directly do not have direct contact with the rest of the plastic parts, thus extending their life. It is composed of two stainless steel plates (Figure 7), the top plate having a silicone heating bed glued under it, the bottom plate, cut in the center to leave room for the silicone bed, acting as an insulating piece, having contact only with the first plate, the two plates being separated from the plastic frame by aluminum spacers (Figure 8).

Fig.7 Top plate (left) and bottom plate (right)

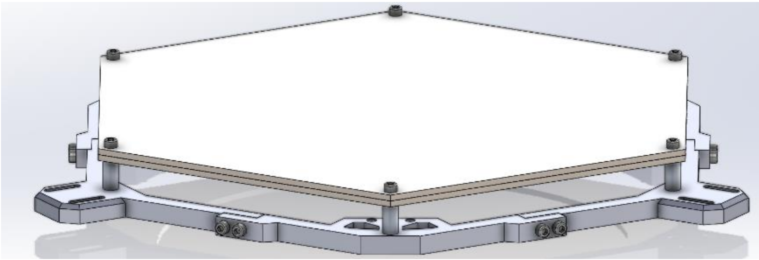

Fig.8 Assembled stainless-steel plates on the frame

Another goal of this work was to try to design a lightweight and compact print head (Figure 9). In this sense, Phaetus x Voron Hot end ST was a practical option, it by itself being compact, yet efficient, being able to print with all types of plastic, including those infused with abrasive materials such as sawdust, carbon fiber or rock. Also, for the calibration probe, Bigtreetech's MicroProbe was chosen, weighing only 6 grams, and also being half the size of the hot-end as shown in Figure 10.

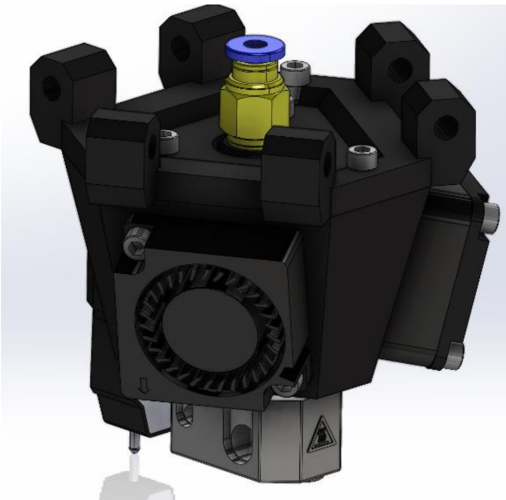

Fig.9 Print head

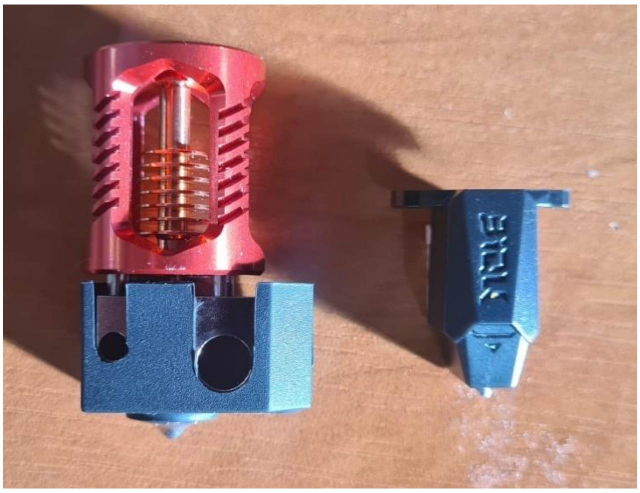

Fig.10 Phaetus x Voron Hot-end ST (left) and BTT MicroProbe (right)

In order for the movement of the print head to be as precise and easy as possible, I opted for the use of MGN12 linear guides, 1 meter long, which are equipped with 2 MGN12H bearings, produced by Hywin, on which they will be mounted later the tensioning block and the mobile element that attaches to the transmission belt, and ensures the movement of the print head (Figure 9).

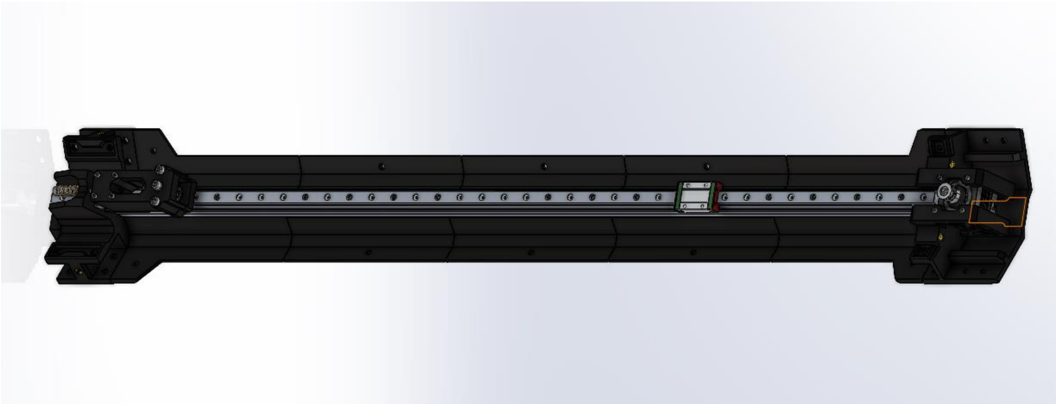

Fig.11 Main column assembly

To ensure increased accuracy of the prints, it is important to make sure that the tension in the belts is adequate and maintained over a long time and, making the adjustment as rarely as possible. To solve this problem, I designed a tensioning block equipped with a compression spring (Figure 8), that is mounted directly to the linear guide of the axis, to ensure the stability of the driving belt during printing.

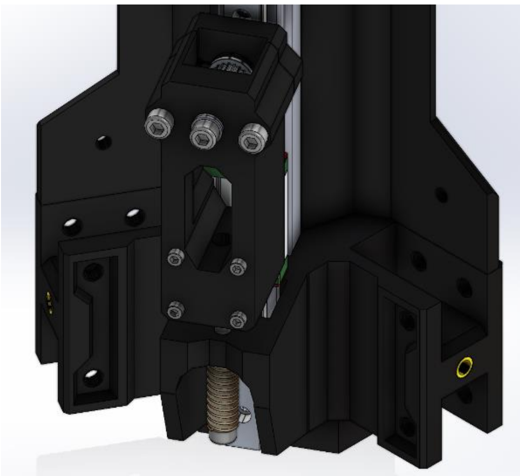
Fig.12 The tensioning block mounted on the main column

At the time of the presentation of this work, the printing assembly, various mounting elements for the electronics, the extruder, the enclosure and the operating system to be installed, configured and tested remain to be made.

4. Conclusions

In conclusion, the design and realization of this 3D delta printer can lead to the improvement of products of this kind, bringing a new design that can also be upgraded or modified to the user's taste. It has also proved that we can make a better use of the working space by using thinner aluminum extrusions, while maintaining its overall rigidity. Also, the successful implementation of the operating system, and fine-tuning of its parameters can bring the possibility of a new product entering the market that can compete with the existing ones. By addressing both hardware and software improvements, this 3D delta printer exemplifies how innovation in design and functionality can lead to superior performance. The adaptability of the printer means that it can evolve alongside technological advancements and user requirements, ensuring its relevance and usefulness over time. Overall, this project underscores the importance of continual improvement and innovation in the field of 3D printing, promising exciting developments for future applications.

BIBLIOGRAPHY:

[1] https://flsun3d.com/pages/v400
[2] https://recreus.com/gb/noticias/learn-with-recreus/direct-extrusion-vs-bowden-type
[3] https://www.corexz.com/theory.html

RESEARCH ON THE DEVELOPMENT OF A WINTER TRACTION ASSISTANCE SYSTEM FOR VEHICLES

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ABSTRACT: The work "Research on the development of a traction assistance system for motor vehicles in winter conditions" aims to improve the traction control system of motor vehicles through the design and experimental modelling of a system that acts when the vehicle skids on ice when leaving theparking place. Its operation consists of 2 subsystems: the sensor assembly and the sand mechanism assembly. Inputs to the system are data read from the car's ABS sensor, a hall-effect sensor that returns digital electrical pulses. Using an Arduino microcontroller, the data read from the sensor is processed and converted into revolutions per minute. Thus, depending on the increase in speed, the system takes various pre-set decisions. When skidding is detected, the subsystem is activated to spread sand in front of the wheel to increase grip.

KEYWORDS: hall effect sensor, sand, skidding, traction control.

1. Introduction to traction control systems

Vehicle grip, an essential factor in the daily life of drivers, refers to the ability of the car to keep the wheels in optimum contact with the surface on which it is standing. To enhance this, car manufacturers have been introducing TCS (traction control system) systems to the market since the 1970s, when the engineer Frank Werner-Mohr patented his work under Mercedes Benz. Although these early versions were only prototypes and had many flaws, such systems became widely available in the late 1980s, initially on Mercedes-Benz and BMW vehicles. [1]

Traction control systems use wheel speed sensors dedicated to anti-lock braking systems, known as ABS, to detect when one or more drive wheels have lost grip. Depending on the vehicle, TCS will either split power to the wheels or apply the brakes to try to restore traction.

Since 2009, the European Union has decided that traction control systems must be fitted to vehicles. Today, this type of system has evolved and ensures vehicle stability and control, increasing driver safety.

2. Speed sensors

The starting point for the traction control system is wheel slip, which is picked up by the speed sensors mounted on the vehicle's planetary gearbox, shown in Fig. 1. The input to the system becomes the information read by the sensors, which is processed by the car's ECU (electronic control unit).

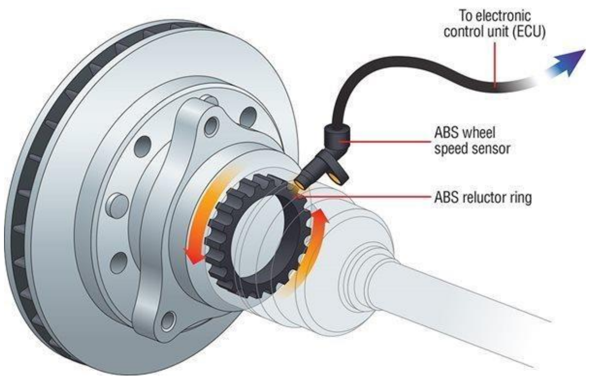

Fig. 1. Speed sensor

Speed sensors can be classified, depending on how they work, into passive sensors and active sensors. Passive sensors, shown in Fig. 2, consist of a coil of wire wound around a magnetic core and a permanent magnet. The outer ring is fixed, and its construction consists of alternating teeth and gaps, like acogwheel. Due to its rotational movement, a magnetic field is created between it and the coil. The changing magnetic field induces an alternating voltage in the coil that can be measured. The frequencies and amplitudes of the alternating voltage are proportional to the speed of the wheel. The sensor creates a signal that changes frequency as the wheel changes speed. The machine's central unit converts the signal into a digital signal for interpretation (Fig. 2) [2].

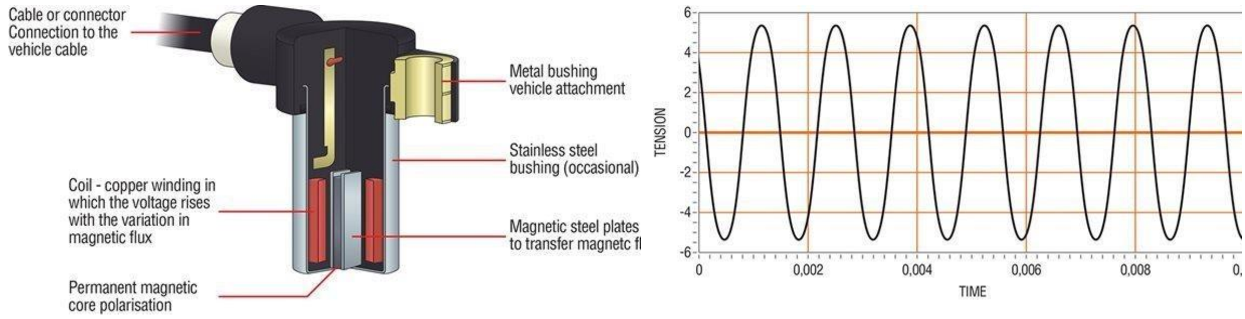

Fig. 2. Passive sensor construction and signal

As for active sensors, there are two types: Hall effect or magnetic ring. These sensors use a ring with alternating pole-positioned magnetic arc segments, which cause a clear change in resistance as they pass the sensor. The signal resulting from the rotational movement is digital (Fig. 3). The ECU thus determines the speed of the wheel according to the frequency of the pole changes. [2]

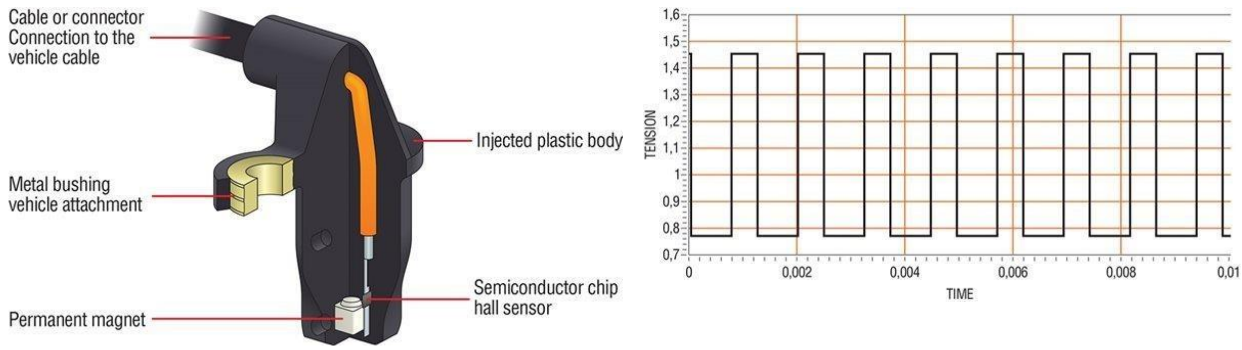

Fig. 3. Construction and signal of the active sensor

3. Current status of traction assistance systems

Nowadays, there are several technologies and equipment to improve the traction of your vehicle on snow or ice. In addition to the electronic systems described above, the market also has physical equipment such as car chains (Fig. 4), anti-skid strips or tyre sprays. Although this equipment is effective, it has considerable disadvantages, such as the need for physical effort and knowledge of use on the part of the driver[3].

Fig. 4. Car chains

4. System design and implementation

The development of the winter traction assistance system aims to increase driver comfort, improve the performance of current electronic systems and automate conventional products. Thus, the development of the prototype started with 3D modelling of the assembly, shown in Fig. 5, in specialised software such as SolidWorks or Onshape.

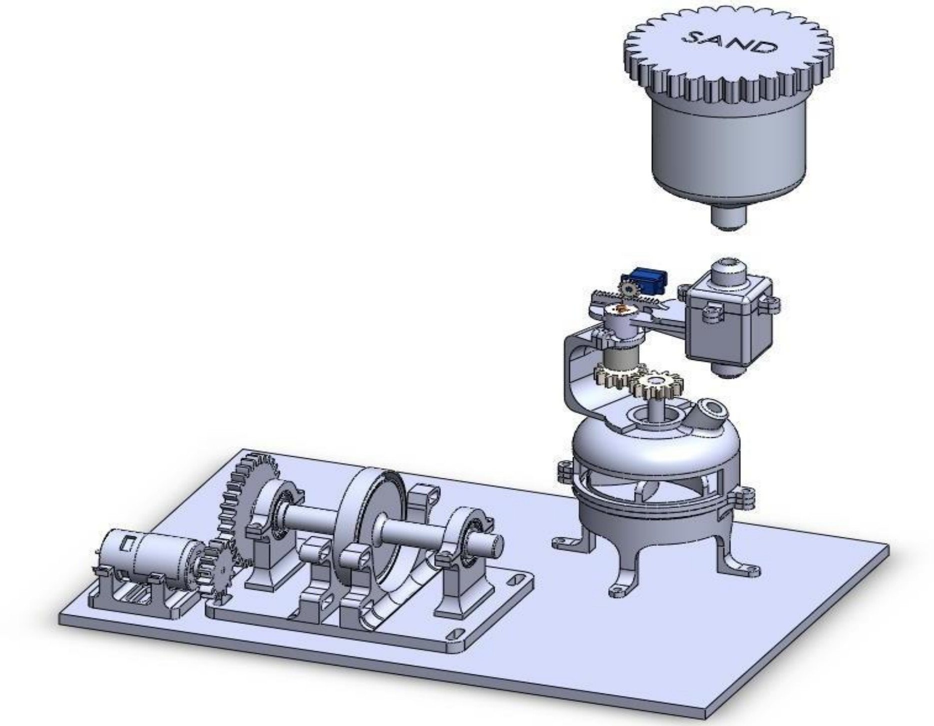

Fig. 5. 3D modelling of the assembly

The subject under investigation consists of two main subsystems: the ABS sensor subsystem (Fig. 6) and the sand mechanism subsystem. With the first specified assembly, it is intended to read data from the vehicle wheel. In order to detect wheel slip, an active sensor mounted on an additively manufactured carrier and a magnetic ring mounted on a machined shaft are used (Fig. 7). A 24V DC motor and a 2:1 ratio gearbox are used to gear the system.

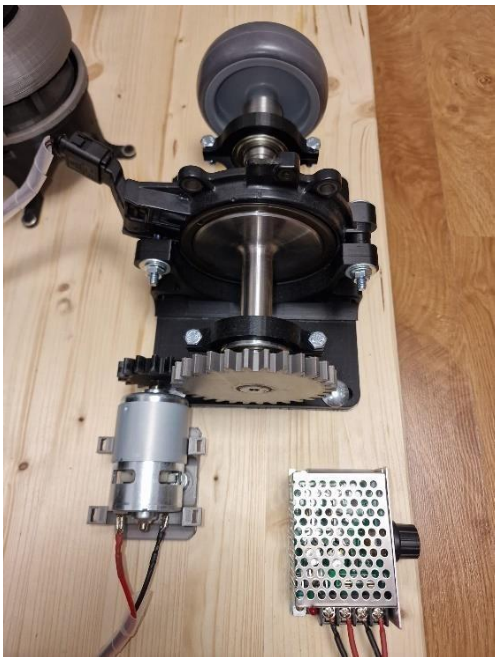

Fig. 6. ABS sensor sub-assembly

Fig. 7. Shaft

The second subsystem, the sand mechanism shown in Fig. 8, relies on centrifugal force to spread the sand in front of the wheel. It consists of a rotor (Fig. 9) that is fed with sand depending on the presence of drift, geared by a 6V DC motor**.**

Fig. 8. Sand mechanism subassembly

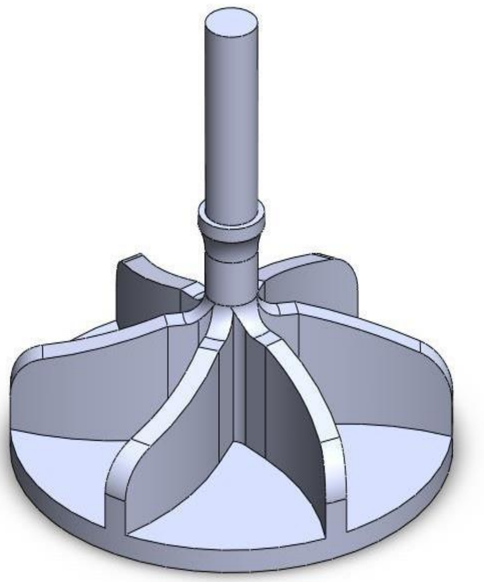

Fig. 9. Rotor

In order to carry out the tests, a wooden board is used, on which the electronic components, the Arduino Mega 2560 microcontroller and the previous subsystems were assembled. The experimental model is powered by a 35V and 10A variable power supply (Fig. 10).

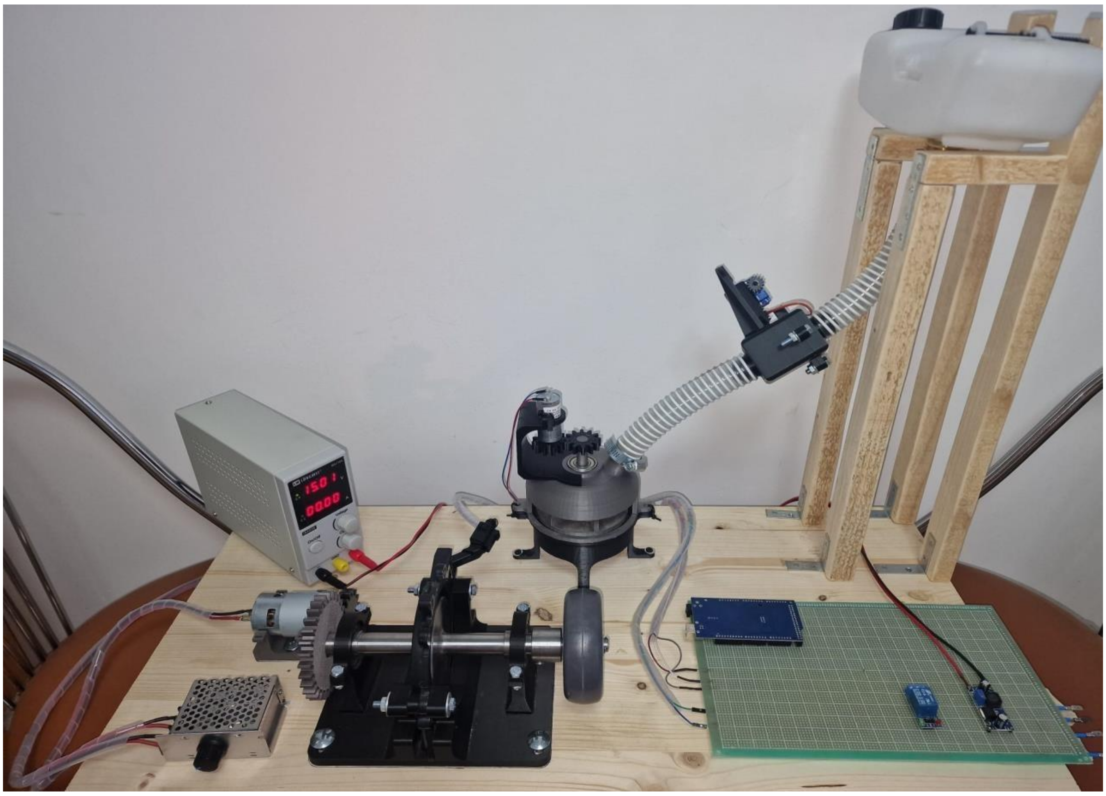

Fig. 10. Test assembly

5. System testing

The choice of sand as an anti-skid material was based on its properties of increasing friction between the wheel and the surface it is on. Sand grains must be in a certain size range, generally between 0.3 mm and 1 mm in diameter. Grains larger than 1 mm are more likely to cause wheel slip, while smaller particles do not have sufficient friction. Ideally, a uniform distribution of grains in that optimum range is ideal [4].

For the programming of the system and the decision-making part, an Arduino Mega 2560 microcontroller is used to read the pulses from the ABS sensor and convert them according to relation (1) into revolutions per minute. Based on the average revolutions per minute over a period of time, a sudden increase in revolutions per minute is monitored, which signals wheel slip and triggers the sand system.

$$rpm = (pulseCount * 600) / 57 \quad (1)$$

Control of the motor that drives the ABS sensor system is achieved via a PWM potentiometer, as the aim is to simulate the vehicle's acceleration as closely as possible. The graph in Fig. 11 shows the detection of skidding, at which point the system is activated and sand distribution begins. To inform the driver, it is desired to monitor the sand level, so an ultrasonic sensor mounted in the main sand tank was used. Also used were LEDs for warning in the event of skid detection, and the information will be displayed on an LCD screen showing the percentage of sand available.

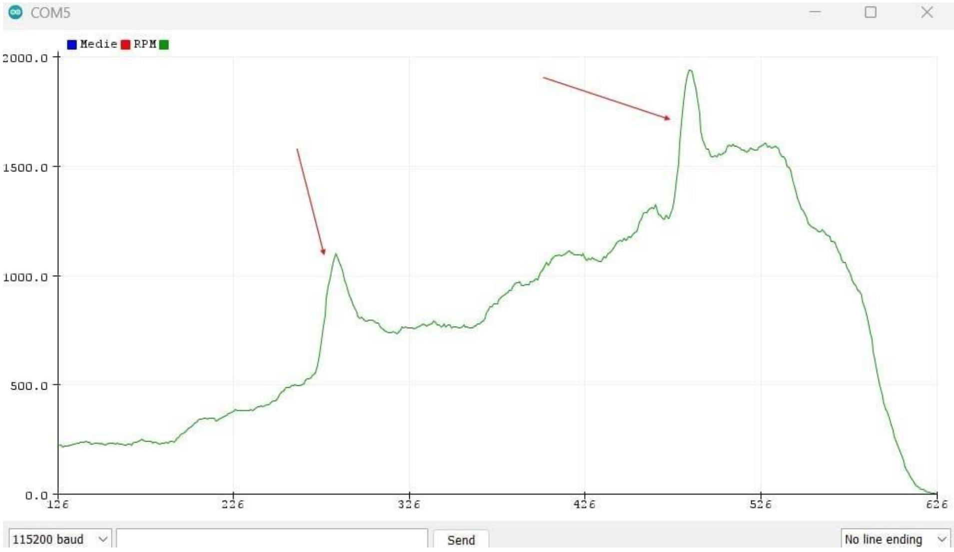

Fig. 11. Drift detection and rpm graph

6. Conclusions

The subject matter can be applied to several categories of vehicles and can act quickly enough to increase traction when needed. Also, by developing the system, it eliminates human intervention in solving this problem and increases comfort.

In the project to date, elements of mechanical engineering, electronics and programming have been combined. The prototype was built to simulate an assembly present on vehicles, initially 3D modelledand then additively manufactured, and through testing several versions, an optimal variant was arrived at thatmet the mechanical requirements. Since the aim was to improve the strength of the shaft, machining technologies were used. After completion of the design of the sand mechanism and its tests, a final version was arrived at, featuring a feed hole and a funnel through which excess sand is recovered. The whole mechanical assembly was therefore intended to be streamlined with various sensors. An Arduino Mega 2560 microcontroller was used to process data from the ABS sensor and other parameters such as sand level, but also to control the motors to close the valve or start the sand subassembly.

7. Bibliography

[1]. Rick Popely, 2021, accessed 25.04.2024, https://www.cars.com/articles/what-does-tcs-stand-for-434356/?oauth_redirect=true&redirect_event%5Bnew_account%5D=true&redirect_event%5Bsocial_platform%5D=google

[2]. Techmate Guides, 2021, accessed 25.04.2024, https://apecautomotive.co.uk/techmate-guides/abs-sensors/

[3]. Accessed 03.05.2024, https://www.lesschwab.com/article/driving/how-to-put-on-snow-chains-and-drive-safely.html

[4]. AdorTech Blog, accessed 04.05.2024, https://adortech.com/blog/all-about-railroad-traction-sand-uses,-advantages,-and-safety#:~:text=Low%20Speeds%20%2D%20Sand%20prevents%20wheel,operating%20at%20very%20low%20speeds.

RESEARCH ON THE DEVELOPMENT OF A ROBOTIC SYSTEM FOR ROAD MARKINGS

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ABSTRACT: The entitled document "Research on the development of a robotic system for road markings" focuses on obtaining a robotic system for applying road markings on asphalt roads, based on the principle of a CNC. Its operation is based on four subsystems aided by software that generates G-code: the subsystem that performs movement on the X-Y-Z axes, the paint printing subsystem, the movement subsystem, and the subsystem that spreads reflective glass microbeads. The actual action involves positioning and selecting the type of marking, followed by paint dispensing for layer application. When this process is complete, the robotic system moves forward and spreads the reflective glass beads onto the freshly applied paint, ensuring visibility at night for traffic participants.

KEYWORDS: system, G-code, CNC, marking, paint.

1. Introduction

Road markings are there to guide and assist drivers to travel safely. They should convey a clear meaning and provide adequate time for the driver to react without causing unpleasant events for him or herself and other road users.

From Edward Hines' (Michigan Commissioner - USA) idea to separate oncoming traffic with a center line, to Frederick Basley's application of it on a street in Madison, Wisconsin in 1921, interest in asphalt road markings grew rapidly around the globe. As the number of paved roads and traffic volumes increased, so did the need for equipment to apply and dry paint quickly (especially in rainy seasons). This is how marking vehicles with capacities of up to 4,500 litres of paint came into being.

Paint has not been neglected either, its composition having evolved significantly over the last 8 decades, from plain paint to thermoplastic paint to the night-visible paint (due to glass beads applied to the freshly painted surface that redirect light) patented by Edwin R. Gill in 1933. [1]

2. Current status

Nowadays there are several types of robotic systems that are a very good example of the application of technology in road safety. This activity can sometimes be dangerous for humans, so using them can increase the safety of the process.

One such example is the "TinySurveyor Terra" (Fig.1), developed in Denmark by engineers at TinyMobileRobots. Equipped with large motorised wheels, it can navigate terrain that is difficult for other equipment to reach, such as gravel, sand, or uneven grass, and in various environmental conditions, and is waterproof. With sensors it can detect and avoid obstacles, helping to reduce risks (Fig.2). [2]

Fig.1 TinySurveyor Terra

Fig.2 TinySurveyor Terra on different working surfaces

3. Robotic system development

The aim of developing the robotic system is to efficiently apply road markings on a paved public road. The 3D design of the assembly, using SolidWorks software, is the first important step, asit allows an overview and simulation before the finished product is realised. In this way, problemswere solved, and optimizations were performed (Fig.3), and then customized parts were obtained with additive manufacturing technologies (Table 1).

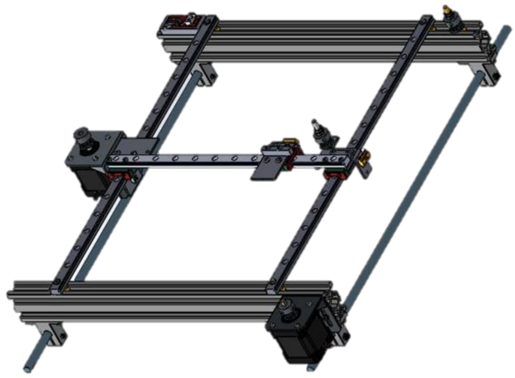
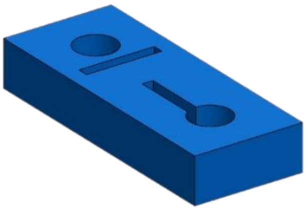
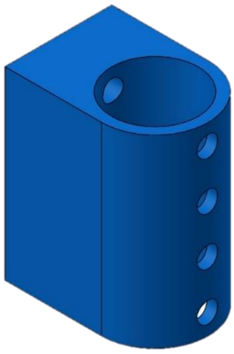
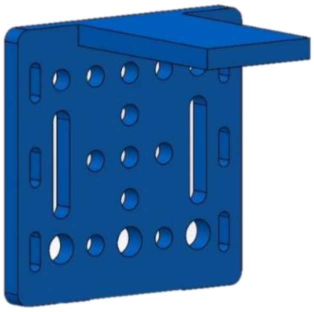


Fig.3 The first 3D model

Table 1 - Custom parts made with additive manufacturing technologies

No. Crt.	Component name	Representation
1.	Mechanical limiting bracket	
2.	Tank clamp	
3.	Tank clamping flange cover	
4.	V-slot profile clamping plate	

The project is based on 4 subsystems (accompanied by a software called GRBL Plotter):

- The subassembly of the axle drive mechanism (Fig.4);
- The actual paint application subassembly (Fig.5);
- The subassembly that performs the scattering of reflective glass microbeads;
- The subassembly ensures the movement of the entire system after the work task has been completed.

The first subsystem deals with the movement of axes [3]. It is the basis of the robotic system and consists of 2 linear guides on which the translation movements along the X and Y axisare performed. The ball slides are clamped on an aluminum v-slot profile, the engagement is done by two 2GT-6mm belts and two stepper motors - Nema 17.

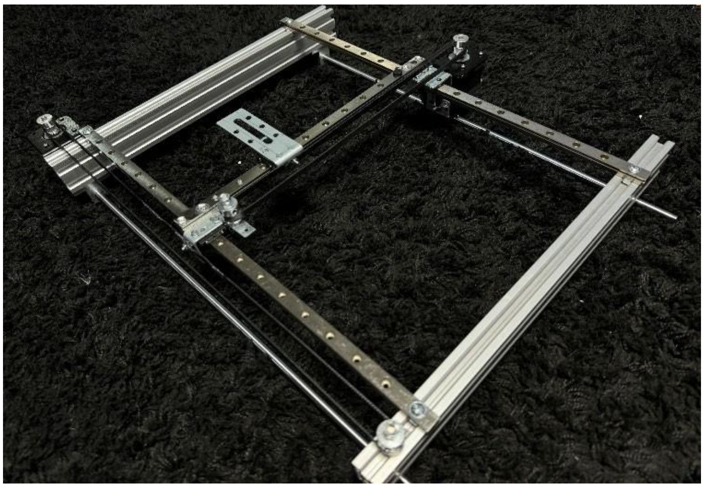


Fig.4 Sub-assembly of the drive mechanism

Subsystem II applies the paint to the work surface. It is placed on the linear guide sled representing the Y-axis of subsystem I (Fig.6). It is based on a simple v-slot profile, on which the other components are applied. Attached to the profile is a clamping plate running on wheels, geared by a screw-nut system clamped by a Nema 17 motor coupling. The motor positions the top of the tank on the surface to be marked and retracts it when each line is completed, the assembly operating on the principle of a CNC.

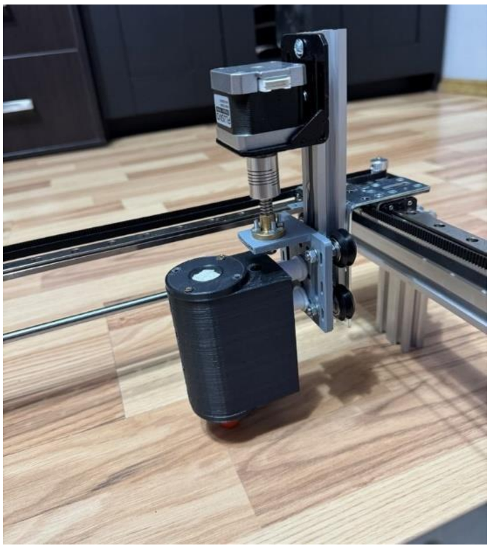


Fig.5 The actual application subset of the paint

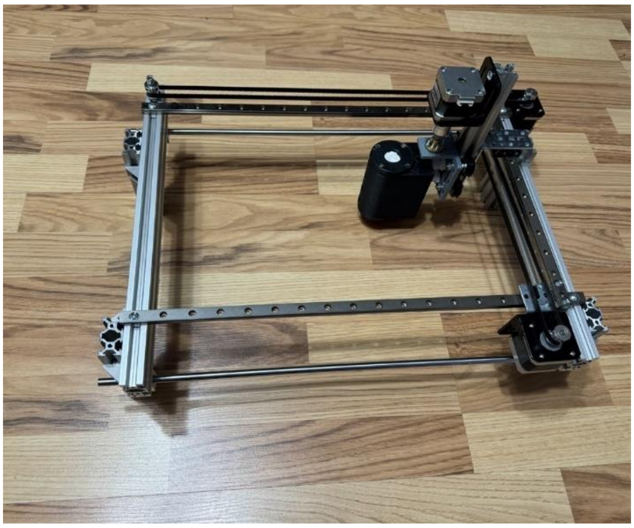


Fig.6 Positioning the paint application subassembly

Subsystems III and IV are activated simultaneously when they receive a signal from the switch, which is operated by the paint subsystem when the process is completed. The reflective glass microbeads that are scattered within subsystem III range in size from 400-800 microns and penetrate directly into the fresh paint layer.

All processes are mainly controlled by the GRBL Plotter software (Fig.7) [4]. It generates G-code for the image inserted by the user and sends commands to an Arduino Uno compatible development board that has attached a CNC Shield V3 with 3 drivers for the 3 motors. Using a modifiedlibrary called "grbl-servo" [5], the default PWM frequency is changed from 1kHz to 50 Hz, which is required to control the Nema 17 motors.

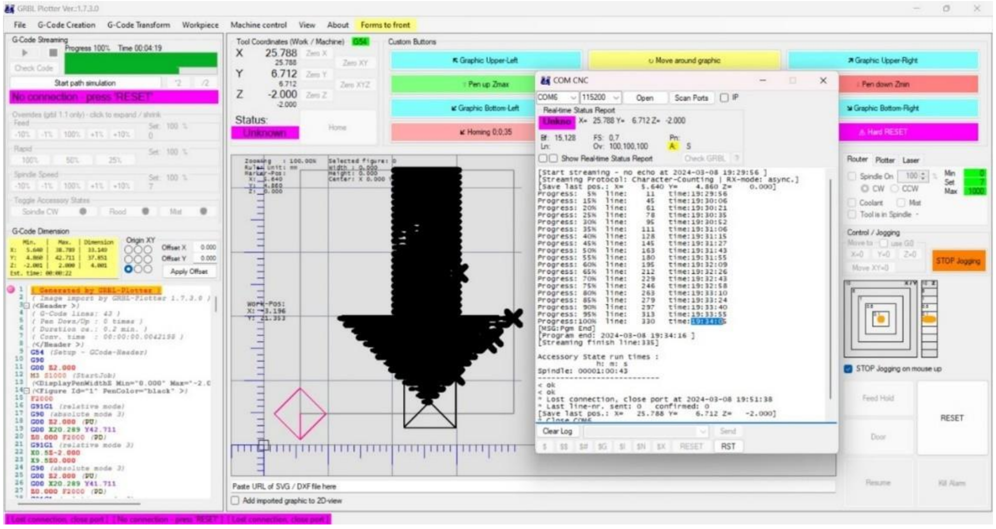


Fig.7 GRBL Plotter software interface

4. Component testing and system functionality

A test image, in this case an arrow, was used to check the components and functionality of the system. This was added to the GRBL software which generated and passed on the G-code after analyzing and processing the image. On the CNC Shield V3 the 3 drivers for the stepper motor control - A4988 were attached, the motors were connected to the related pins, the 12V power supply was connected (Fig.8), and then the program was run (Fig.9).

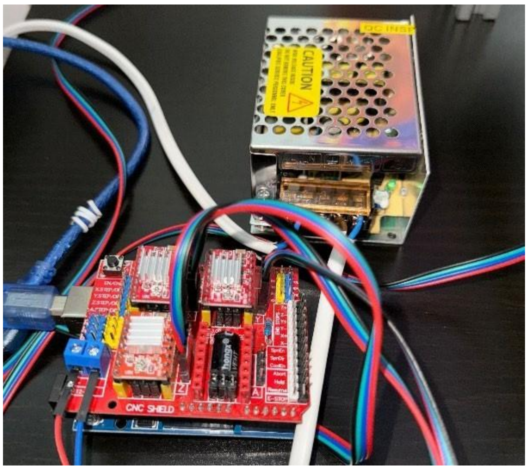


Fig.8 Connections on the CNC Shield V3

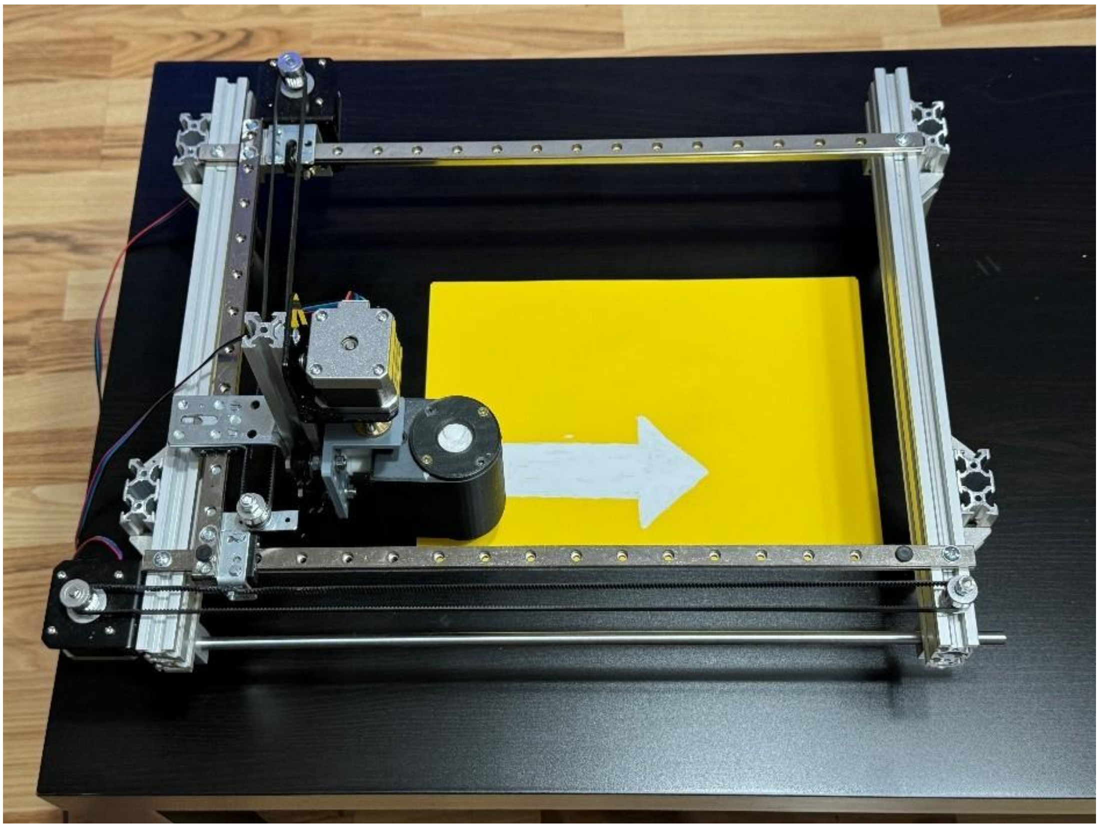


Fig. 9 Running the program and applying the paint

5. Conclusions

The robotic system has real-life applicability and offers a modern solution, easing the work of the human user while increasing process safety.

At present, the first 2 subsystems, namely the axle travel and the paint application subsystems, have been completed and have passed the testing part, with favorable results. The next 2, the scattering of reflective glass microbeads and the robotic system displacement, are under development. During the testing it was noted that some metal elements can be replaced by additively manufactured elements, thus lowering the final weight of the robotic system without negatively influencing stiffness and functionality.

6. Bibliography

[1] Brian Bowman (2001), *Estimating the Effective Live of Pavement Marking Based of Crash History* - https://www.eng.auburn.edu/files/centers/hrc/IR-01-02.pdf - accessed on 03.05.2024

[2]. TinySurveyor Terra, https://tinymobilerobots.com/road-marking-robot/tinysurveyor-terra/ - accessed 03.05.2024

[3]. Saurabh Sharma, Harish and S.B.Nikam (2019) "XY-Drawing Robot using Arduino", volume 6issue 2, 4 pages, ISSN: 2349-6002.

[GRBL-PLOTTER - https://grbl-plotter.de/ - accessed 04.05.2024

[5]. Sungeun K. Jeon for Gnea Reserch LLC, *Grbl-servo* - https://github.com/cprezzi/grbl-servo - accessed on 04.05.2024

DESIGN AND REALIZATION OF AN EXPERIMENTAL SYSTEM MODEL FOR OBJECT SORTING THROUGH IMAGE RECOGNITION

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ABSTRACT: The paper proposes the development of an image processing algorithm for detecting the shape of small, flat, metallic parts that are to be sorted using an articulated robotic arm. The robot will be equipped with an end-effector, designed and printed using a 3D printer, which holds an electromagnet to manipulate the parts, as well as a video camera for capturing images. After detecting the shape, the center of the part to be sorted will be determined to ensure proper positioning of the electromagnet.

KEYWORDS: sorting, image processing, robotic arm, end-effector

1. Introduction

In the modern industrial context, process automation has become essential for improving efficiency and reducing human errors. Sorting objects is a crucial task in many industries, from recycling to manufacturing and product distribution.

This paper aims to design and build an experimental model of an articulated robotic arm capable of sorting metal objects based on their shape. The objective will be achieved by using a video camera and a Kinova Gen3 Lite robotic arm. Additionally, an end-effector will be designed using SolidWorks software, which will include both the video camera and the electromagnet used to manipulate the elements to be sorted. Programming will be done in LabVIEW, and image recognition will be performed in Vision Assistant.

2. Defining the operating mode of the robot

2.1. Scientific context

In the current context, there are countless applications in which industrial robots are integrated. They offer both speed and precision, as well as numerous possibilities for adaptation to imposed conditions. However, one of the biggest challenges in this field is handling metal parts due to the wide variety of shapes and sizes they come in. Among the commonly used applications in the field are Bin Picking or automatic part collection. This application involves the automatic recognition of objects, gripping, and extraction. However, the difficulty of the application increases when the arrangement of objects is random.

One of the ongoing projects aimed at improving the sorting process is ROBOTT-NET, developed by Arnold AG and FORMHAND Automation GmbH in collaboration with the Danish Technological Institute. The project aims at a multifunctional robot that is easy to use and capable of handling metal parts in various scenarios. The robot will be able to identify and detect the position of an object even in complex situations, such as randomly stored in a container or on a conveyor. The end-effector is optimized and capable of gripping objects of multiple shapes and sizes with a single grasp, which reduces hardware costs and assembly times.

This project develops an adaptable cell for various situations. Thus, it features a KUKA articulated robotic arm (Fig.1), is small-sized, making it easy to transport and install in different spaces, and is equipped with an advanced image recognition system capable of recognizing different shapes and sizes, as well as atypical situations, such as if the robotic arm lifts 2 pieces at the same time or if the pieces have certain defects (Fig.2). The end-effector is configured with a vacuum system, which allows for the safe lifting of the pieces and is designed to be easily adapted to various situations of varying difficulty (Fig.3). [1]

Fig.1. Articulated robotic arm KUKA [1]

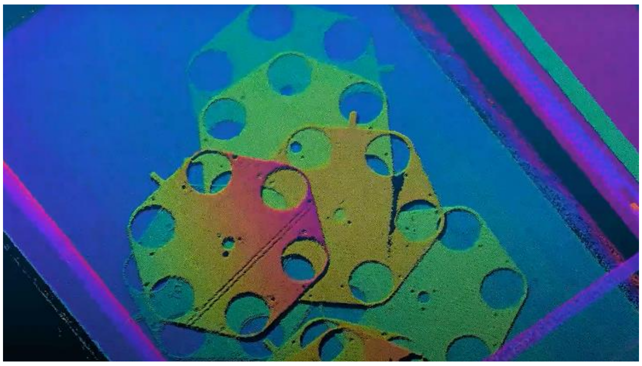


Fig. 2. The image recognition system of the cell [1]

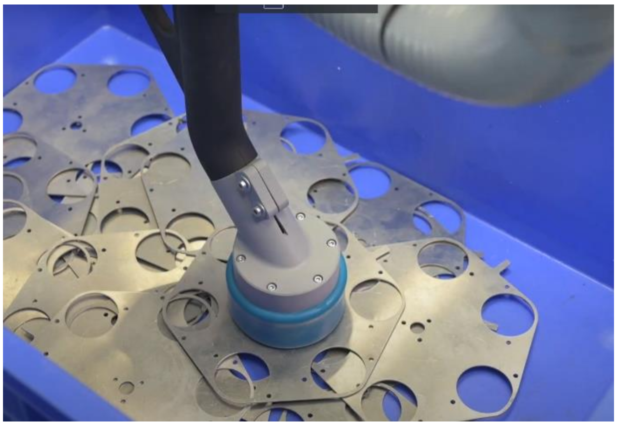
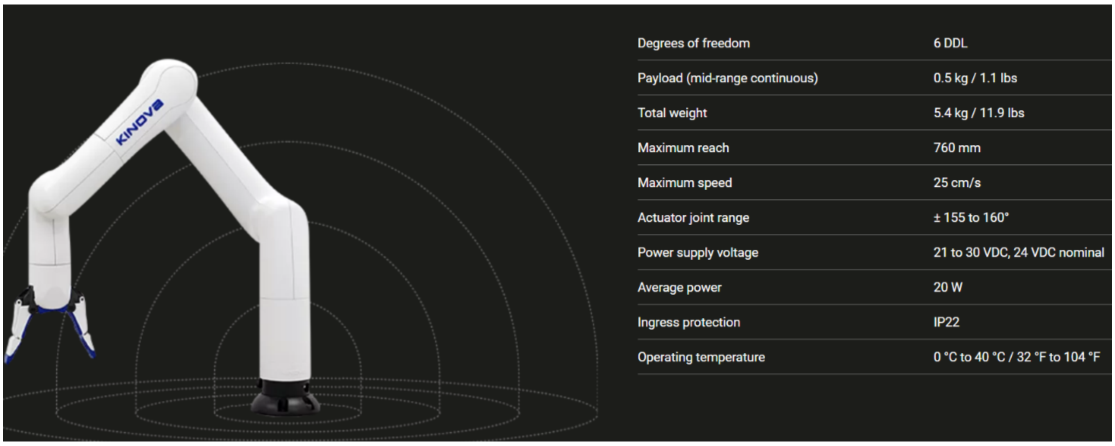


Fig. 3. The vacuum-type end-effector [1]

2.2. Theoretical aspects and proposed solutions

After analyzing the final purpose of the work, the Kinova Gen3 Lite articulated robotic arm was chosen. It features six degrees of freedom and a reach of 760mm, aspects that facilitate the smooth execution of complex motion sequences in a confined space. Additionally, the robot has a maximum payload of 0.5kg, which impacts the design and printing of the end-effector, as well as the choice of electromagnet. (Fig. 4) [2]



Degrees of freedom	6 DDL
Payload (mid-range continuous)	0.5 kg / 1.1 lbs
Total weight	5.4 kg / 11.9 lbs
Maximum reach	760 mm
Maximum speed	25 cm/s
Actuator joint range	± 155 to 160°
Power supply voltage	21 to 30 VDC, 24 VDC nominal
Average power	20 W
Ingress protection	IP22
Operating temperature	0 °C to 40 °C / 32 °F to 104 °F

Fig. 4. The technical specifications of the Kinova Gen3 Lite robotic arm [2]

Initially, a system diagram was created to highlight both the subsystems and components of the experimental model. (Fig. 5)

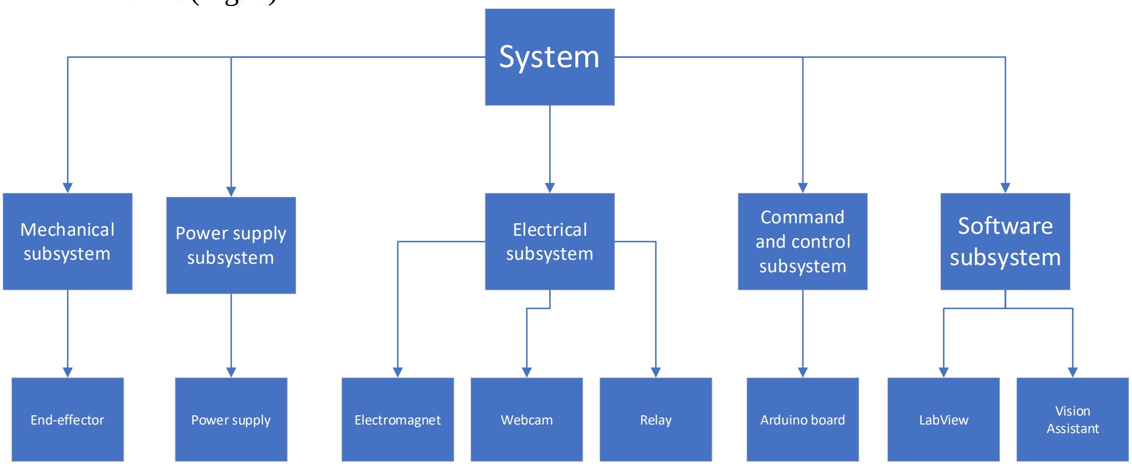


Fig. 5. System diagram

As part of the electrical subsystem, a small-sized electromagnet (20mm x 15mm) was chosen, with a working voltage of 24V and minimal mass (26g). This component choice reduces the maximum payload of the robot to 0.474kg. Additionally, a 5V relay was chosen to control the electromagnet.

For the command and control part, an Arduino development board was chosen, easy to program and integrate into any application. It receives and transmits information to the relay to control the state of the electromagnet (on/off). To make this possible, the following hardware configuration was created, controlled by an algorithm implemented using LabVIEW software. (Fig. 6 și Fig. 7)

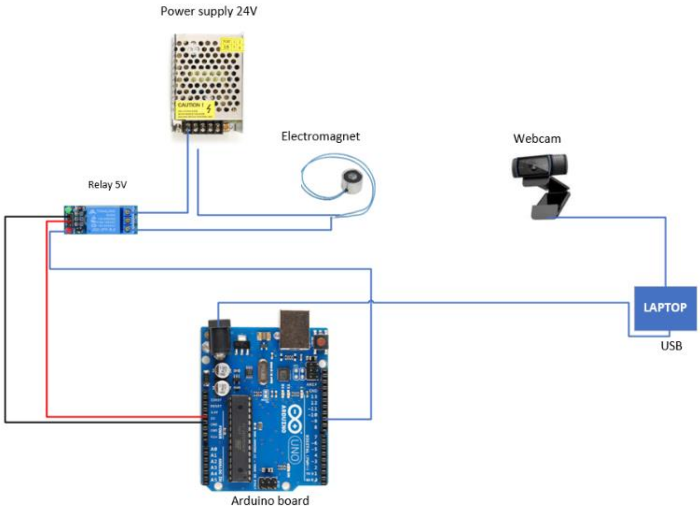


Fig. 6. The electrical schematic of the components

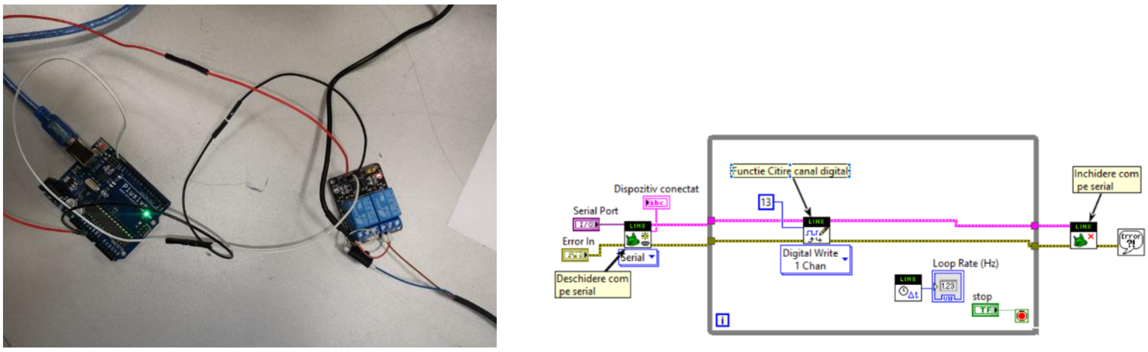


Fig. 7. The electrical configuration and algorithm for controlling the electromagnet

For easy sorting of metal parts, their manipulation was chosen using the electromagnet, and a special end-effector was designed for supporting it. The effector consists of two parts (Fig. 8), in the design of which consideration was given to maximizing material reduction during printing, as well as creating special spaces for proper placement of electrical wires. Together with the articulated robotic arm, it forms the hardware component of the system. (Fig. 9)

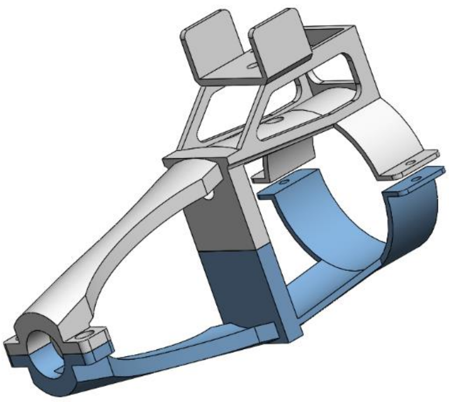


Fig. 8. End-effector for electromagnet support

Fig. 9. Assembly of articulated robotic arm and end-effector

For printing the end-effector, the Prusa slicer was used, and printing parameters were defined as presented in the figures below. (Fig. 10 și Fig. 11)

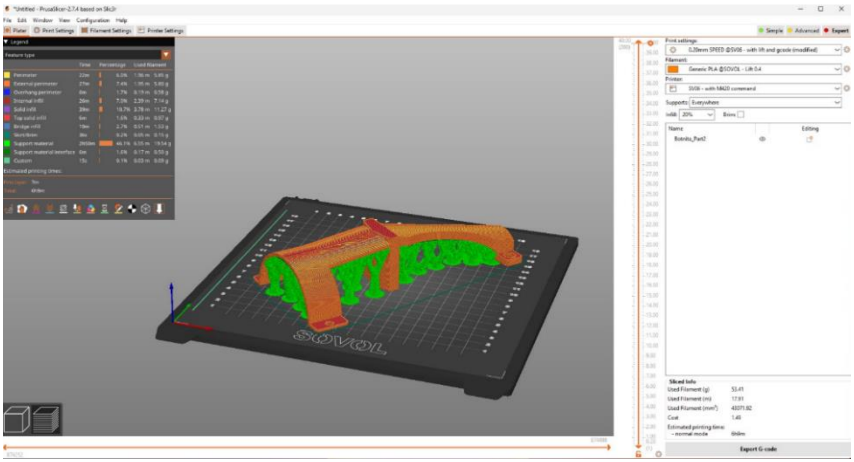


Fig. 10. Printing parameters for the bottom part of the end-effector

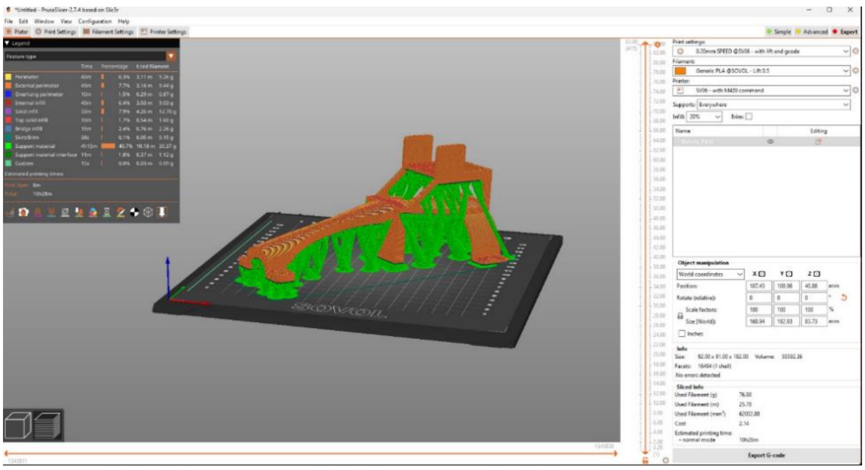


Fig. 11. Printing parameters for the top part of the end-effector

Following printing, it was found that the end-effector assembly weighs approximately 130g. This reduces the maximum payload of the robot to 0.344kg. For proper system operation, the sorted parts in this work should not exceed 300g each.

3. Detailed design of the software application

The software application is divided into two parts: image processing and recognition, and an algorithm that calculates the position of the piece's center and controls the movement of the robotic arm.

To begin with, a program was created to define the intermediate position of the robot, called the "Home" position. Additionally, two positions in proximity to the objects were defined. These are called "Proximity 1" and "Proximity 2". The last two positions serve to move the robot in favorable positions for image capture. (Fig. 12)

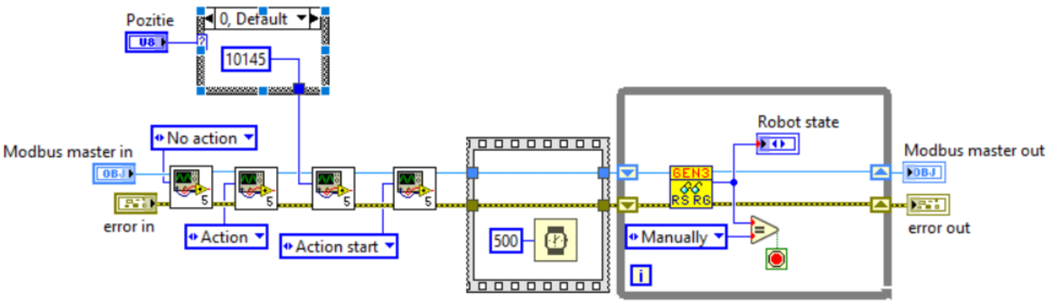


Fig. 12. VI for proximity movement

The image recognition process was created using Vision Assistant software. After the robot was moved to the "Proximity 1" position, images of the parts placed in random positions were saved.

Initially, the red color plane was extracted using the “Color Plane Extraction” function. Subsequently, the actual object recognition process began. The “Pattern Matching” function was used for the first shape, namely the disc, for which a template was created. Similarly, functions and templates were created for the square shape and the rectangle shape, and it was verified whether the functions were configured correctly. (Fig. 13) For a more accurate verification, other parts that were not to be sorted were included in the photos. For the identified parts, the functions return the coordinates of each part as well as the number of parts in each category.

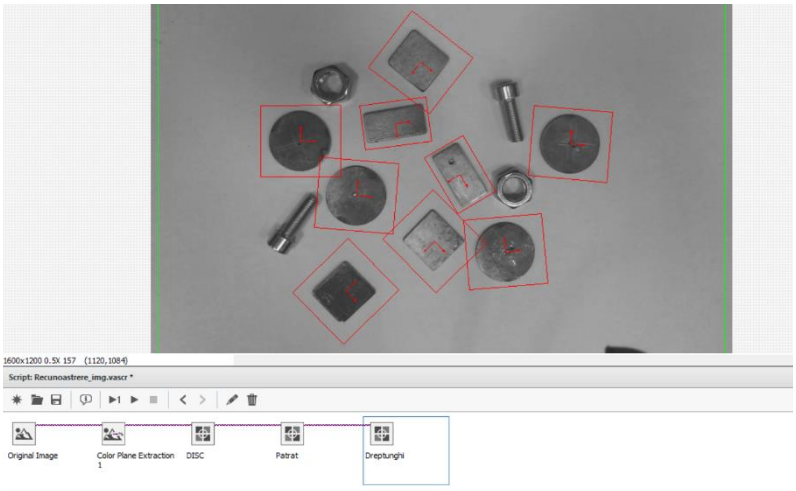


Fig. 13. Image recognition application with Vision Assistant

This application was exported into a VI, compatible with LabVIEW, to be further integrated into the robot movement algorithm. (Fig. 14) In the next sequence of steps, the robot moves to the "Proximity 1" position from which it captures an image, then returns the coordinates of the identified parts and the number of parts identified in the image. The same procedure is followed for the "Proximity 2" position. The center of each identified part is then calculated, and the robot is moved so that the electromagnet is positioned at the center of the part. (Fig. 15) Using the electromagnet control algorithm, when the robot is in the aforementioned position, the electromagnet is activated, and the part is lifted from the surface. The part is then moved to a storage box specially designated for parts of the same shape.

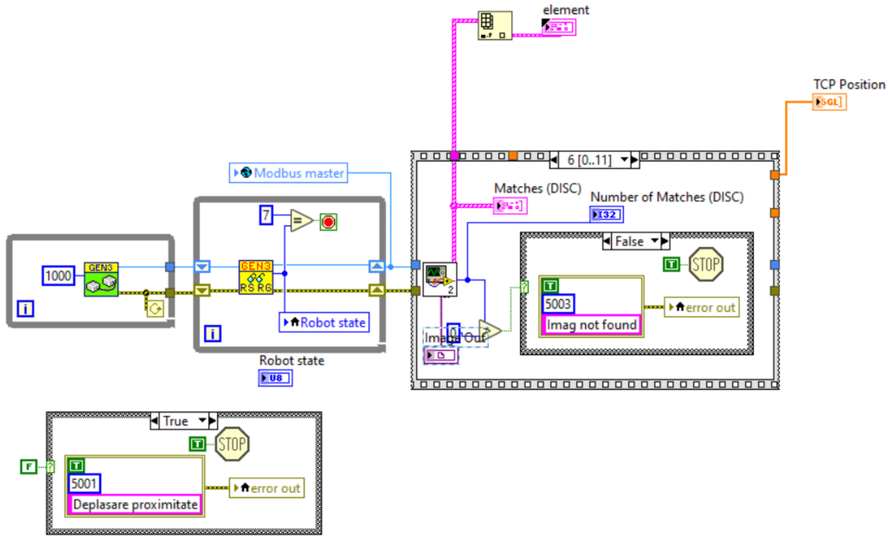


Fig. 14. VI for the movement of the robotic arm

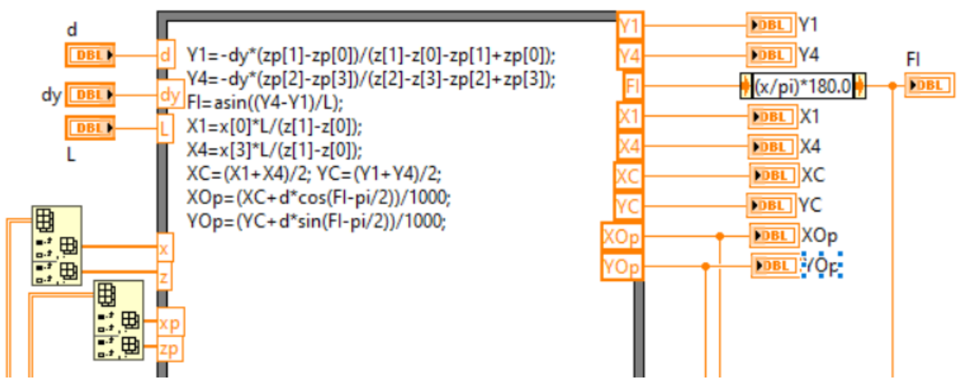


Fig.15. Calculation for determining the center of the parts an orientation of the robot arm

4. Current stage of the project, testing the software application

All hardware components have been purchased, printed, assembled, and tested up to the current moment. Regarding the software application testing section, the program is finalized to the point where the software application obtains the coordinates of the parts, which are necessary to determine their distance from the robotic arm, to calculate the center of each part, and to subsequently orient the end-effector. Problems arose with calculating the actual distance between the end-effector and the part and with orienting the end-effector.

5. Conclusions

This paper proposes optimizing the sorting process of small metal objects using image recognition with the help of an articulated robotic arm, thus eliminating the need for human presence in performing such repetitive tasks. Additionally, the risks of sorting errors are minimized, and the time required to complete the sorting task is significantly reduced. The use of a video camera and electromagnet for manipulating these parts not only optimizes the sorting process but also opens up new perspectives for applicability in various industrial sectors where the selection and manipulation of metal objects are of major importance.

Furthermore, the paper highlights the importance of interdisciplinary collaboration in robotics, combining knowledge from the fields of image processing, part design, mechanical engineering, and 3D printing technology for efficient solutions.

The future prospects of this project include further development to improve the recognition capability for an even wider range of shapes and sizes, the integration of weight sensors for each box containing sorted parts, used to indicate when the boxes need to be changed. Additionally, there is a focus on optimizing the end-effector and the printing process to minimize filament waste.

6. Bibliography

[1]. https://robott-net.eu/pilots/sosta/

[2]. https://www.kinovarobotics.com/product/gen3-lite-robots#ProductSpecs

[3]. Tom SAVU, .. 06-FIIR-L-A1-S1: Programarea calculatoarelor şi limbaje de programare 1 (Seria IAII - 2020)

[4]. Tom SAVU, .. 06-FIIR-L-A2-S2: Analiza si prelucrarea imaginilor (Seria IAII - 2021)

[5]. Mihaela-Elena ULMEANU, .. 06-FIIR-L-A2-S2: Bazele proiectarii tehnologice asistate de calculator (Seria IAII - 2021)

[6]. Cristian-Vasile DOICIN, .. 06-IIR-L-A4-S1: Tehnologii și echipamente pentru fabricare aditivă (Seria AD – 2023)

DESIGNING AN ALGORITHM AND DEVELOPING A SOFTWARE APPLICATION FOR PLANNING THE DISTRIBUTION CIRCUIT OF PERISHABLE PRODUCTS TO CUSTOMERS

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ABSTRACT: The paper "Designing an algorithm and developing a software application for planning the distribution circuit of perishable products to customers" focuses on developing a software application utilizing a MySQL database created with phpMyAdmin and a web interface constructed using HTML, PHP, CSS, JavaScript , and SQL programming languages. The application aims to optimize a distribution circuit among customers to achieve the most efficient route while also adhering to time constraints for orders (failure to meet time constraints incurs a penalty). The goal of the paper is to present the current state of the database, web interface, and algorithms that can be used to obtain the distribution circuit with the lowest cost. This application can be used by companies providing delivery services for perishable products.

KEYWORDS: traveling salesman problem, web interface, distribution circuit, software application

1. Introduction

The present work focuses on the development of a computer application that addresses the Traveling Salesman Problem with Soft Time-Windows (TSPSTW). This problem arises in the context of a demand for optimal distribution route planning, given the associated time constraints and cost efficiency. The main objective of this work is to implement an IT application that provides efficient solutions for planning distribution routes. To achieve this goal, it will be developed a platform that allows the input of specific data such as customer dates and locations, their orders with time restrictions and other key information for making the distribution circuit. To solve the problem, a series of algorithms can be used to find the best solutions.

1.1 Resolution algorithms for TSPSTW

The Nearest Neighbor algorithm is a greedy algorithm, which means that it makes decisions incrementally, choosing at each step the most advantageous option at that moment, such an algorithm does not consider the entire set of possibilities or the long-term consequences resulting in a circuit that satisfies the user's requirements but not in an efficient method. Nearest Neighbor consists of repeatedly choosing the nearest unvisited city until all cities have been visited. The algorithm works like this: it starts from the given repository then while there are unvisited cities, finds the nearest unvisited city, moves to that city and marks it as visited, and finally returns to the repository. [1]

The 2-opt algorithm is an algorithm that attempts to improve the solution by a series of simple changes to the existing route. In general, the algorithm tries to remove intersections from a route by swapping two route segments so as to improve the total route length. The algorithm starts by making a valid route ignoring the distance costs, chooses two distances from the route and then checks if the other two distances formed by the four initially chosen cities (there is only one way to form these two new roads in such a way as to preserve the structure of a circuit) have a lower cost. If the cost is lower (time restrictions will also be taken into account) the algorithm updates the circuit using the new roads. This continues until there are no more edges that can be effectively swapped. [2]

The "Tabu-Search" algorithm consists in allowing moves (2-opt or k-opt) with negative results in the absence of options with positive results. However, this freedom can lead to a cycle of suboptimal solutions because a negative move can cancel out previously obtained benefits. To avoid these situations, Tabu-Search saves a list of "forbidden" moves so that a moved solution is not reconsidered if it does not bring a significant improvement or if it has already been banned. One approach to this algorithm is to add to the list the shortest edge that was removed by a 2-opt move and to forbid any move involving this edge. However, a disadvantage of tabu search is the high execution time which increases exponentially with the number of cities to be visited. [2]

The "Ant-colonies" algorithm is one inspired by the natural behavior of ants when they search for the best routes between food sources and their colony. These algorithms are part of a class called nature-inspired algorithms, which use principles from different fields such as physics and biology to solve optimization problems. The algorithm starts by placing a number of fictitious ants in different cities in the graph, then each ant starts building its own route, moving from one city to another according to certain rules. As ants move through the graph, they deposit a "pheromone" on the edges they travel, the amount deposited differs depending on the quality of the solution. The better the solution, the more "pheromone" is deposited. So the ants use the information to decide which is the next city on their circuit. They are attracted to edges that have a higher amount of deposited pheromones but also to edges that are shorter or those that have not been explored recently. The search process runs for a defined number of iterations or until a specific condition is met. As the algorithm progresses, the ants will gradually move closer to the best solutions, which are influenced by the "pheromones" left by previous ants . [2. 3]

1.2. Databases - MySQL

MySQL is a database management system, providing a platform for storing and manipulating data. In the context of relational databases, information is organized into structured tables, and the relationships between these tables are managed through a system of keys and links. This allows efficient data structuring and facilitates complex queries to access and process information. [4]

One of the key features of MySQL is its high performance, which makes it an ideal choice for web applications and other environments where fast response time is crucial. Also, its scalability allows databases to grow and expand as project requirements become more complex without compromising performance. [4]

Another great advantage lies in the versatility and flexibility offered, allowing the transfer of data in different formats thus facilitating the interaction with MySQL databases. Also, phpMyAdmin is open-source (users have the right to use and modify the source code), which means it can be customized according to the user's specific needs. [4,5]

1.3. Programming languages used in developing web pages and applications

To create a web interface, you can use programming languages such as:

- HTML (HyperText Markup Language) is a language used to create and structure web pages, as it provides a set of elements that define the structure and content of a web page. [6]
- CSS (Cascading Style Sheets) is a styling language used to format and style the appearance of a web page created with HTML. [6]
- JavaScript is a programming language used to make web pages as dynamic and interactive as possible, when it is used together with HTML and CSS. [6]
- PHP (Hypertext Preprocessor) is a programming language used to develop web pages, as it allows connection to the database and interaction with it directly from the web interface. [6]

2. Current State of the Work

The application consists of two parts: the database and the web application. The database was created using phpMyAdmin. It includes a number of 6 tables: "administrare", "clienti", "distante_locatii", "planificare_distributie", "program_comenzi_clienti", "vehicul_comenzi" tables that will later be used by the calculation application. The tables are shown in Fig. 1 and Fig. 2.

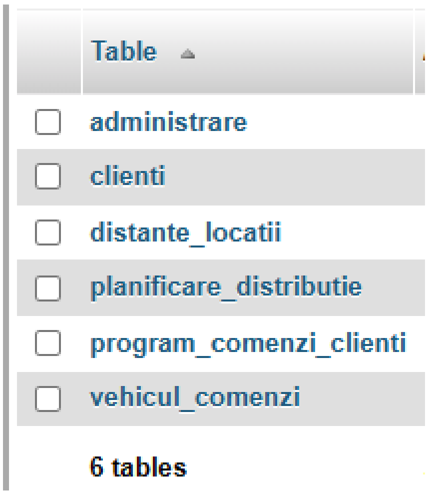

Fig. 1. The tables in the database

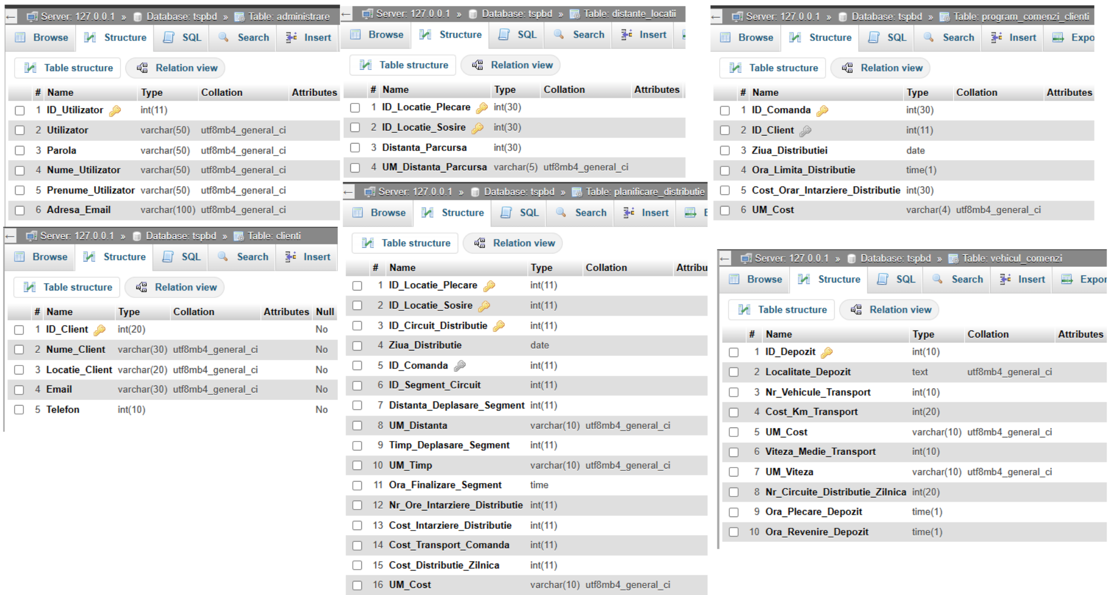

Fig. 2. The structure of the component tables of the database

These tables contain the data needed to solve the TSPSTW problem. In the "planificare_distributie" table the data will be written by the application, by retrieving or calculating data taken from other tables by the algorithms used to solve the problem. In Fig. 3 are shown the components of the "planificare_distributie" table after filling with data.

ID_Locatie_Plecare	ID_Locatie_Sosire	ID_Circuit_Distributie ▲ 1	Ziua_Distributie	ID_Comanda	ID_Segment_Circuit ▲ 2	Distanta_Deplasare_Segment	UM_Distanta	Timp_Deplasare_Segment	UM_Timp
0	3	1	2024-04-15	3	1	161	Km	194	Minut
3	2	1	2024-04-15	2	2	22	Km	27	Minut
2	1	1	2024-04-15	1	3	22	Km	27	Minut
1	0	1	2024-04-15	1	4	185	Km	222	Minut
0	4	2	2024-04-16	5	1	182	Km	219	Minut
4	5	2	2024-04-16	4	2	25	Km	30	Minut
5	0	2	2024-04-16	4	3	177	Km	213	Minut

Ora_Finalizare_Segment	Nr_Ore_Intarziere_Distributie	Cost_Intarziere_Distributie	Cost_Transport_Comanda	Cost_Distributie_Zilnica	UM_Cost
09:14:00	0	0	805	1950	Ron
09:41:00	0	0	110	1950	Ron
10:08:00	0	0	1035	1950	Ron
13:50:00	0	0	1035	1950	Ron
09:39:00	0	0	910	1920	Ron
10:09:00	0	0	1010	1920	Ron
13:42:00	0	0	1010	1920	Ron

Fig. 3. The component elements of the "planificare_distributie table"

Fig.4 shows the relationships between the tables. Relationships have the role of allowing users to access and manage information in the most organized way. Relationships are essential to ensure data integrity and facilitate database queries and updates, and primary keys are displayed to uniquely identify records in the respective tables.

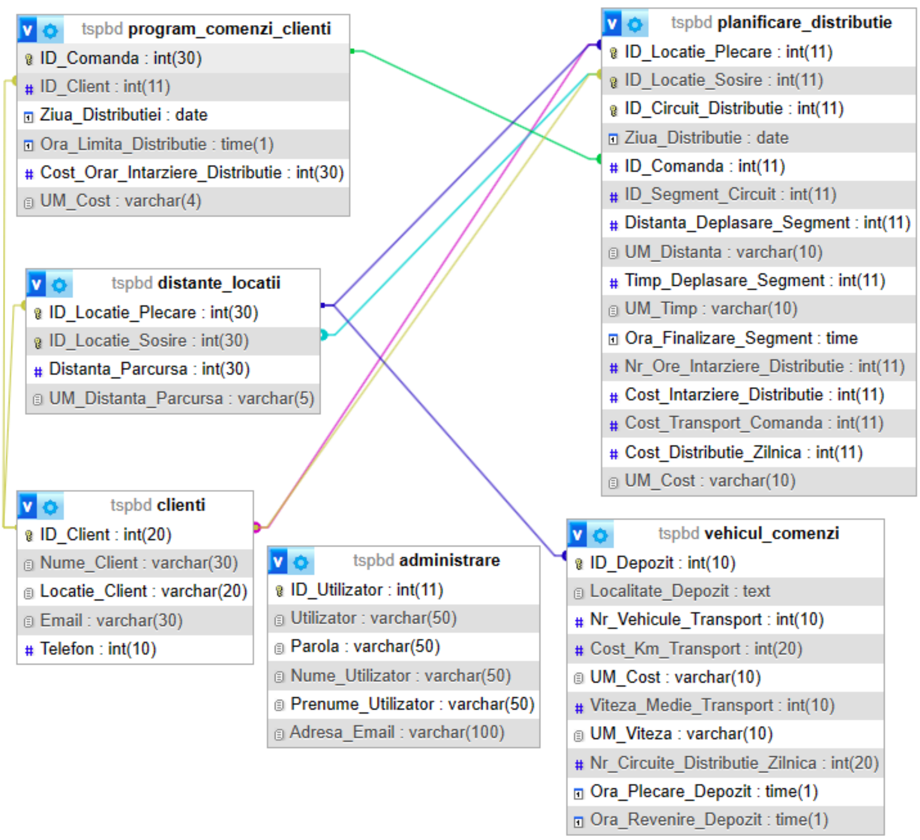

Fig. 4. Relationships between tables

The web interface is connected to the database, making it possible to access the data, but also to add table data using the web application. In Fig. 5, the first page of the web interface is presented, where the administrator's input data is required to be able to access the following pages.

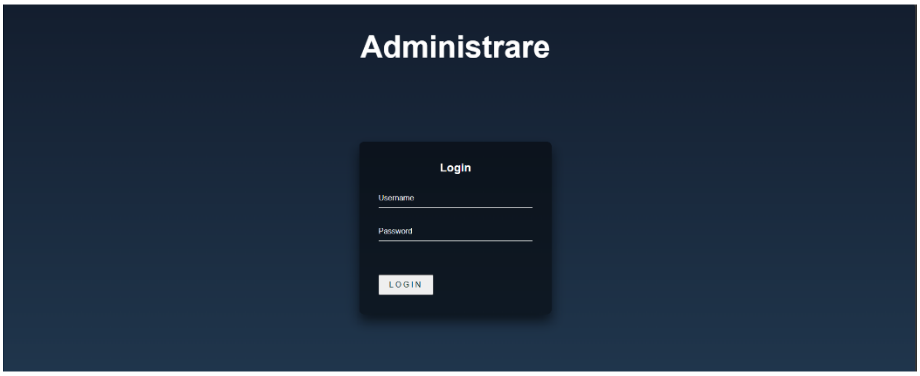

Fig. 5. Administration page

After logging in, if the login data is found in the database, the web pages showing specific data in the tables can be accessed. Each web page contains a navigation bar at the top, which facilitates navigation through pages, as shown in Fig. 6 and Fig. 7.

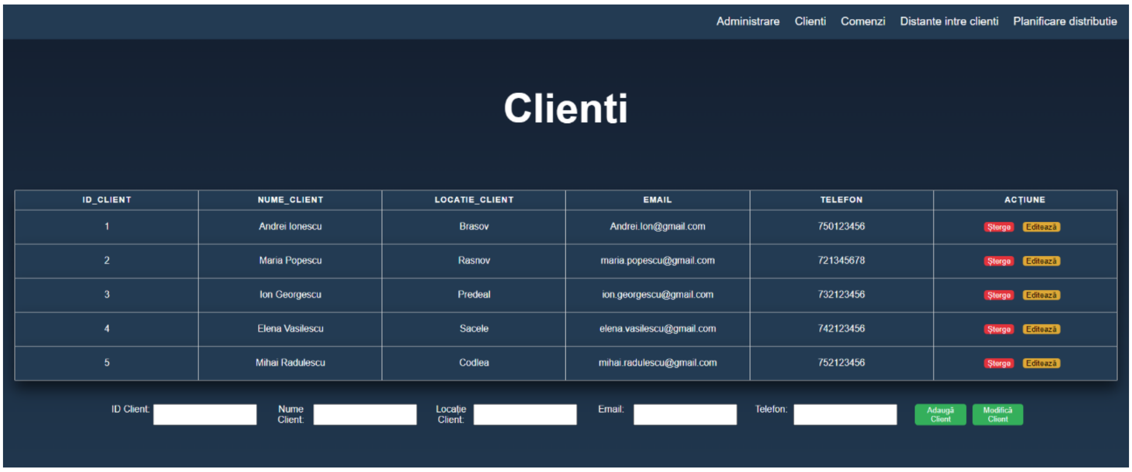

Fig. 6. Web page of the "clienti" table

Fig. 7. Page navigation bar

The database administrator can fill out the form at the end of the table to add or modify customer data in the database. The "Editează" button is used to automatically fill in the database the customer's details existing in the form, by simplifying the process of updating the data. The "Șterge" button is used to delete a customer from the database.

Through the web interface, the information of the placed orders can be easily viewed, as shown in Fig. 8.

Fig. 8. Web page of "program_comenzi_clienti" table

3. Conclusions

To date was developed an engaging and interactive web interface for the database by using technologies such as HTML, CSS and PHP. This interface allows users to enter and manage data related to customers and orders in a simple and efficient way. It was also created a robust database using MySQL, to store and manage the data in an organized and efficient manner.

In the development process, was integrated and used PHPMyAdmin, which was an essential tool in the management and administration of the MySQL database. The platform offers a friendly and intuitive interface that allowed interaction with the data in a simple and efficient way. Extensive useful functionalities were provided, such as adding and modifying tables, running SQL queries, and managing users and privileges. By PHPMyAdmin, it is possible to monitor and manage the database without having to write complex SQL code or focus on technical details. Thus, PHPMyAdmin represented a valuable tool in the development process, contributing to the efficiency and success of the application.

In the future, it is planned to extend the functionality of the web interface and optimize the performance of the database. It will be also developed a specialized application for solving the TSPSTW problem using PHP and advanced algorithms such as 2-opt and nearest neighbor. The integration of this application with the existing web interface and database will provide a complete and automated solution for distribution route planning.

4. Bibliography

[1]. Bhagavan (2023), "Solving the Traveling Salesman Problem in Python using the Nearest Neighbor Algorithm", https://medium.com/@suryabhagavanchakkapalli/solving-the-traveling-salesman-problem-in-python-using-the-nearest- neighbor-algorithm-48fcf8db289, accessed on 03.03.2024.
[2]. Christian Nilsson, "Heuristics for the Traveling Salesman Problem", http://160592857366.free.fr/joe/ebooks/ShareData/Heuristics%20for%20the%20Traveling%20Salesman%20Problem%20By%20Christian%20Nillson.pdf, accessed on 03.03.2024
[3]. Marco Dorigo and Luca Maria Gambardella (1996), "Ant colonies for the traveling salesman problem", https://people.idsia.ch/~luca/acs-bio97.pdf, accessed on 10.03.2024
[4]. Nicolae Tunsoiu, "Web Interfaces and Services", Course Notes, UPB, 2022-2023
[5]. Bringing MySQL to the web, https://www.phpmyadmin.net/, accessed on 10.03.2024
[6]. W3Schools Online Web Tutorial, https://www.w3schools.com/, accessed on 14.03.2024

5. Notations

The following notation is used in the work:
TSPSTW = Traveling Salesman Problem with Soft Time-Windows

THE DESIGN OF AN EXPERIMENTAL MODEL OF A SYSTEM FOR VERIFYING THE DIMENSIONS OF SOME PARTS

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ABSTRACT: In order for a part to be manufactured to design specifications and function properly, it must first pass through the engineering quality control process. The purpose of this control is to reduce the costs caused by the possible occurrence of defects and to reduce the time in terms of the production of metal parts. The implementation of such quality control systems in various industries is necessary and must comply with national and international regulations and requirements.

KEYWORDS: dimensional control, image processing, database, NI Vision Assistant

1. Introduction

Image analysis and processing is a technique practiced to increase productivity, quality and efficiency in various industrial processes. It supports people who, although they perform their tasks related to performing visual inspection and quality control, cannot work for a long period of time because they get tired [1]. Another problem would be non-compliance with the rules regarding the process of measuring the dimensions of some machined parts. [2] The purpose of this work is based on the efficiency of the way of checking the dimensions of mechanically processed landmarks by analyzing and processing images with the help of two video cameras positioned in such a way as to acquire the necessary images with views of the landmark, but also by implementing a system of the Poka-Yoke type [3]. These dimensions are later saved in a database.

The system for checking the dimensions of some landmarks can be described in a simplified way by the following steps:

1. The operator at the workstation is announced via a loudspeaker that he must place the marker in the device.

2. Orient and fix the hand mark in the special clamping system of the device and press a button to start the check. Confirmation of the start of the benchmark verification process is done by lighting an LED and turning on a speaker.

3. Acquire the necessary images from the two video cameras positioned one above and one on the side of the device to perform image processing by measuring the dimensions of the landmark.

4. The platform on which the landmark is placed will rotate from 90^o to 90^o whenever necessary to acquire a sufficient amount of images from the camera positioned on the side of the device.

5. The dimensions are cataloged into three broad categories and displayed in the form of lighting of some LEDs, as follows: good part with the abbreviation "B" in case a green LED will light up, recoverable scrap with the abbreviation "RR" in the case where a yellow LED will light up and irretrievably rejected with the abbreviation "RI" where a red LED will light up.

6. The dimensions are saved in the database along with other information such as: workstation name, operator name, landmark name, date and time.

2. Current status

The paper is divided into 3 sub-chapters as follows: 3D model, electronic system and computer system.

2.1. The 3D model

In this subchapter, the essential component elements for supporting the video cameras, rotating the turntable, but also for assembling the electronic components will be presented. Figure 1 shows the main components of this device:

1 – The subassembly that consists of an extension with support, but also with a limiter for fixing and adjusting the video camera.

2 – Vise used to manually grip and fix the landmark.

3 – Turntable with internal cylindrical gear with straight teeth that allows the part to rotate at various angles.

4 – Base that allows supporting electronic components, but also non-electronic ones.

5 – The subassembly that is made up of component elements with the role of supporting and adjusting the position of the video camera. It has a background for obscuring unwanted elements captured by the video camera.

6 – Microcontroller used to control the other electronic components.

7 – Video cameras used for high quality image acquisition.

8 – Driver that allows controlling the motor step by step.

9 – Stepper motor that rotates the platter by engaging the gear wheel assembled on its axis with the gear wheel integrated in the platter.

10 – System that allows the display of the answer to the check in the form of LEDs of different colors, but also to notify the operator through a loudspeaker.

11 – Bearings that allow the plate to move freely.

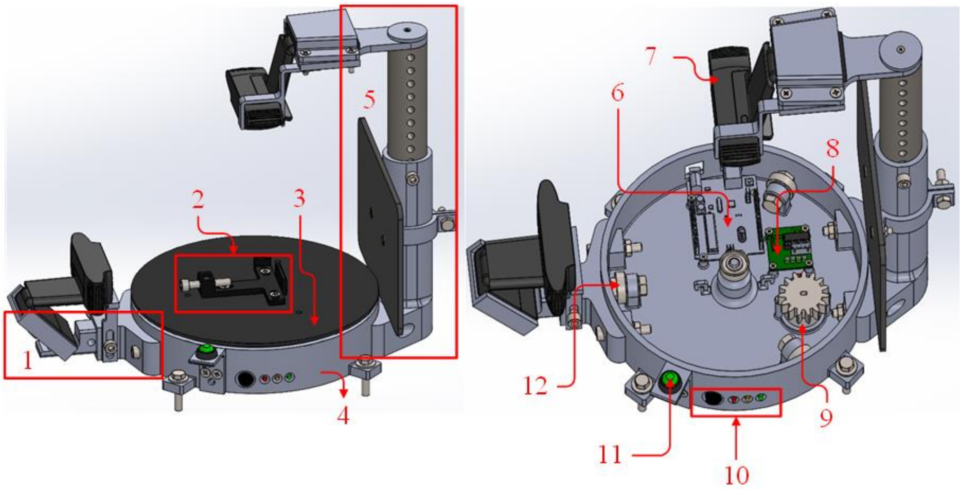

Fig. 1. The 3D model

2.2. Electronic system

Electronic components have been selected according to specific technical characteristics, purchased and individually tested to ensure that they work properly. The part called "Base" in figure 1 was designed in such a way as to allow a better assembly of electronic components, but also of other non-electronic components. In figure 2 you can see an electrical diagram containing the electronic components with the connections made.

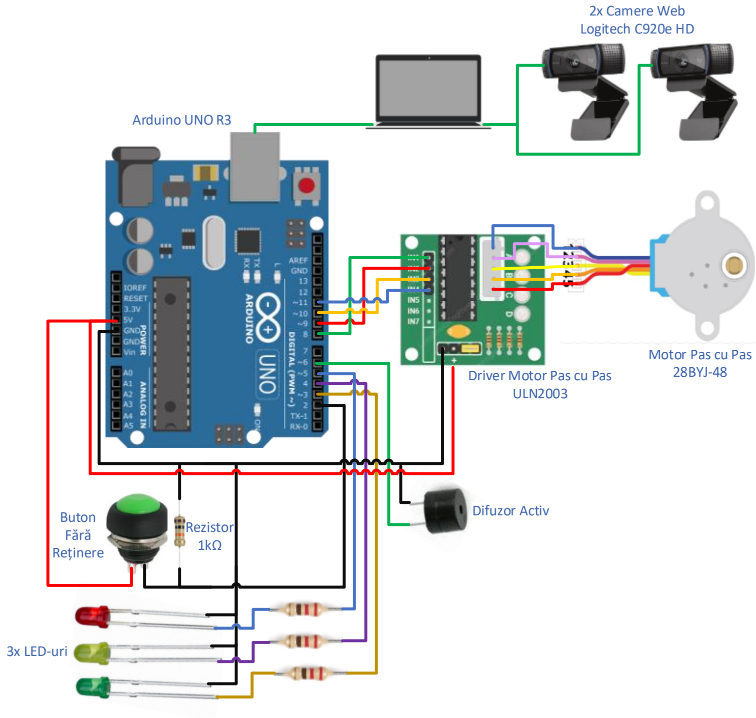

Fig. 2. Wiring diagram

In figure 2, the video cameras and the microcontroller are connected to a laptop. Video cameras are used for image acquisition, and the laptop allows the analysis and processing of images from the video cameras to verify the dimensions of the landmarks. At the same time, the laptop will also send the response after the verification through the Arduino microcontroller to the three LEDs of different colors, but also to the server for storing the dimensions along with information such as: the name of the workstation, of the operator, of the landmark, the date and time at which the check was carried out. The laptop can be replaced with any other hardware device, but which allows compatibility with the LabVIEW application.

The loudspeaker fulfills two important functions, namely to announce the control interval, but also to confirm the start and completion of the verification process. In order to control the 28BYJ-48 stepper motor, a ULN2003 driver was used that allows signal amplification, which is why the Arduino microcontroller cannot directly transmit the pulses to the motor.

To protect and increase the life of the LEDs, resistors with a resistance of 220 Ω were connected. The button is non-retentive and has a "pull-down" type connection with a resistor with a resistance of 1 kΩ, so that when it is pressed it sends a value of 1 for true, and otherwise a value of 0 for false, so the verification process will start depending on the answer given when the button is pressed.

2.3. Step by step motor control application

To control the stepper motor, a program was created in the LabVIEW programming environment and the Linx module was used to communicate with the Arduino microcontroller. This program will be used as a subVI in the dedicated device program. It can be seen in figure 3 from left to right how the application opens a communication port and iterates a "For Loop" type structure 581 times. This value was given through repeated trials and it was found that this number is equivalent to an angle of 90o.

The application transmits through the four pins a set of combinations of values of 1 or 0 to allow electrical current to pass through the four coils inside the stepper motor. It was also chosen to introduce a "Wait" type function of 10 milliseconds both inside the loop and after it. The "Flat Sequence" structure allows better organization in terms of running the application.

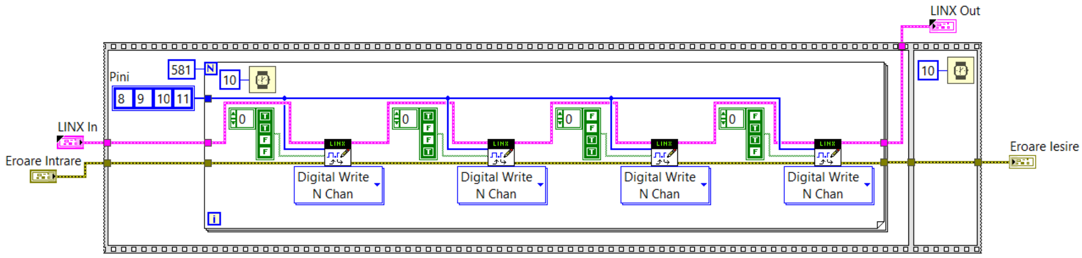

Fig. 3. Step by step motor control application

2.4. Image analysis and processing application

In order to achieve this application, a landmark with the functional role of a pipe connector under the name "RA001" was designed. In the figure below there is an execution drawing with that reference. The design of this landmark was necessary to have a physical product on which to make the application and then to do the necessary tests to measure the dimensions.

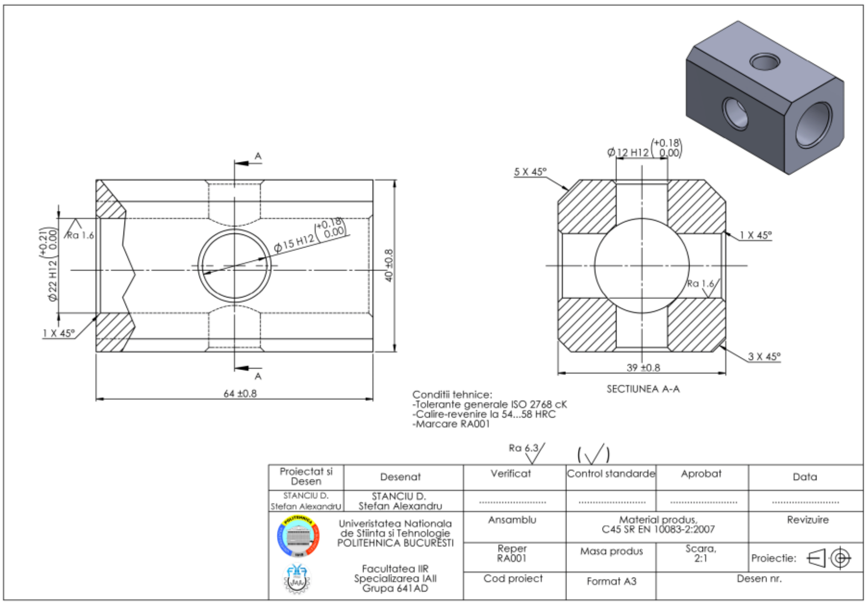

Fig. 4. The blueprint for RA001

This application was made using the NI Vision Assistant mod and deals with the image processing part. Figure 5 shows that the part was extracted using functions from the NI Vision Assistant library. The most important functions used are:

- Color Threshold - used to select objects against the background according to color.
- Advanced Morphology - cleans the image of unwanted particles according to some criteria.
- Shape Detection – shape detection – identifies if there are circles present in the image and is used to extract the radius in pixels, but also to extract the coordinate of the center of the circle.
- Particle Analysis - particle detection - identifies the particles present in an image and displays the length, width, but also the coordinates of the points that form the respective particle.

The application is used in the form of a script generated by the NI Vision Assistant module as a subVI for both the device's top and side cameras. The values obtained in pixels are correlated with the dimensions of the part in reality using the simple rule of three, so the application is taught to measure accordingly.

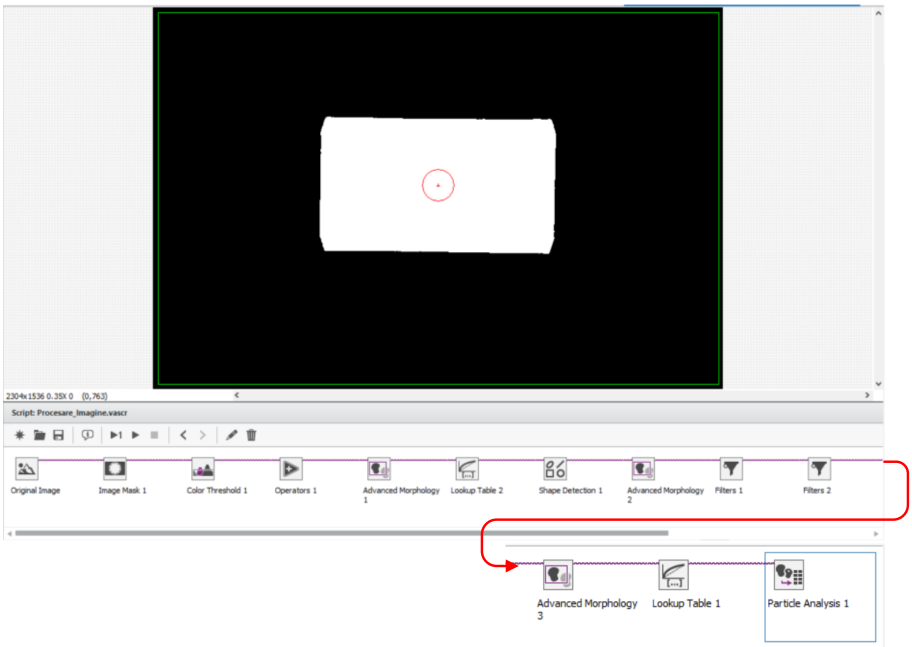

Fig. 5. The application made in NI Vision Assistant

2.5. The application deployed in the device

The application has a simple interface that displays a series of information for the operator. It has a "Panel" type panel with two tabs called "Operator" and "Moderator". The "Moderator" panel contains details such as the name of the workstation, but also details about the connections of the microcontroller and the two video cameras made with the USB ports on the laptop. The "Operator" panel contains: an "Image Display" type indicator for displaying the image acquired by the video cameras; three Boolean indicators of which one is for start, the second is to warn the operator of approaching the control interval, and the third is to indicate the state of the part. The measured dimensions next to the check response are displayed in a matrix; date and time; the name of the workstation, the name of the operator, but also of the landmark.

Fig. 6. Application interface

At application startup all pointers are initialized to 0 to avoid residual data. This aspect will also happen when the "Stop" button is pressed. The whole application runs continuously in a repetitive "While" structure and in that structure the "Event Structure" structure was used to manage events and minimize the use of processor resources. When the button on the device is pressed, the three LEDs will receive the value false through the "Digital Write" function, and the speaker and the green LED will turn on and turn off after 500 milliseconds.

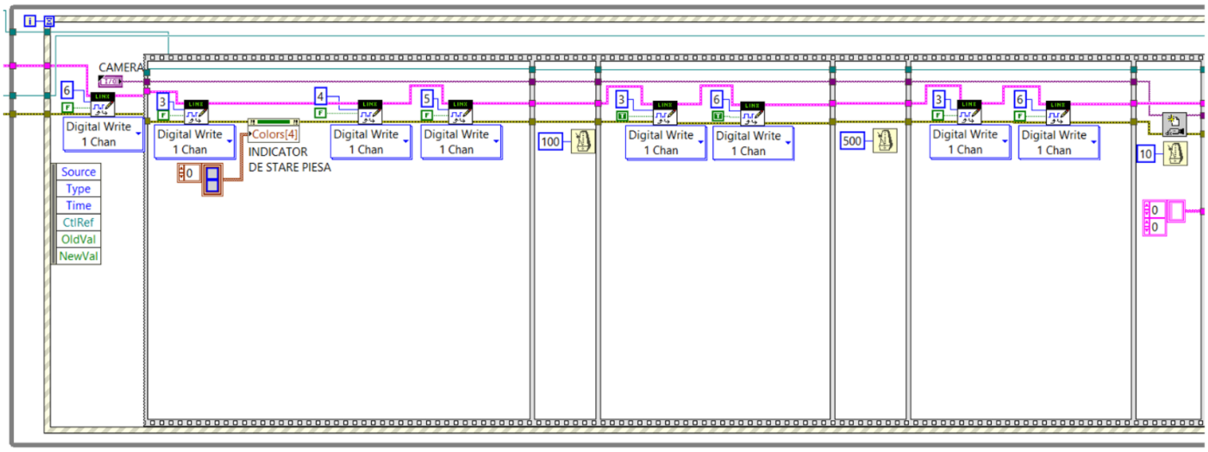

Fig. 7. Confirmation of the start of the verification process

Once the start of the verification process is confirmed, the camera on the side of the device will acquire a vertical image of the part and measure a first dimension which is the height of the landmark. The platen will rotate 90º so that another image can be acquired with the side camera and the diameter of a hole can be measured. All these dimensions are later saved in an array called "Dimension". The rotation of the plate is done with the help of the subVI from subchapter 2.3.

Once the image acquisition with the side camera is complete, it will disconnect and the other camera positioned above will acquire an image in the horizontal plane, thus measuring the length, width and diameter of the landmark. The turntable will rotate the marker 90o clockwise, and the side camera will take one last image to measure the diameter of a circle.

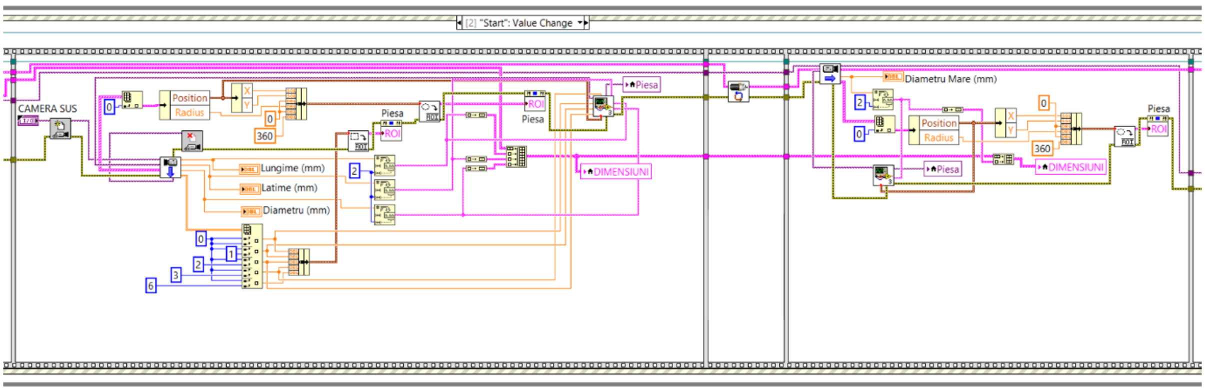

Fig. 8. Block diagram of the VI for measuring the other dimensions

All these dimensions are sent along with information such as the name of the workstation, the operator, but also the landmark to the server by means of a protocol called TCP (Transfer Control Protocol) which has been open since the start of the program. In figure 9 it can be seen that data is received from the server through the TCP protocol, which also contains the response after checking the dimensions. With the help of the "Search 1D Array" function, it is searched if there are dimensions that attest to which category the landmark belongs. A "Flat Sequence" type structure was used to create a source code to be executed in chronological order.

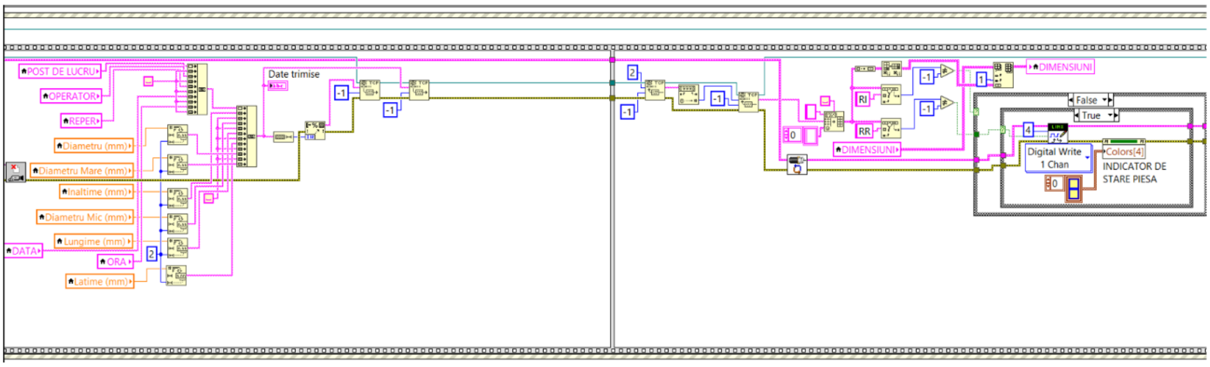

Fig. 9. Receiving the response after verification from the server

2.6. The server

The server is another essential part in the communication between the device and the database. It has the role of receiving, processing and transmitting data both from the device to the database and vice versa. Figure 10 shows one of the most important codes within this sever. In the first phase, data such as the name of the workstation, operator, landmark, date and time are extracted and stored in a vector. From this vector only the dimensions are extracted.

It is checked which of the dimensions represent the diameters of the holes or not by assigning abbreviations such as: "G" for the hole and "D" for the rest of the dimensions. This was achieved using a "Case" type structure. Based on the ID extracted for the landmark, it is checked whether the measured size is between a minimum and a maximum size. These limit sizes are pulled from a database based on the landmark ID. Following the checks, abbreviations are given for dimensions such as: "B" for the good part, "RR" for recoverable scrap and "RI" for unrecoverable scrap. The measured dimensions will be stored in a database along with the categories they belong to (B, RR or RI).

At the same time, the server also deals with the allocation of operators and milestones according to the work station. Thus, two structures of the "While" type were used, where one is for allocations, and the other is for size checks.

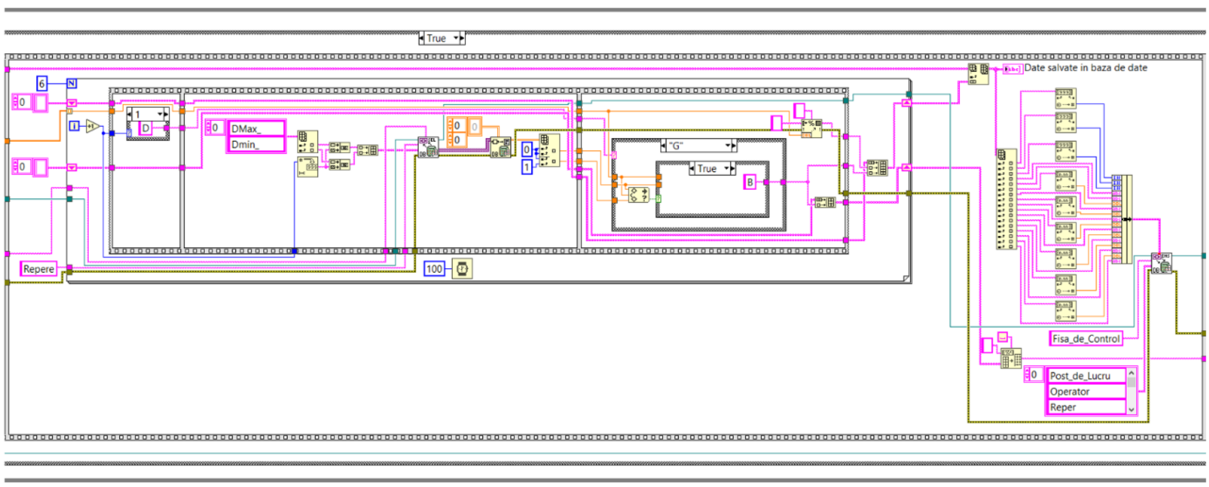

Fig. 10. Checking the dimensions and saving them in the database

2.7. Database

A database was created to store various information about operators, landmarks and workstations. The storage of the dimensions and the category to which they belong is done in the table called "Control_sheet" along with some additional details such as the job, the name of the operator, of the landmark, but also the date, respectively the time. The "Allocation_Operator" table has the role of indicating which milestone must be processed, but also who will be assigned as an operator to the respective workstation.

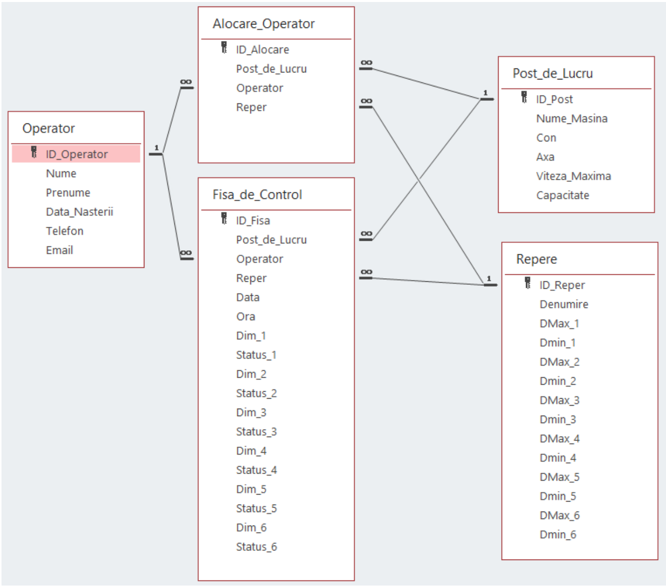

Fig. 11. Database

3. Conclusions

These image processing based inspection systems are absolutely necessary for increasing productivity, quality and efficiency in industrial processes. The device can be easily modified to measure different parts with different geometric configurations thanks to the presence of camera extensions for adjusting the distance from the camera to the part and the clamping system on the replaceable turntable. Other components with better technical characteristics can be used and a dedicated web interface can be created for the staff from the Technical Quality Control Department for an easier and more useful visualization of the dimensions stored in the database.

4. Bibliography

[1]. Ciora Radu Adrian, Simion Carmen, "Industrial Applications of Image Processing", https://www.researchgate.net/publication/273303696_Industrial_Applications_of_Image_Processing

[2]. Embrey David, "Understanding Human Behaviour and Error", https://www.researchgate.net/publication/266334170_Human_Error_Understanding_Human_Behaviour_and_Error

[3]. Rajan Kumar, Dwivedi R.K., Verma Ajay, "POKA-YOKE TECHNIQUE, METHODOLOGY &DESING",https://www.researchgate.net/publication/304656076_Pokayoke_technique_methodology_design_Publication_History_POKAYOKE_TECHNIQUE_METHODOLOGY_DESIGN

DESIGN AND IMPLEMENTATION OF AN EXPERIMENTAL GESTURE-TO-AUDIO AND TEXT CONVERSION EQUIPMENT

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ABSTRACT: The project aims at designing and building a prototype equipment that converts user gestures into audio and text messages, offering assistance to people with speech disabilities. The project consists of two main modules: the Acquisition Module, which uses flex sensors to capture gesture movements, and the Processing Module, which processes the captured information, converts it into audio messages to be played on a speaker and text to be displayed on an OLED display. The project has the potential to significantly facilitate communication for people with speech disabilities, offering them an alternative way to express themselves and interact with others. The development of a functional prototype is planned, demonstrating the feasibility of the concept and allowing for further evaluation of its performance and usefulness..

KEYWORDS: gesture conversion, audio message, text message, communication impairments, sign language

1. Introduction

Communication is a fundamental human need, essential for social integration, self-expression, and access to information. People with language impairments face significant communication barriers, being limited in their interaction with others and in their access to education, employment, and social life. The project aims to contribute to the elimination of communication barriers by designing and implementing a prototype device that converts user gestures into audio and text messages. The project will be carried out in two main stages: the design phase, which will include defining the functional and technical requirements of the equipment, selecting the hardware and software components, and designing the system architecture; and the implementation phase, which will include assembling the prototype, programming the software, and testing the functionality of the equipment. It is expected that a functional prototype will be developed that will demonstrate the feasibility of the concept and allow for further evaluation of its performance and usefulness.

2. Current stage

Over time, there have been various attempts to combat this disability. The following will analyze different experimental models developed from 2010 to the present. Figure 1 shows a special device developed for Pakistani citizens in 2014 that contains technology that is easily accessible to them. Communication between the two modules is carried out using a fixed cable, which makes it difficult to manage the product. The LCD screen on the subject's abdomen hinders their mobility. These two features failed to convince the subjects.

Fig 1. Gesture-to-Text Conversion Device Developed in Pakistan[2]

Figure 2 shows a prototype device used for converting finger gestures into audio content. It utilizes an Arduino microcontroller, which renders the system rather bulky and immobile.

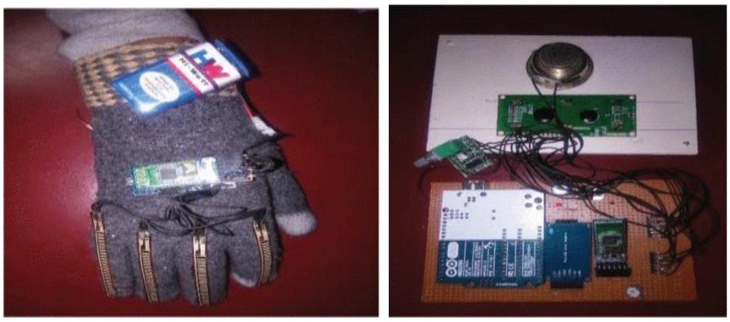

Fig. 2. Gesture Conversion Device Comprising Two Parts: Glove and Station[3]

3. Product development

Figure 3 illustrates the schematic diagram of the experimental setup. The left side depicts the equipment worn by the subject. This glove captures finger movements and converts these movements (analog signal) into a digital signal (signal compatible with the I2C protocol on the Raspberry Pi Pico microcontroller). This digital signal is recorded only when the touch button is pressed. After recording, the analysis stage follows, where it is checked whether the desired gesture corresponds to another predefined gesture. If it exists, a coded signal will be sent to the corresponding Bluetooth module of the glove. This code is transmitted through the Bluetooth communication channel to the main station (the basic diagram can be seen on the right side). Once this code is received, the appropriate audio file stored on the SD card is selected and played on the speaker, and then a confirmation message is displayed on the OLED screen.

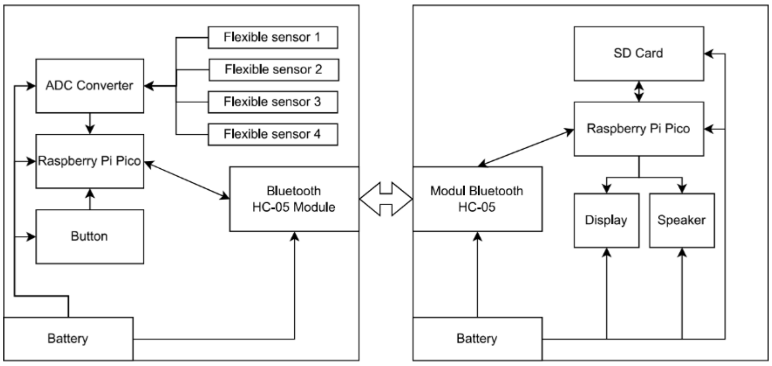

Fig. 3. Block diagram

Table 1 provides an overview of the equipment's features and how they are evaluated technically. The measurement units used allow for an objective comparison of the performance of the functions.

Table 1. Units of measurement of functions

Fn	Function Name	Technical Characteristic	Functions unit of measurement
F1	Accurate and fast information retrieval	To have reliable flexible sensors	no. of bendings
F2	To have an ergonomic design	Maximum transportable size	w x l x h
F3	High autonomy	High battery capacity	mAh
F4	High command distance	High-range Bluetooth module	m
F5	Product accessibility software	Saving messages from any smartphone device	-

The table presents a list of features and their technical characteristics, along with the measurement units used to express them.

To determine the system's composition, it will be divided into the two distinct modules illustrated in Figure 4. The components used are: Raspberry Pi Pico, Flex sensor, HC-05 Bluetooth module, 4-channel ADC converter, 0.96" OLED display, Breadboard, Touch button, 47KOhm resistor, Batteries, Audio amplifier module, On/Off button, and various designed and printed components such as the 'Station' module housing and the 'Glove' module housing.

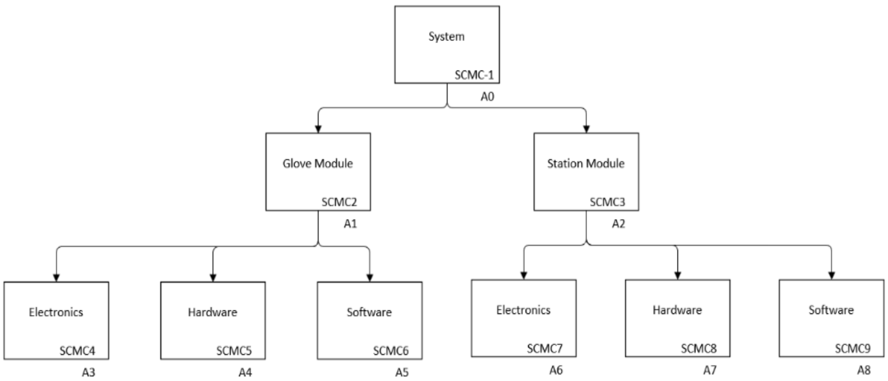

Fig.4. Initial system diagram

Figures 5 and 6 illustrate the electrical connections of the components within the system.

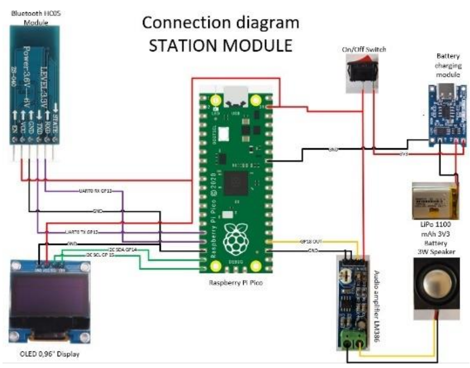

Fig. 5. Station Module Connection Diagram

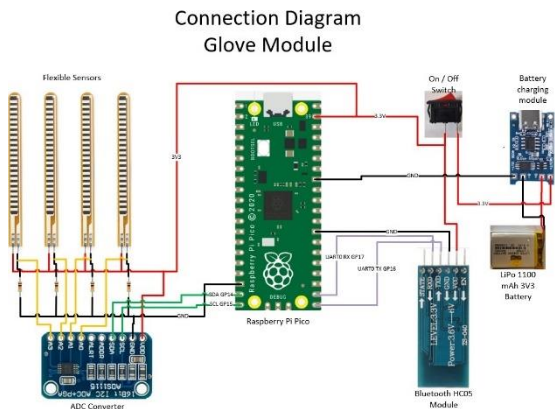

Fig. 6. Glove Module Connection Diagram

The design of the necessary components will be done in the onshape parametric design software. The specific station module housing will need to include mounting surfaces for the components specified above as well as interfaces for user access. The following requirements can be noted: mounting surface for the perforated board with electronics, speaker, battery charging module, OLED display, but also an access area to the electronics area through a cover that also serves as a hook (Figure 7).

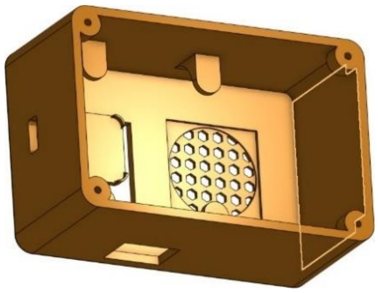

Fig. 7. Station module housing

Figure 8 shows the main interface of the Station Module. This interface includes: Display access area: This area houses the display screen that prevents information about the device’s status and functions; Speaker area: This area allows sound to exit the device. Type-C Charging Port: Located on the left side of the device, this port allows the connection of a charging cable to power the battery. On/Off Switch: Placed above the charging port, this switch turns the device on or off, connecting or disconnecting it from the power source.

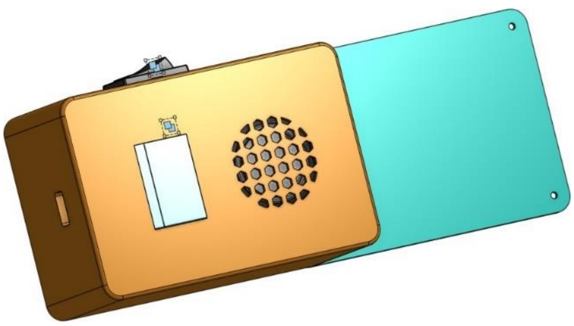

Fig. 8. Station module assembly. Main view

Figure 9 illustrates the layout of the electronic components inside the Station module housing: Perforated board: The key components of the module are soldered onto a small perforated board: Raspberry Pi Pico, audio amplifier and Bluetooth module, Battery: A compact battery with a capacity of 1100 mAh is positioned on the right side of the perforated board, powering the device. Multifunctional cover: The housing cover fulfills a dual role: it closes the housing and provides a mounting point on various surfaces, thanks to the central support.

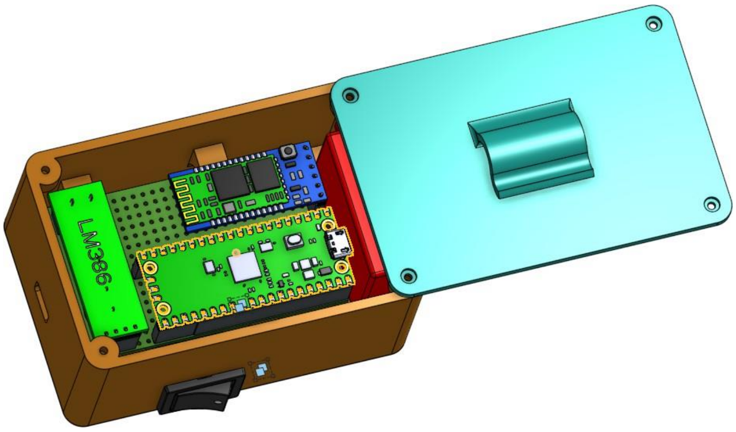

Fig. 9 . Station module assembly. Top view

Figure 10 illustrates the following components: Flexible sensors: placed on the four fingers, these sensors capture data about finger movement. Main housing: Houses the microcontroller along with the analog-to-digital converter that analyzes the captured data and then transmits it via Bluetooth. Battery housing: Contains the battery and charging controller, as well as an on/off button. This module has been divided into two separate elements to facilitate the wearing of the equipment. All of these components will be sewn onto a textile glove that the user will wear.

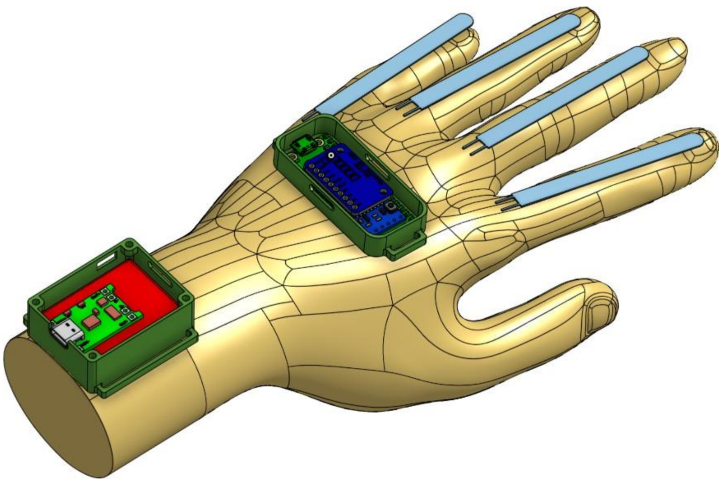

Fig 10. Glove assembly. Isometric view

4. Conclusions

The project "DESIGN AND IMPLEMENTATION OF AN EXPERIMENTAL MODEL OF EQUIPMENT FOR CONVERTING GESTURES INTO AUDIO AND TEXT MESSAGES" hasdemonstrated the feasibility of the concept of facilitating communication for people with hearing impairments by converting gestures into audio and text messages. The prototype developed has highlighted the basic functionality and has allowed the identification of optimization directions, including the integration of a gyroscope for better gesture accuracy. The development of dedicated software with additional functionalities, testing with users with hearing impairments and the creation of a final version that is affordable and easy to use, with a significant impact on their quality of life, are planned.

5. Bibliography

[1] - WENDT, Oliver. LLOYD,Lyle. Assistive Technology: Principles and applications for Communication Disorders and Special Education. Augmentative and Alternative Communication Perspectives, Volume 4, 1-22, 1991

[2]. K. Kanwal, S. Abdullah, Y. B. Ahmed, Y. Saher and A. R. Jafri, "Assistive glove for Pakistani Sign Language translation," 17th IEEE International Multi Topic Conference 2014, Karachi, Pakistan, 2014, pp. 173-176, doi: 10.1109/INMIC.2014.7097332. keywords: {Image recognition;Calibration;Delays;Instrumented glove;Pattern Recognition;Principal component Analysis;Euclidean Distance;Urdu sign language},

[3]. A. Nagpal, K. Singha, R. Gouri, A. Noor and A. Bagwari, "Hand Sign Translation to Audio Message and Text Message: A Device," 2020 12th International Conference on Computational Intelligence and Communication Networks (CICN), Bhimtal, India, 2020, pp. 243-245, doi: 10.1109/CICN49253.2020.9242549. keywords: {Visualization;Flexible printed circuits;Microcontrollers;Sociology;Liquid crystal displays;Sensors;Statistics;Speech Impaired;Microcontroller;Communication;Secure Digital;Amplification},

6. Notations

OLED - Organic Light Emitting Diode

ADC - Analog to Digital Converter LCD

- Liquid Crystal Display

DESIGNING AND ASSEMBLING A CONTROL SYSTEM FOR A COLLABORATIVE ROBOTIC ARM

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ABSTRACT: This paper aims to present the design, realization and testing of an experimental stand for a collaborative robotic arm made by additive manufacturing methods. In order to solve the proposed theme, software applications and a physical model were developed. During the experimental stand, the computational effort is supported on a development board made in Romania, compatible with Arduino Mega 2560 (Ground Studio - Jad Mega). For the design and manufacture of the experimental stand, we used the Dassault Systemes Catia V5 CAD program together with UltimakerCura 5.5.

KEYWORDS: robotic arm, collaborative, design, manufacturing, software

1. Introduction

According to [1] and [2] Collaborative robots, known as Cobots, are small robotic arms used in a wide range of applications to automate repetitive work, usually done by workers. They were designed to share the same workspace with people, automating processes in a wide range of domains.

Collaborative robots are designed to be much simpler to use than traditional industrial robotic arms. Humans have revolutionized the configuration of collaborative robots, significantly reducing deployment time. Many common work processes have become programmable and operable with the training of their program according to the user's wishes.

The workspace was also minimized because the wide range of processes that could be automated were implemented without changing the location or the specialist. The low weight of these robots also makes them easy to move, if necessary, without the need for major changes.

Fig. 1 Workspace between cobot and operator [2]

The first cobots ensured the safety of humans by having no internal source of motive power. Instead, motive power was provided by the human worker. The function of the cobot was to allow computerized control over movement, by redirecting or directing a payload, in a cooperative way with the human worker. [2]

Later, cobots also provided limited amounts of motive power. General Motors and an industry working group used the term Intelligent Assist Device (IAD) as an alternative to the cobot, which was seen as too closely associated with the Cobotics company. At that time, the market demand for intelligent assistive devices and the safety standard "T15.1 Intelligent assistive devices – personnel safety requirements" was to improve industrial material handling and automotive assembly operations.

2. State of the art

Collaborative robots are robots designed to interact directly with human staff within the same workspace. The aspects that differentiate collaborative robots from the usual ones are, first of all, safety.

According to the International Federation of Robotics, there are four levels of collaboration between industrial robots and human operators:

- Coexistence: the robot and the human operator work together, without separating elements, but do not share the same workspace;
- Sequential collaboration: the robot and the human operator work in the same workspace, but the operations performed by each do not take place at the same time;
- Cooperation: the robot and the human operator work in the same workspace at the same time;
- Collaboration: the robot responds in real time to the actions performed by the human operator [3]

The term "collaborative robot" is a commercial one, as it is not included in the standards related to industrial robots. The degree of integration of a robot in the category of "collaborative robot" can be argued that it depends on the degree of safety of the application that the robot performs rather than on its construction, given the fact that the structures of collaborative robots are largely based on the structures of common industrial robots. [3]

Elements specific to collaborative robots are components made of lightweight materials, rounded outer surfaces protected with easily deformable materials, as well as means of immediate collision detection. The controller's software configuration must include safety measures to avoid injury to human personnel, such as immediate stop protocols in case of collision detection.

3. Experimental booth

The robot presented in this paper is a collaborative robotic arm with gripper-type effector. It was chosen in order to be able to move/assemble/sort objects or parts from the production line of a factory or storage hall. The flexible model helps to make it easy to use, being able to be handled manually, so the operator has absolute control over it but also the possibility of implementing an automatic work program.

The parts were made entirely through additive manufacturing methods, the material chosen and used being a PET-G to provide a resistant structure to the articulated arm. Also, the connecting parts between the parts are assisted by ball bearings, one of which is axial, for a smoother and easier handling of the motors, assembly by screw-nut of M3 and M2 respectively for mounting the micromotors in direct current on the support, and the use of metal rods for assembling the arms on the motor shaft.


Fig. 2 Physical model of the experimental booth

The experimental stand is a collaborative robotic arm with four axes numerically controlled by a compatible controller Arduino Mega 2560 [4] (Ground Studio - Jad Mega). The programming language used to drive the motors is a variation of C modified by the Arduino CC. The development environment we used is the Arduino IDE.

The robotic arm with the end-effector attached has five degrees of freedom, two servo motors, one with the angle of 120° MG995 [5] used in the end-effector, respectively a continuous 360° DS04-NFC [6] used at the base of the robotic arm, and three Pololu micromotors [7] in direct current. The load-bearing load of the entire boom together with data on the maximum travel speed on each axis can be found in Table 1.

Table 1. Robotic Arm Specifications

Base Displacement Limit	280°	
Load-bearing load	65 g	
Maximum travel speed	M1	45 rpm
	M2	52 rpm
	M3	52 rpm
	M4	52 rpm
	M5	45 rpm
Robotic arm spindle dimensions	Bx1	45mm
	Bx2	80 mm
	Bx3	75 mm
	Bx4	5 mm

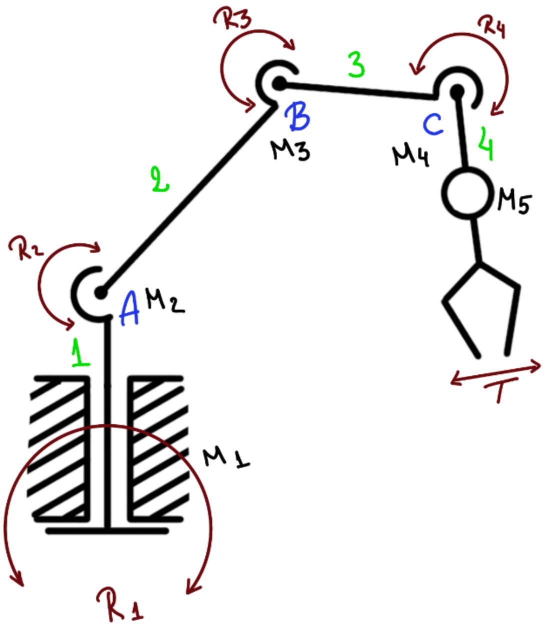

Fig. 3 Kinematic diagram of the articulated arm

The kinematic diagram represents the mode of operation and placement of the motors, respectively M1, M2, M3, M4 and M5. The joints were denoted with A, B and C respectively, the engine rotations with R1, R2, R3 respectively R4 and with T the opening angle of the end-effector type gripper with two sticks.

The size of the working space around the axis of the M1 motor is 280°, respectively the rest of the motors having a variable angle depending on the working space. To the M1 we attached a metal flange to make the connection between the M1 and the 1 axis.

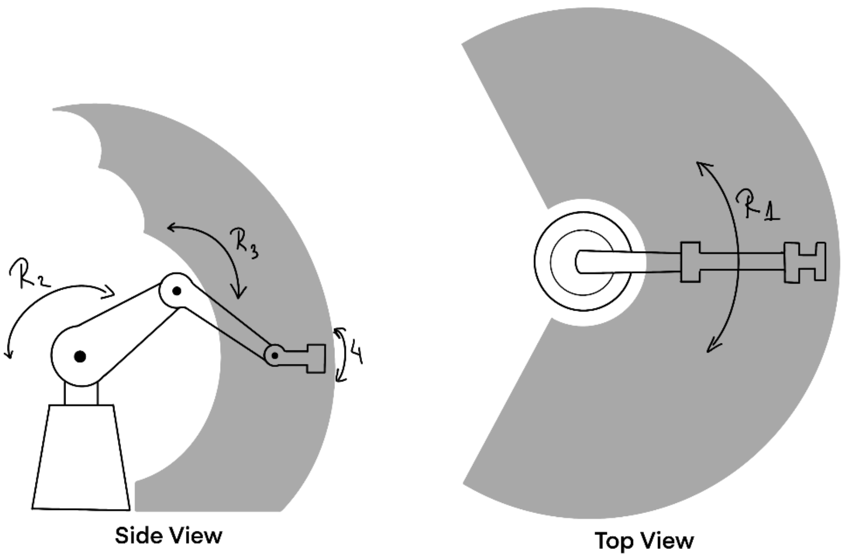

Fig. 4 Workspace layout

The design and 3D visualization of the entire assembly was carried out in the Dassault Systemes Catia V5 CAD program together with UltimakerCura 5.5; for the realization of the G. code and visualization of the printing mode of the parts and the support necessary for printing the complex shapes of the segments that make up the articulated arm.

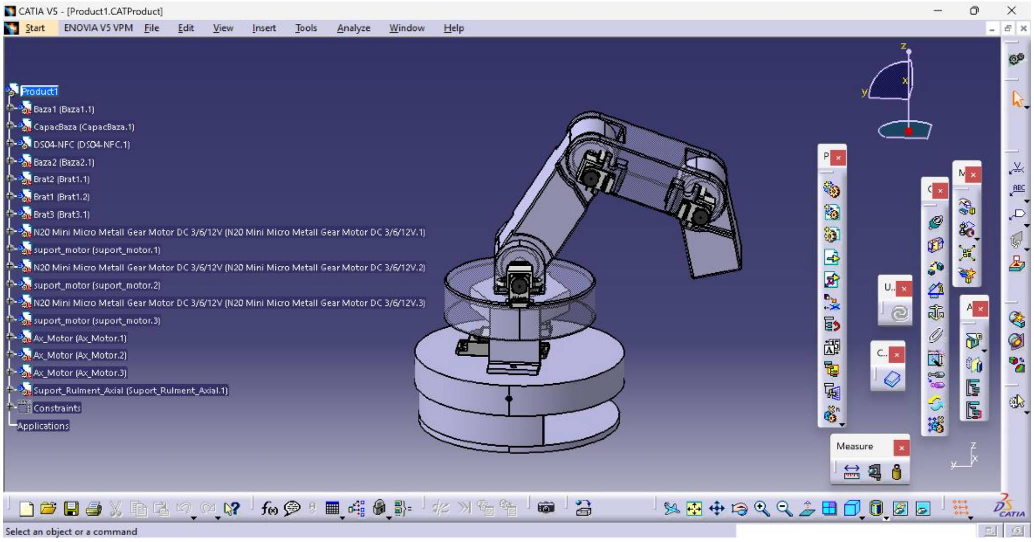

Fig. 5 Catia V5 program interface and final product assembly

The settings chosen for small resistance parts: accurate printing and easy deburring prose, we used the settings as in Table 2. For the production of large component parts, the settings are similar, differentiating the degree of filling, which is 30%, reducing the weight and total consumption of material, respectively the printing time.

Table 2. Required settings UltiMakaer Cura

Features	Settings used
Profiles	Draft
Layer Height	0.2 mm
Wall Thickness	0.2 mm
Infill Density	100%
Infill Pattern	Triangles
Printing Temperature	220
Print Speed	60 mm/s
Support (Yes/ No)	Yes
Support Placement	Everywhere
Bracket overhang angle	45
Support pattern	Zig Zag
Build plate adhesion type	Brim

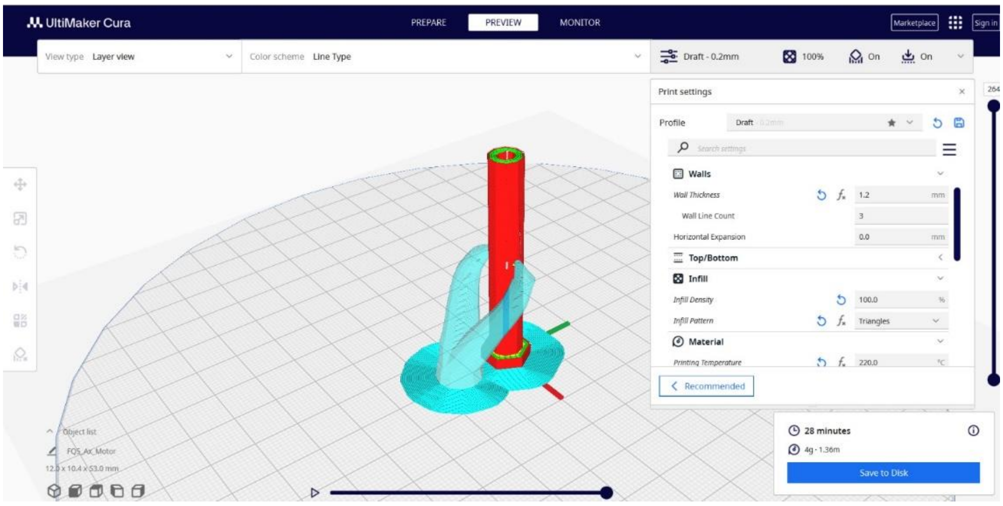

Fig. 6 UltiMaker Cura Interface

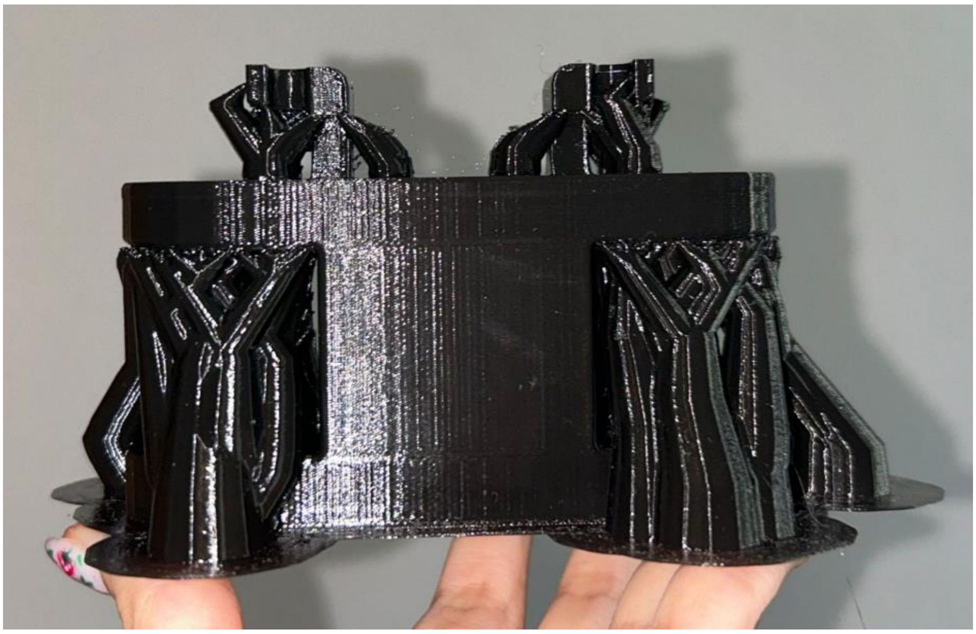

Fig. 7 The "Brat2" part made by 3D printing

The execution drawing in Fig.8 represents the dimensions of the finished product but also the list of component parts, including the motor elements. However, the composition table does not include the overall elements, namely screws, nuts and bearings used.

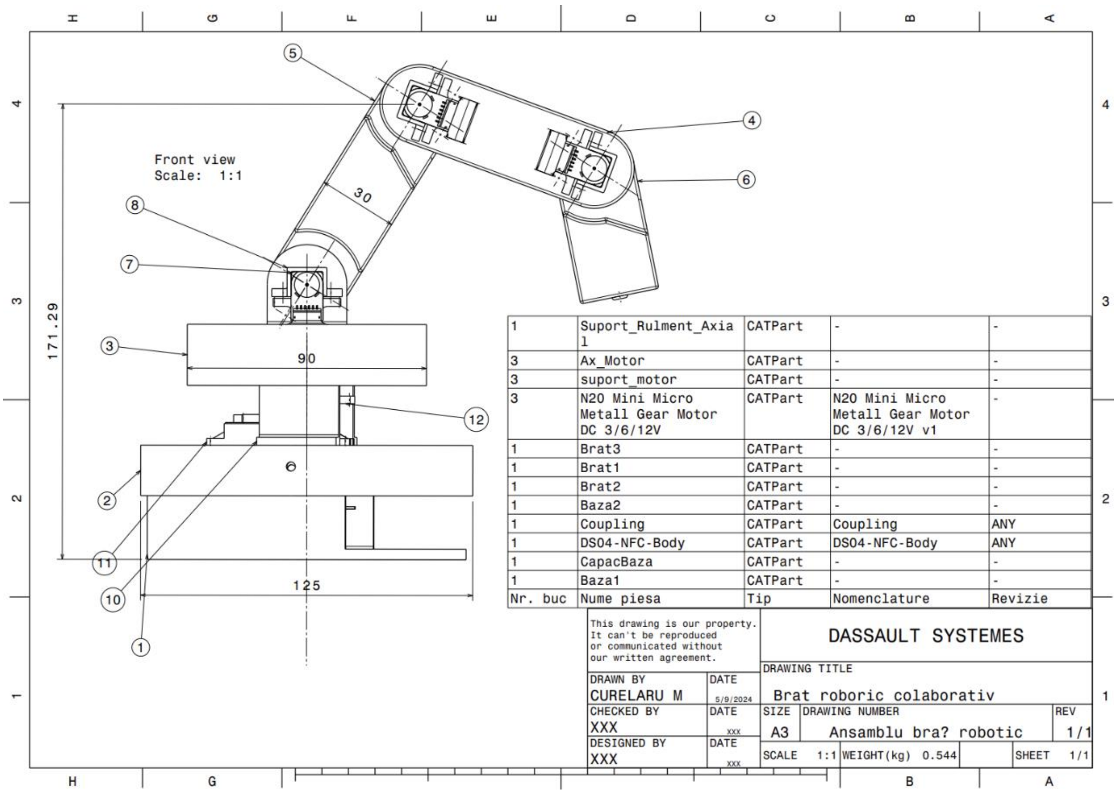

Fig. 8 Execution drawing of the articulated arm

Therefore, Table 3 shows the unprinted components, their name and the quantity needed to assemble the robotic arm made and studied.

Table 3.Components required for robotic arm assembly

Product name	Quantity purchased
Servo Motor Gripper: MG995	1
Servo Motor Base: DS04-NFC	1
Pololu 298:1 DC micromotor	3
Driver motor DRV8838	3
Grand Studio Jade Mega	1
Thrust Ball Bearing 51103 WELT	1
608RS Radial Ball Bearing	6
M3 x 5mm Screw	≈25
Screw M2 x 5mm	≈6
M3 Nut	≈25
M2 Nut	≈6
Metal rod 2mm x 150mm	2

In figure 9 I represented the electronic diagram based on which I made the electrical circuit for the experimental stand. For a better understanding of the circuit I have established a color convention as follows: red - power, black - GND, green - digital I/O, respectively blue - analog I/O.

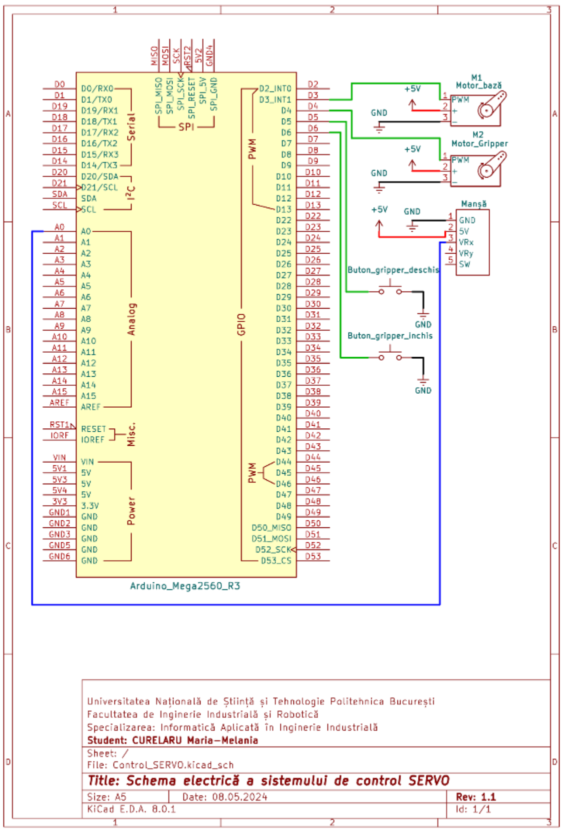

Fig. 9 Electrical diagram of the SERVO control system made in the KiCAD program

Considering the specifics of the work, I chose as a control method a set of two return buttons together with a unidirectional handle. The buttons are connected to the Arduino Mega microcontroller using the integrated PULL-UP resistors, reducing the complexity of the circuit. They are used to close and open the gripper jaws.

Compared to the return buttons that only require a digital signal (1 or 0), the handle returns an analog value between 0 and 1023. This gives the experimental stand the possibility of a sufficiently fine adjustment of the speed to achieve a smooth movement.

4. Conclusions

As a result of the research carried out on the current stage, we have noticed that the use of non-collaborative robots is well received in small industrial applications, for example: computer assembly, assistance in additive processes, assistance in palletizing, respectively in the pharmaceutical field (making customized mixtures, encapsulation of medicines).

Another important factor when it comes to collaborative robots is the versatility they show. A single collaborative robot can perform multiple tasks depending on the code applied to it. Thus, considering the task it has to perform, the collaborative robot can be equipped with another set of tools, cameras or sensors, as well as specially established functions.

Given the small size of a cobot, it can be said that the manufacturing process is relatively difficult. The difficulty arises due to the shape and specificity of the collaborative arm, which is made of easily deformable and light-weight materials. The printing of the parts required multiple trials and versions, respectively for the drive shaft, because the precision of the printing did not allow exact printing, plus measurement error of the assembly parts, such as bearings and screws.

In conclusion, using a collaborative robotic arm is useful for small productions to ease repetitive and long-term work. Eliminating them increases productivity and reduces the time needed to complete the proposed application. Therefore, purchasing a cobot, but also manufacturing one with mid-level characteristics, represents a lower cost.

5. Bibliography

[1] "What Are Collaborative Robots, Cobots | A3 Robotics Collaborative Robots," Automate. Accessed: Apr. 23, 2024. [Online]. Available: www.automate.org
[2] Universal Robots, "Why Cobots? | All the Benefits of Collaborative Robots," Collaborative robots. Accessed: Apr. 23, 2024. [Online]. Available: www.universal-robots.com
[3] Prof. Dr. Ing. Diana POPESCU, "Robotic Manufacturing Systems," National University of Science and Technology Polytechnic Bucharest, 2024 2023.
[4] "A000067-datasheet.pdf." Accessed: May 08, 2024. [Online]. Available: https://docs.arduino.cc/resources/datasheets/A000067-datasheet.pdf
[5] Caldas Electronics, "MG995_Tower-Pro Servomotor," Datasheet. [Online]. Available: www.electronicoscaldas.com
[6] Luxorparts, "DS04-NFC 360 Continuous Servomotor," Dadasheet, Nov. 2017. [Online]. Available: www.kjell.com
[7] Pololu, "Micro Metal Gearmotors Pololu," Datasheet Rev 6.1, Apr. 2024. Accessed: Sep. 05, 2024. [Online]. Available: www.pololu.com

6. Notations

I/O = input/output connector
GND= grounding
Cobot = collaborative robot

DESIGNING AN ALGORITHM AND DEVELOPING A SOFTWARE APPLICATION FOR PHASED DISTRIBUTION OF PRODUCTS WITH AFLEET OF TRANSPORT VEHICLES

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ABSTRACT: The paper "Designing an Algorithm and Developing a Software Application for Phased Distribution of Products with a Fleet of Transport Vehicles" is based on the development of a software application that uses a Microsoft Access database and a web interface created with HTML, CSS, JavaScript, SQL, and PHP programming languages. The application aims to optimize product distribution for a certain number of clients with a fleet of vehicles, allocating the products to each vehicle based ontheir volume without exceeding the vehicle's total capacity, while simultaneously maximizing profit. The purpose of the paper is to present the current status of the web interface and the database, as well as to discuss algorithms that can be used to optimize the distribution process.

KEYWORDS: knapsack problem, database, web interface, algorithm, distribution

1. Introduction

In the digital era we live in, the integration of information technologies is imperative in the context of any business activity. The importance of information systems in today's era lies in facilitating efficient information management, automating processes, improving communication, and making data- driven decisions. The application is based on the "Multiple Knapsack Problem," which involves assigninga subset of items to different knapsacks in such a way that the profit obtained from the chosen items is maximized without exceeding the capacity of the knapsack. For this type of optimization, exact or heuristic algorithms (Greedy Algorithms) are used, employing methods of complete enumeration, dynamic programming,or techniques of decomposing the problem into subproblems that can be solved separately, with the partial solutions being combined to obtain a global solution. The product distribution optimization application with a fleet of vehicles considers a number of clients who may have multiple orders, the same product in multiple quantities, or multiple clients ordering the same product. Products must be allocated to vehicles based on the profit they bring, ensuring that their total capacity does not exceed that of the vehicle and that allorders are delivered on the scheduled date to avoid delay costs.

2. General considerations

2.1. Multiple Knapsack Problem - concept and applicability

MKP is a generalization of the classic Knapsack Problem, where we have a single knapsack and must choose items to maximize the total value without exceeding the knapsack's capacity. In the case of MKP, we have multiple knapsacks and must distribute the items among them in an optimal way. This problem arises in various practical fields, such as inventory management, production planning, packing and distribution of goods, resource allocation in communication networks, etc. Efficiently solving the MKP can contribute to cost optimization and improve operational efficiency in various industrial and commercial domains.

Combinatorial optimization is the process of finding the best or optimal solution for problems with a discrete set of feasible solutions. Applications appear in numerous contexts involving operations management and logistics. The economic impact of combinatorial optimization is profound, affecting diverse sectors. While much progress has been made in finding exact solutions for some Combinatorial Optimization Problems (COPs), many challenging combinatorial problems are still not solved exactly in areasonable time and require good heuristic methods. The aim of heuristic methods for COPs is to quickly produce high-quality solutions. Modern heuristics include simulated annealing, genetic algorithms, tabu search, and ant colony optimization. In many practical problems, these have proven to be efficient and effective approaches, being flexible enough to adapt to variations in problem structure and objectives consideredfor solution evaluation. For all these reasons, metaheuristics have likely been one of the most stimulating research topics in optimization over the past two decades [1].

2.2. Algorithms and efficient resolution methods for the Multiple Knapsack Problem

- Subset-sum Method: Lower bounds are obtained by dividing the chosen elements in the SMKP into the m knapsacks. This is achieved by solving a series of Subset-sum Problems, where the knapsacks are considered for increasing values. Smaller knapsacks are generally more difficult to solve than larger ones, as very few elements fit inside. In the first iteration, is filled the smallest knapsack as much as possible and corresponding elements are removed from the problem, then proceed to the next smallest knapsack [2].

- Reduction Algorithm: As known from standard 0-1 Knapsack problems, the size of an MKP can be reduced through preprocessing. For a given element j, let u0(j) be any upper bound with the additional constraint ∑i=1mxij=0. If u0(j)<z for any lower bound z, then can be added the constraint

∑i=1mxij=1 to the problem, meaning that in any optimal solution for MKP, element j must be included in some knapsack [2].

- Threshold-based Online Algorithm (OTA): The basic idea of OTA is to use threshold functions toestimate the cost of a non-fractional knapsack assignment under minimal assumptions and determinethe online solution by solving a pseudo-utility maximization problem, i.e., the value obtained fromthe element minus its packing cost. This idea is extended to FOMKP, where the estimated cost of assignment decisions is approximated by an integral of the threshold function [3].

- Upper Bound Algorithm: Upper bounds for MKP can be derived by relaxing some of the secondary constraints, where surrogate, Lagrange, and linear relaxations are the most common.By relaxing the constraint ∑i=1mxij⩽1, j=1,…,n, it is shown that the Lagrangean relaxed problemcan be decomposed into m independent 0-1 Knapsack Problems. However, there is no optimal choiceof multipliers {λj} for relaxation, so a subgradient optimization technique is usually employed [2].

- Greedy Algorithm: This is one of the simplest and most widely used algorithms and works by iteratively selecting elements based on a certain heuristic. The algorithm uses the element withthe highest value from the remaining elements; this maximizes the knapsack value as quickly as possible, after which the lightest element from the remaining ones is chosen, utilizing capacity as slowly as possible, allowing more elements to be packed into the knapsack [4].

2.3. Database - Microsoft Access

Microsoft Access is a relational database management system (RDBMS) developed by Microsoft Corporation. It is a powerful tool for storing and managing data, allowing users to create, edit, and save data in a structured format. Additionally, Microsoft Access provides functionality for creating user-friendlyinterfaces, reports, and forms for data presentation [5].

Microsoft Access is a highly popular solution for database management due to its ease of use, integration with other Microsoft products, and the flexibility it offers. Moreover, Microsoft Access is a scalable tool, meaning it can be used for both small and large databases. With Microsoft Access, users cancreate and manage relationships between different data sets, allowing them to create complex reports that combine data from multiple tables [5,6].

Additionally, users can use SQL to query the database and retrieve data based on search criteria. Overall, implementing an Access database in a web application can be an efficient and convenient solutionfor creating and managing real-time data and improving business process efficiency. However, it is importantto consider performance, security, and data integrity to ensure a proper and secure experience for users [5,6,7].

2.4. Programming languages and technologies used in the development and creationof web pages and applications

To create a web interface, we can use various programming languages, among which we include:

- HTML (HyperText Markup Language) is a markup language used to create web pages. Using HTML, you can create elements such as text, images, hyperlinks, and web forms [8,9].

- CSS (Cascading Style Sheets) is a styling language used to define the appearance and style of elements on a web page. CSS can be used to change background colors, fonts, margins, and manyother styling features of a web page [8,9].

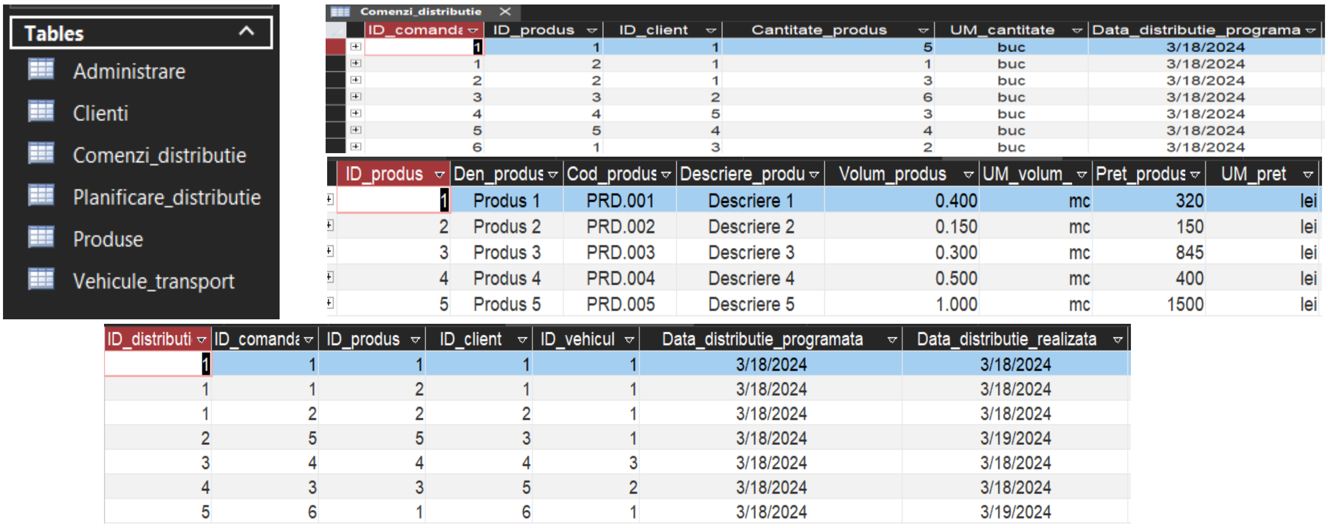
- JavaScript is a programming language primarily used to create interactivity in web pages. JavaScriptcan be used to validate forms, create special effects, modify page elements, and much more [8,9].

- PHP (Hypertext Preprocessor) is an interpreted web programming language used to generate dynamic content for web pages. PHP can be used to create web applications, forums, blogs, and much more [8,9].

3. Current work state

The application consists of two fundamental parts: the database and the web interface. The database was created using Microsoft Access and contains 6 tables with data used for testing the application ("Administrare" "Clienti", "Vehicule_transport", "Produse", "Comenzi_distributie", and "Planificare_distributie").

The tables are presented in Fig. 1.



Tables
Administrare
Clienti
Comenzi_distributie
Planificare_distributie
Produse
Vehicule_transport

Comenzi_distributie

ID_comanda	ID_produs	ID_client	Cantitate_produs	UM_cantitate	Data_distributie_programa
1	1	1	5	buc	3/18/2024
1	2	1	1	buc	3/18/2024
2	2	1	3	buc	3/18/2024
3	3	2	6	buc	3/18/2024
4	4	5	3	buc	3/18/2024
5	5	4	4	buc	3/18/2024
6	1	3	2	buc	3/18/2024

ID_produs	Den_produs	Cod_produs	Descriere_produ	Volum_produs	UM_volum_	Pret_produs	UM_pret
1	Produs 1	PRD.001	Descriere 1	0.400	mc	320	lei
2	Produs 2	PRD.002	Descriere 2	0.150	mc	150	lei
3	Produs 3	PRD.003	Descriere 3	0.300	mc	845	lei
4	Produs 4	PRD.004	Descriere 4	0.500	mc	400	lei
5	Produs 5	PRD.005	Descriere 5	1.000	mc	1500	lei

ID_distributi	ID_comanda	ID_produs	ID_client	ID_vehicul	Data_distributie_programata	Data_distributie_realizata
1	1	1	1	1	3/18/2024	3/18/2024
1	1	2	1	1	3/18/2024	3/18/2024
1	2	2	2	1	3/18/2024	3/18/2024
2	5	5	3	1	3/18/2024	3/19/2024
3	4	4	4	3	3/18/2024	3/18/2024
4	3	3	5	2	3/18/2024	3/18/2024
5	6	1	6	1	3/18/2024	3/19/2024

Fig. 1. The structure of the database and the tables comprising it

In Fig. 2 are shown the relationships between tables that allow users to access and manage information.

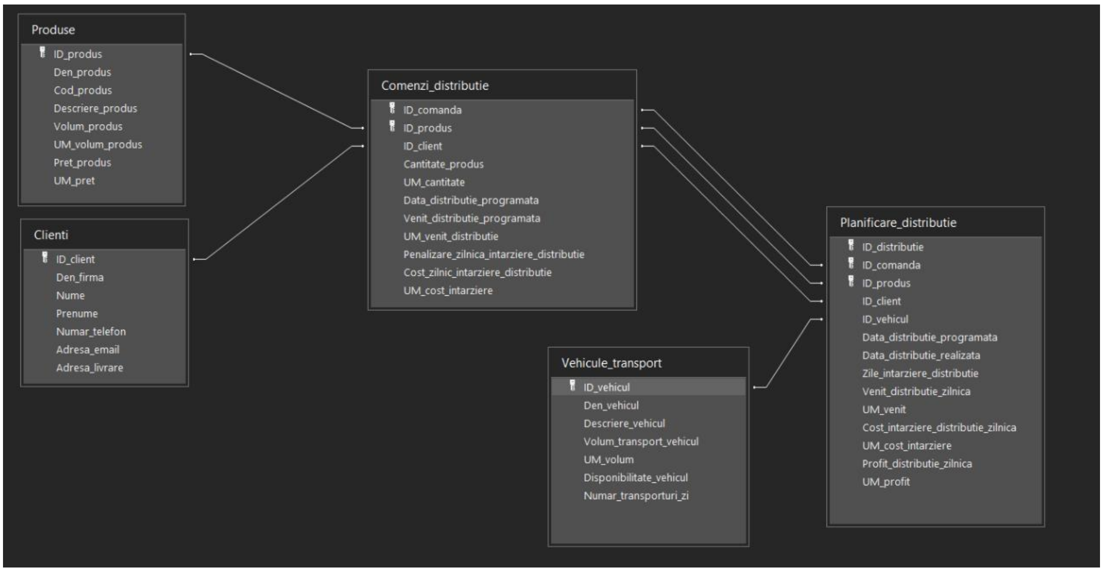


Fig. 2. Database table relationships

In Fig. 3, the web interface for the user login window is presented. It also features a "Home"button that redirects the user to the main page shown in Fig. 4.

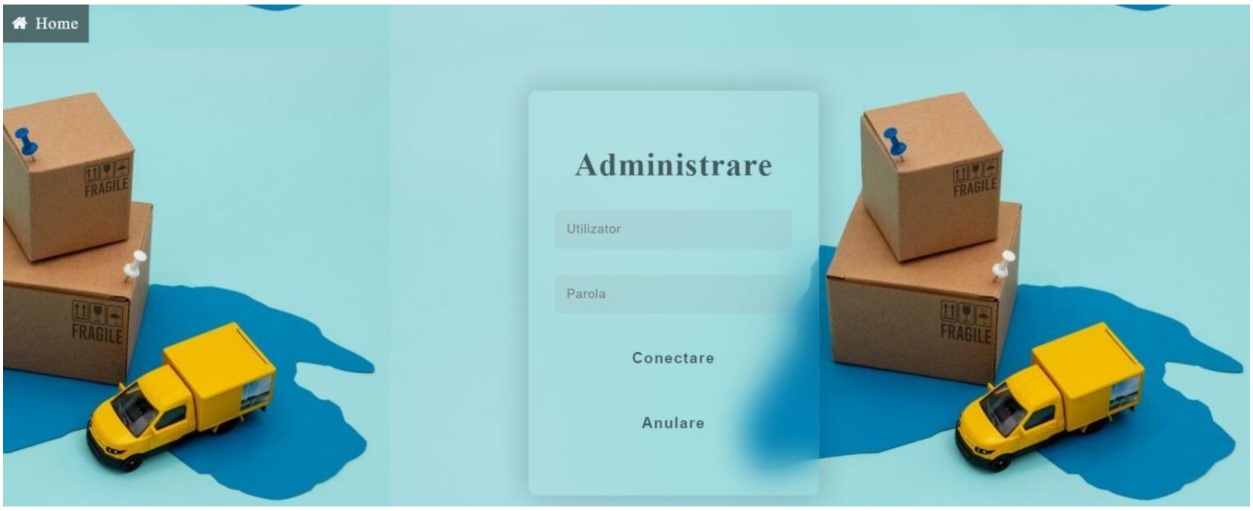


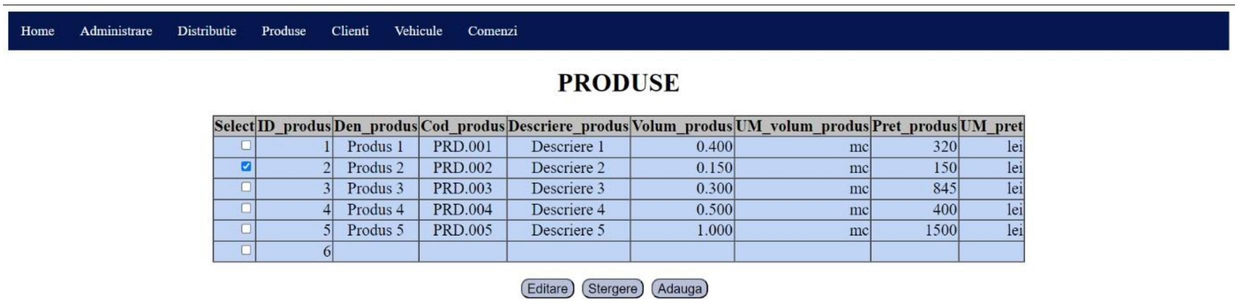
Fig. 3. Login Page

From the main page, the tables in the database can be accessed. The main web page was created using HTML and CSS for styling, and each click on the desired section in the navigation bar will open a new page characteristic to a table in the database.

Fig. 4. Main Page

In Fig. 5, the page corresponding to the "Produse" table from the database and the relevant data are observed. The page also contains a navigation bar that the user can use to access another page with data or return to the main one.

Additionally, three buttons, "Editare", "Stergere", "Adauga", have been added. By positioning thecursor, the user can choose to edit the data, delete them by selecting the desired row, or add a new row with data.



Select	ID_produs	Den_produs	Cod_produs	Descriere_produs	Volum_produs	UM_volum_produs	Pret_produs	UM_pret
☐	1	Produs 1	PRD.001	Descriere 1	0.400	mc	320	lei
☑	2	Produs 2	PRD.002	Descriere 2	0.150	mc	150	lei
☐	3	Produs 3	PRD.003	Descriere 3	0.300	mc	845	lei
☐	4	Produs 4	PRD.004	Descriere 4	0.500	mc	400	lei
☐	5	Produs 5	PRD.005	Descriere 5	1.000	mc	1500	lei
☐	6							

Fig. 5. Page corresponding to the "Produse" table

4. Conclusions

Up to the present moment, it has been developed a database designed in Microsoft Access and connected to a web interface created using HTML and CSS programming languages, which can provide accessibility and direct administration of the database from the platform, by allowing simple and efficient data editing, deleting and addition.

Furthermore, by using the concept of the "Multiple Knapsack Problem" and the Greedy algorithm presented, it can be identified one of the best optimization methods for a distribution process based on limited capacity and profit maximization.

To complete the work, it is planned to improve the performance of the database and the web interface, and to create an application based on solving the MKP problem using the Python programming language and the Greedy algorithm, where the products will be selected based on the ratio of benefit to weight, starting with the most profitable ones until the chosen vehicle is full.

In conclusion, by combining the mentioned tools a software for data management and product distribution process optimization can be created to significantly increase performance and productivity.

5. Bibliography

[1]. https://www.researchgate.net/publication/282523976_Local_Search_Heuristic_for_Multiple_Knapsack_Problem, accessed on May 7, 2024.
[2]. https://www.sciencedirect.com/science/article/abs/pii/S0377221798001209, accessed on May 7, 2024.
[3]. https://groups.cs.umass.edu/wp-content/uploads/sites/24/2020/12/Sigmetrics2021.pdf, accessed on May 8, 2024.
[4]. https://www.micsymposium.org/mics_2005/papers/paper102.pdf, accessed on May 8, 2024.
[5]. Alupei O., Databases, Course Notes, UPB 2020-2021.
[6]. Microsoft, "Microsoft Office Access 2007", ISBN: 978-973-0-05945-8.
[7]. Cirstoiu D., Olteanu A., Cernian A., "Databases. Laboratory guide", Matrix Rom Publishing, ISBN:9789737555250.
[8]. Tunsoiu D., Web Interfaces and Services, Course Notes, UPB, 2020-2021.
[9]. *** HTML, CSS, JavaScript, PHP Documentation, W3SCHOOLS: https://www.w3schools.com/, accessed on May 8, 2024.

6. Notations

SMKP - Maximum Sums of K Subsets FOMKP - Orthonormal Families of K-Pair Sets

DESIGN AND IMPLEMENTATION OF A NAVIGATION SYSTEM FOR A SET OF INTRALOGISTIC ACTIVITIES USING AN AUTONOMOUS VEHICLE (AMR) INTEGRATED INTO ROS2 AND NAV2 AND TESTING IN PLANT SIMULATION

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ABSTRACT: The paper proposes the development and implementation of a navigation system for an Autonomous Mobile Robot (AMR), integrable with ROS2 and NAV2, to optimize intralogistics activities in a production center. The system aims to efficiently manage workflows, using the AMR for transporting semi-finished products, processed parts, and finished pieces. Optimization of intralogistics flows such as Line feeding and End of Line is pursued, leveraging the Nav2 navigation algorithm. The work also includes implementing a temperature measurement and control system for the robot's motors and creating simulation scenarios. The main outcomes will be the AMR's control and navigation algorithm, a simulation model developed in Plant Simulation, and hardware enhancements for the AMRTCM. Additionally, the paper details the design of the software application using ROS 2 and Nav2, along with the implementation and testing of the software application.

1. Introduction

The paper proposes the development and implementation of a navigation system that can be integrated into ROS2 and NAV2 for intralogistics activities with an autonomous vehicle (AMR) within a given production center. The purpose of the paper is to provide an efficient and flexible solution for managing and optimizing workflows within production centers, using an AMR for the transport of semi-finished products, processed parts, as well as finished parts. By integrating this autonomous navigation system within a production center, the aim is to optimize workflows, reduce costs, and increase operational efficiency.

2. General Structure and Operating Principles of the Software Application

The main targeted intralogistics activities are Line feeding and End of Line. Optimizing the line feeding intralogistics flow involves using mobile robots to transport materials and products between production lines and storage. These robots are capable of making autonomous decisions, adapting to changing environments, and delivering materials precisely. Optimizing the end of line intralogistics flow involves using these robots to streamline the processes of picking up and delivering finished products from production lines to storage.[1][2]

The operation of the AMR for executing intralogistics activities involves the use of a Nav2 navigation algorithm that should integrate roles such as: perception of the environment, planning of optimal routes, control and precise localization of the vehicle, complete modeling of the environment, dynamic route planning, and obstacle avoidance to ensure autonomous and efficient movement between stations within the location of a production center with a predefined configuration.

In this study, a predefined hardware configuration of a differential autonomous vehicle called AMRTCM[3] will be used. This is based on a chassis of dimensions 420x290x400, a propulsion subsystem consisting of two DC motors Andy Mark 2964 NeveRest 40, a BasicMicro RoboClaw 2x30A controller for motors, a localization subsystem consisting of: an inertial sensor IMU MPU9250, a lidar LD19, a computer: Raspberry PI 4b 4GB with Ubuntu 22.04 and ROS2, as well as a FirstPower FP1290 12V 9Ah battery. The

AMRTCM will be able to transport loads of up to 50Kg in boxes/pallets with predefined volumes with a placement surface of 500mmx500mm.

In this specific configuration, the AMRTCM will operate in a given location: the CK004 hall within the IIR faculty. A simplified work scenario will be considered for processing a reference according to a technological process that uses two machine tools. Thus, the AMRTCM will feed semi-finished products to a KNUTH LabCenter 260 processing center, and after processing, the parts are transported by AMR to another machine tool, the MG 16 drilling machine, where they will be processed again. Once completed, the finished parts are transported by the same AMR to a discharge station. The tasks of the AMR are clearly defined and include transport from the loading station to pick up the semi-finished products, then navigation to the processing center, the drilling machine, and the discharge station. These routes are established in advance, and the AMR must move autonomously, using the Nav2 navigation algorithm, to avoid obstacles and ensure dynamic route planning. At the processing center, the AMR leaves the semi-finished products and can perform other activities or return to the battery charging station for recharging. It is essential that the algorithm provide a comprehensive perception of the surrounding environment and be capable of managing planning and control in real time to ensure the efficient operation of the entire process. Analyzing the initial operation of the AMR, it was found that it would also be necessary to implement a temperature measurement and control system on the robot's motors for several reasons:

- Preventing Overheating: The robot's motors can become very hot during operation, especially if the robot is used for long periods of time or under difficult conditions. Overheating can lead to motor damage and can reduce its lifespan.
- Performance Optimization: By monitoring the temperature, we can adjust the speed and load of the motor to ensure that it operates within optimal parameters. This can help improve the efficiency and performance of the robot.
- Safety: An overheated motor can pose a fire risk, especially if the robot is left unattended for long periods of time. By monitoring the temperature, we can detect any anomalies and take measures to prevent any unwanted incidents.
- Maintenance and Diagnosis: A temperature measurement system can help identify potential problems before they become critical. For example, a sudden increase in temperature may indicate a problem with the motor's cooling system or with the motor load.

The input data for the current topic includes the site configuration, which will be used to generate the navigation map, the technical specifications of the existing equipment, such as the CNC machine, and the hardware configuration of the pre-existing robot.

The main results of the topic will be represented by: the control and navigation algorithm of the AMR, a simulation model made in specialized software application: Plant Simulation. which will illustrate the workflows and efficiency of the proposed system. Also, hardware improvements will be made to the AMRTCM by implementing the temperature measurement and control subsystem on the robot's motors.

3. Detailed design of the computer application

ROS 2, also known as Robot Operating System 2, is an essential software platform for creating robotic applications, often referred to as a software development kit (SDK) for robotics. A crucial aspect is that ROS 2 is an open-source product, distributed under the Apache 2.0 License. This provides users with the freedom to modify, use, and redistribute the software, without being obliged to contribute back. Although ROS is not an operating system in the traditional sense, it offers services that are designed for a cluster of heterogeneous computers, such as hardware abstraction, low-level device control, implementation of commonly used functionalities, message passing between processes, and package management. In addition, ROS2 continues to offer valuable tools for developers, including drivers and state-of-the-art algorithms, which are essential for every robotics project.[4][5]

ROS 2 is based on the concept of uniting different workspaces through the shell environment. In ROS, a "workspace" is the place in the system where ROS 2 development takes place. The main workspace in ROS 2 is known as the "underlay", while additional local workspaces are called "overlays".[4][5]

Nav2 represents an evolution of the ROS navigation stack, adapting the technology used in autonomous vehicles to suit the needs of mobile and surface robots. This navigation library allows robots to move in complex environments and perform a variety of user-defined tasks. Nav2 not only manages movement from one point to another, but it can also manage intermediate positions and other tasks, such as tracking objects or fully navigating an area. Offering a wide range of functionalities, including perception, planning, control, localization, and visualization, Nav2 builds highly reliable autonomous systems. The navigation library calculates an environmental model based on sensory data, dynamically plans routes, calculates speeds for motors, avoids obstacles, and coordinates complex robot behaviors. In addition, Nav2 uses behavior trees to create customized and intelligent navigation behaviors, coordinating multiple independent modular servers that can calculate paths, control efforts, or any other navigation task. These servers communicate with the behavior tree through the ROS interface, allowing a robot to use multiple behavior trees to perform a variety of unique and complex tasks.[6]

Based on these concepts, the architecture of the Nav2 navigation algorithm has been defined, customized for AMRTCM according to Fig.1.

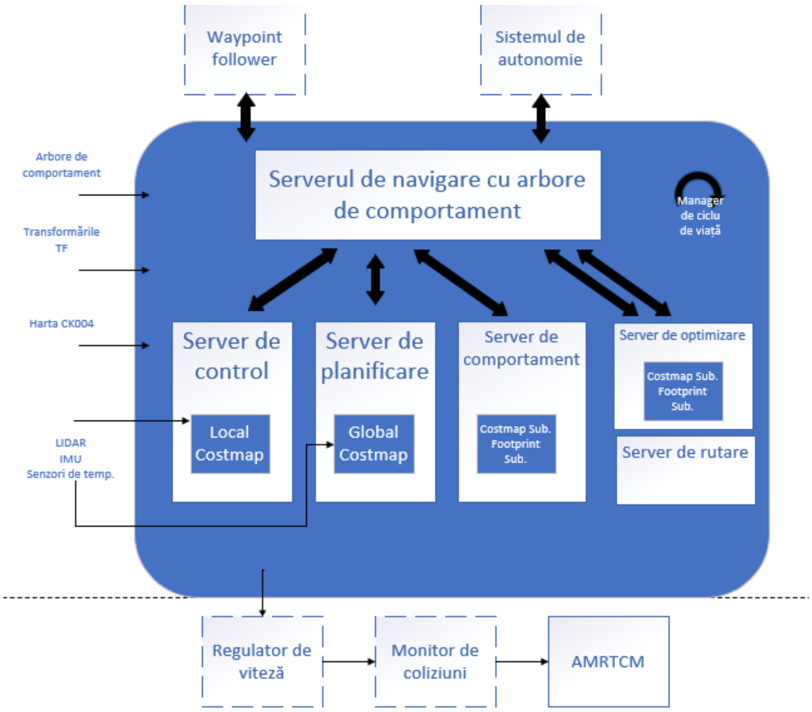

Fig.1. The architecture of the Nav2 navigation algorithm customized for AMRTCM

To implement a navigation algorithm with Nav2, the following steps are taken: the robot is configured and the correct operation of the hardware and software components, including ROS2 and Nav2, is ensured; Nav2 is launched by running a launch script that initializes the ROS nodes; the mapping process is initiated, in which the robot explores the room and collects data from its sensors, which are used to build a map of the room; the data is visualized in RViz (Robot Visualization), which is a ROS2 tool for visualizing and debugging robotic systems, for monitoring and evaluating the collected data; the built map is saved for later use; and finally, the room is navigated using the saved map. This complex approach ensures the efficient and safe guidance of the robot through the environment, dynamically adapting to conditions.

Tecnomatix Plant Simulation is a simulation software developed by Siemens, specializing in production processes and logistics. It allows the creation, visualization, analysis, and optimization of production systems and logistic processes.[7]

Creating a simulation model for intralogistics activities with an autonomous vehicle (AMR) is essential for operational efficiency, allowing the testing and optimization of various scenarios and operating strategies in a virtual environment. It can be used for planning and designing the infrastructure necessary for the implementation of AMRs, including the location of charging stations, transport routes, and space optimization. Through simulation, the performance of AMRs can be evaluated in different scenarios, facilitating informed decision-making and strategy adjustment. Also, simulation helps identify and manage potential risks before the physical implementation of AMRs, allowing for preventive measures. In addition, the simulation model can be used for training operators and maintenance staff, reducing adaptation time and increasing efficiency during actual implementation.[7][8]

Creating a simulation model is essential for achieving an efficient, safe, and well-planned implementation of these technologies in the production environment. At the entrance to the CK004 hall, there is a feeding and picking area for parts. On the left side of the feeding area, there is the LabCenter KNUTH 260, used for part processing. Also on the left side, but closer to the feeding area, there is a charging station for the AMR battery. At the opposite end of the hall entrance, there is a drilling machine MG16. To connect all these elements, there is a route that links the feeding area, the CNC machine, the AMR battery charging station, and the drilling machine according to fig.2.

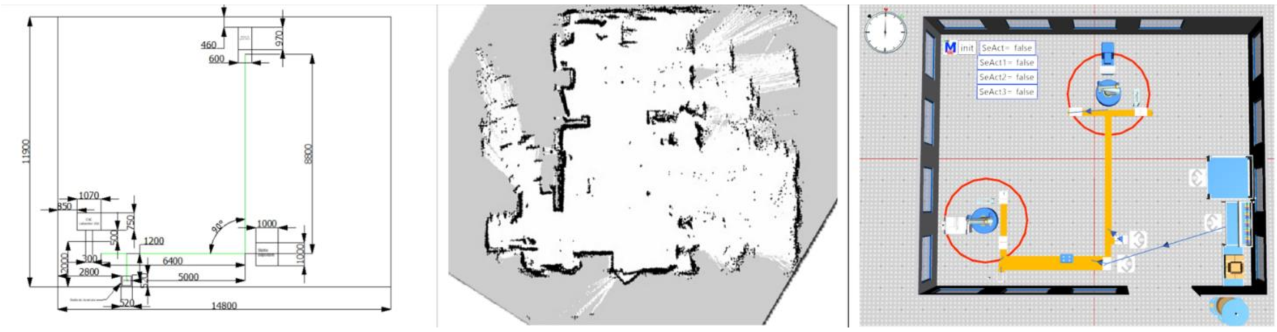

Fig. 2. The sketch of the CK004 hall, the map resulted from the mapping and the hall simulated in Plant Simulation.

4. The creation and testing of the computer application

A workspace in ROS 2 is a directory that hosts the ROS 2 packages under development, making it the ideal place for their development and testing. It includes folders such as: “src” for developed packages, “build” for files generated during construction, “install” for generated programs and resources, and “log” for build and run logs. Inside “src”, there are folders such as “cmake” for CMake files, “config” for configuration files, “environment” for setting environment variables, “launch” for launching ROS 2 packages, “maps” for maps, “params” for ROS 2 node parameters, “rviz” for RViz configuration, “urdf” for robot models, and “worlds” for Gazebo simulations.

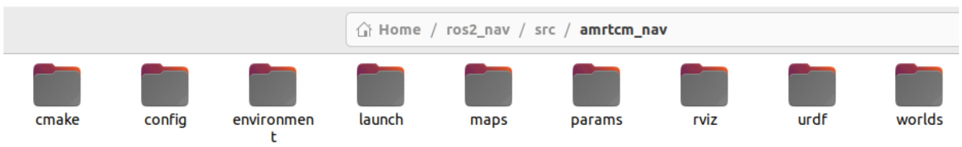

Fig. 3. The structure of the source folder (src)

The physical robot's workspace has a similar structure, containing ROS 2 packages developed for motor control, sensors, motion planning, and interaction with external environments, along with configuration files for initial settings, launch files for configuring ROS 2 nodes, the URDF model for describing the robot, packages for interacting with specific hardware, packages for simulation and RViz visualization, packages for advanced planning and control, as well as other project-specific packages for additional functionalities and integration with other systems. The ROS2 launch script defines and launches a series of nodes: the ROS2 control node, the robot state publishing node, the controller generation nodes, the LIDAR node, as well as the node for the inertial IMU sensor. Also, a series of paths to various configuration files and parameters necessary for nodes are defined.

Regarding the measurement and control of temperature, the DS18B20 sensor represents the optimal choice in this case due to its wide temperature range (-55°C to +125°C), ease of connection to the Raspberry Pi4, the ability to be mounted directly on the surface of interest, and its availability and competitive price on online platforms.[9] At the same time, a 3D printed clamp is necessary to protect the sensor from damage, ensure stable contact with the motor for precise measurements, and allow customization to perfectly fit the motor and sensor. As a material for 3D printing, PETG is the ideal choice for the sensor clamp due to its durability, temperature resistance, ease of printing, and recyclability.

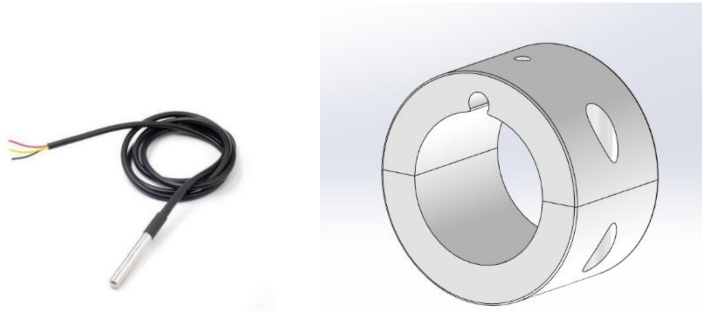

Fig. 4. The DS18B20 temperature sensor and the CAD model of the clamp.

The testing part of the temperature sensor was carried out using a Raspberry Pi 4 equipped with Ubuntu and an Andy Mark 2964 NeveRest 40 type motor, identical to those in the AMRTCM configuration. Using Raspberry PI and a breadboard, the sensor was connected as follows: the red wire to pin 1 of 3.3V, the black wire to pin 6 of GND, and the yellow wire to pin 7 (GPIO4) on Raspberry PI, with a 4.7k resistor between the red and yellow wires. The motor was powered from the socket with a 60W, 12V, 6A source, and the sensor was placed in the clamp to maintain contact with the motor. In addition, to monitor the temperature evolution and cooling conditions, a fan was added behind the motor. The fan helps dissipate the heat generated by the motor, allowing the sensor to measure the temperature in a cooler environment. This is useful for understanding how the measurement system works and for optimizing motor performance. In the final version, the use of the breadboard will be abandoned, and the connections will be made directly on the pins on the Raspberry Pi. This will simplify the wiring diagram and reduce the space needed for mounting the entire system, making the installation cleaner and more efficient. This will also allow better cable management and improve the reliability of the connections.

Fig.5. The placement of the fan and the final connection diagram.

A Python program was created to read the temperature, which communicates with the sensor via the 1-Wire interface. It loads the w1-gpio and w1-therm modules, identifies the sensor in the base directory /sys/bus/w1/devices/, reads the sensor's unique identifier and data from the sensor, processes this data to extract the temperature in Celsius and Fahrenheit, and displays these values in a repetitive loop that writes every minute. The engine ran continuously for 30 minutes, with temperature monitoring continuing for another 30 minutes after it stopped, to track the temperature evolution during heating and cooling. This process was repeated with the fan in operation, and the results were graphically represented to more clearly visualize the data, detect trends, and identify possible anomalies that could help optimize performance and prevent engine failures. The graph illustrated two different temperature trends depending on the presence or absence of cooling, with a blue curve indicating a gradual decrease in temperature with cooling and an orange line suggesting a faster temperature increase without cooling. If the engine temperature exceeds a certain threshold, AMRTCM enters a fault mode to prevent damage to the robot's internal components caused by overheating, underscoring the importance of maintaining engine temperatures within specified limits to ensure efficient and durable robot operation.

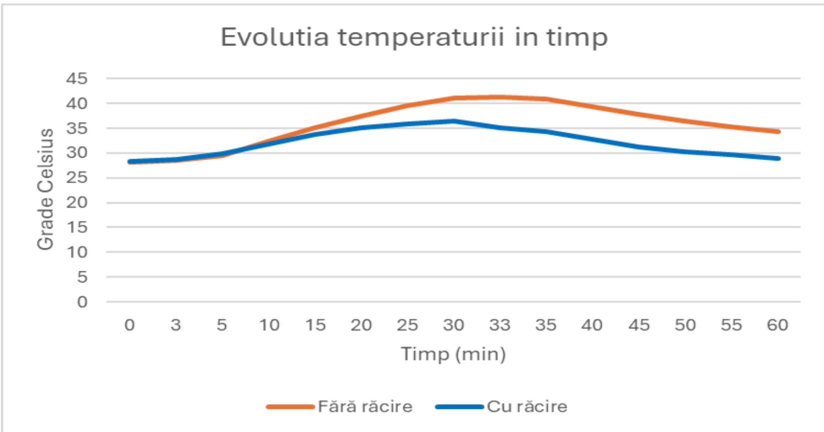

Fig.6. The graph of temperature evolution over time

Regarding the simulation of intralogistics activities, the AMR is configured in a virtual environment using Tecnomatix Plant Simulation. In the first scenario, an operator places a box of semi-finished products in the AMR's loading area. The AMR picks up the box and moves towards the CNC processing center, where a robotic arm is located. The robotic arm takes the semi-finished products from the box and introduces them into the CNC machine for processing. After the processing is completed, the robotic arm removes the processed parts from the machine and places them back in the AMR's box. The AMR transports the box back to the operator, who unloads the finished parts.

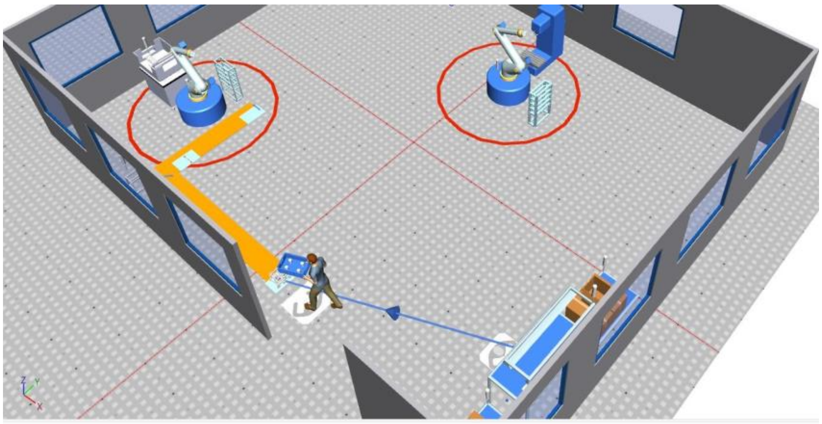

Fig.7. Creating the first simulation scenario

In the second scenario implemented in Plant Simulation, an operator loads a box of semifinished products onto an autonomous mobile robot (AMR), which transports the box to a CNC processing center. Here, a robotic arm picks up the semifinished products, places them into the CNC machine for processing, and then loads the finished parts back into the box. The AMR then takes the box to a drilling machine, where another robotic arm retrieves the processed parts, places them into the machine for further processing, and finally loads the finished pieces back into the box. Ultimately, the AMR returns the box to the operator, who unloads the final parts. In the future, simulations will be conducted using experimentally estimated values for the travel times of the AMRTCM and estimates for processing times for specific machining operations from the two machine tools. These simulations aim to demonstrate the efficient integration of the AMR into a production flow, ensuring optimal transport of semifinished products and finished parts.

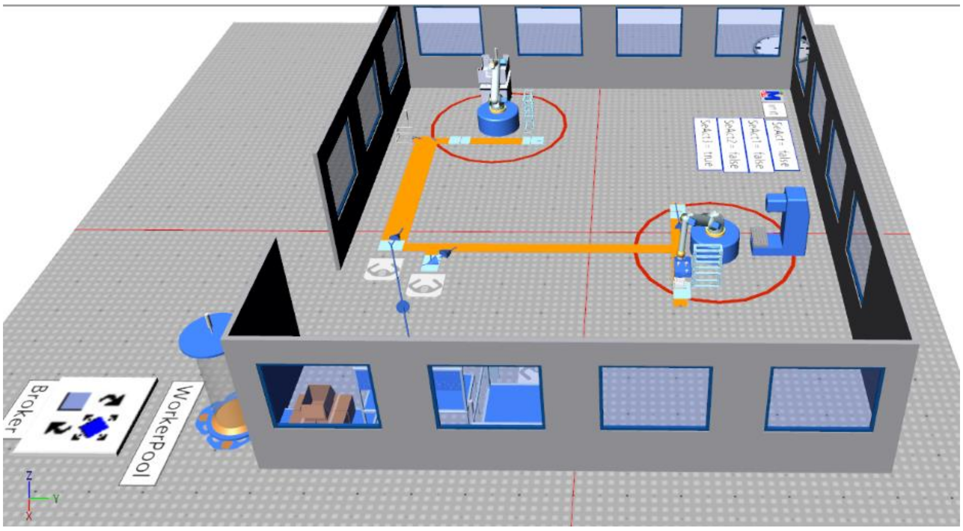

Fig.8. Creating the second simulation scenario

6. Conclusions and Development Directions

In the study, an advanced navigation algorithm was developed for an autonomous mobile robot (AMR), integrated with ROS2 and NAV2. This algorithm was tested by creating a map of the CK004 hall and navigating within it using the AMR. The system can enhance operational efficiency by automating the transport of semifinished products, processed parts, and finished pieces, while also providing flexibility in managing workflows to quickly adapt to changes within processing centers. Looking ahead, there are plans to improve the Nav2 navigation algorithm to more efficiently handle environment perception, optimal route planning, precise control, and vehicle localization. On the hardware side, a temperature measurement and control system has been developed for the robot's motors. This system can prevent overheating, optimize performance, ensure safety, and facilitate maintenance and diagnostics. It was tested by verifying temperature sensors under both cooling conditions and without cooling. The Python program for temperature reading will be transformed into a ROS2 node to fully integrate it into the application, providing better integration and greater flexibility for application development and expansion. Additionally, a simulation model of multiple intralogistics flows was developed in Plant Simulation. This model was evaluated by simulating two working scenarios of the AMR. Looking ahead, the simulation model in Plant Simulation will be optimized to more accurately reflect real operating conditions and allow more efficient testing and validation of various scenarios and operating strategies. Furthermore, experimental estimates of travel times for the AMRTCM and processing times for machining operations from the two machine tools will be incorporated into the simulation.

7. Bibliography

[1].Conf.dr.ing.ABAZA Bogdan (2024)-Managementul Rețelelor Logistice, Curs 4

[2].Conf.dr.ing.ABAZA Bogdan (2024)-Managementul Rețelelor Logistice, Curs 7

[3].Ing.George-Sebastian BANU, Ing.Silviu-Daniel DRĂGAN, Ing.Andreea-Alina PĂUN, Ing.Ștefan-Mădălin POPENETE(2022)-Realizări disertație IMPC 2022:Echipa1:Dezvoltarea unui Vehicul Ghidat Automat(AGV)

[4].S. Macenski, T. Foote, B. Gerkey, C. Lalancette, W. Woodall, "Robot Operating System 2: Design, architecture, and uses in the wild," Science Robotics vol. 7, May 2022.

[5].S. Macenski, A. Soragna, M. Carroll, Z. Ge, "Impact of ROS 2 Node Composition in Robotic Systems", IEEE Robotics and Autonomous Letters (RA-L), 2023.

[6]. https://navigation.ros.org/index.html

[7].https://docs.plm.automation.siemens.com/content/plant_sim_help/15/plant_sim_all_in_one_html/en_US/tecnomatix_plant_simulation_help/tecnomatix_plant_simulation/tecnomatix_plant_simulation_help.html

[8]. Bangsow, S. (2010). Plant Simulation. In: Manufacturing Simulation with Plant Simulation and SimTalk.

[9].https://www.optimusdigital.ro/ro/senzori-senzori-de-temperatura/586-senzor-de-temperatura-rezistent-la-apa.html?gad_source=1&gclid=Cj0KCQjwxeyxBhC7ARIsAC7dS390xzVFfonsXoFOFkQPfKJWZK2rp8JkiQItsBTdRhQSwlX1QqLj-LsaAp2hEALw_wcB

DESIGNING AN ALGORITHM AND REALIZING A COMPUTER APPLICATION FOR PROGRAMMING IN THE ROS OPERATING SYSTEM OF AN AMR WITH A ROBOTIC ARM

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ABSTRACT: This paper aims to present the design and development process of an IT application that controls an AMR (Automated Guided Vehicle) platform with a robotic arm through the ROS2 (Robot Operating System 2) framework. This technology allows high modularity in industrial and logistics processes, representing a crucial element for adaptability to various working conditions. With the help of this application, we can automate any type of AMR platform as long as it is equipped with LIDAR and encoders. This framework allows us to update the software of old robots and integrate them in advanced processes without the need to replace the hardware part.

KEYWORDS: AMR, ROS2, LIDAR,

1. Introduction

This paper aims to create a software application for the autonomous navigation of an AMR vehicle. The system control will be carried out by the ROS2 framework on a PC station. The control system will communicate via the DDS protocol with the controller placed on the vehicle. The controller will perform both the acquisition of data from the sensors and their transmission back to the PC station, as well as the control of the electrical motors on the vehicle.

The components of the system:

- ROS2[1] (Robot Operating System 2) is an open-source framework that aims to provide developers with a standard software platform that can be used for research, prototyping, implementation, and production. Due to the standardization of these software solutions, the libraries communicate with each other efficiently, offering a high modularity to a robotic system controlled by ROS2.

- LabView is a graphical programming environment created by National Instruments. It allows a faster understanding of the program than a traditional programming language, the functional nodes being linked by wires, so it is easy to detect the transfer and the path that the data follows.

- MyRIO is a controller made by National Instruments. This is an intuitive and easy-to-use controller, its purpose being educational. MyRIO allows LabView programs to be loaded onto it, so the program can run in a remote environment. It has Wi-Fi connectivity and is equipped with several inputs and outputs to be connected to sensors and actuators.

For a good functioning of the system, all these components must communicate with each other. This is done through the DDS protocol. The PC equipped with the ROS2 framework communicates via DDS with the LabView program on the PC. The LabView program on the PC communicates through the DDS with the program on the MyRIO. Thus creating a communication loop with the help of which the system can function (Fig.1).

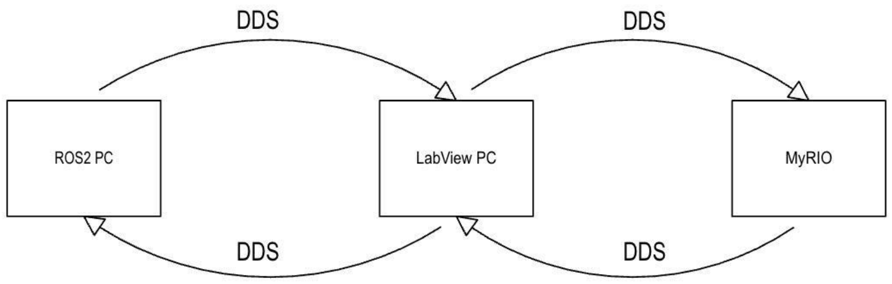

Fig.1 Data communication path

2. Identifying the necessary technologies

An AMR (Autonomous Mobile Robot) must be able to operate autonomously without human intervention in an uncontrolled environment without having fixed trajectories. It must be flexible and be able to change its trajectory in real time, either due to a new obstacle or due to a human intervention on the route.

Main software technologies to be implemented:

- Autonomous navigation
- Mapping capability
- User machine interface
- Controller-vehicle communication
- Data acquisition
- Control of the actuators
- Simulation environment

Regarding "Autonomous Navigation", "Mapping Capability", "User Machine Interface" and "Simulation Environment", these can be obtained with the help of ROS2 modules that guarantee a good communication between them. And "Control of the actuators", "Acquisition of data" and "Communication controller - vehicle" will be carried out with the help of the libraries present in LabView.

3. AMR design for simulation in ROS2

The project is initiated by installing a virtual machine running Linux. With the help of the documentation[2] provided by the ROS2 developers, we can install the ROS2 Iron version. Functionality testing is carried out with the help of the demo programs provided by ROS2 (Talker demo and Listener demo, Fig.2).

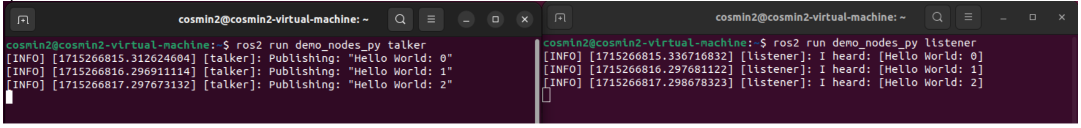

Fig. 2. Talker Listener demo

Realizing a project in ROS2 requires the creation of a work environment. It was created using a standard way that is easy to understand and navigate.

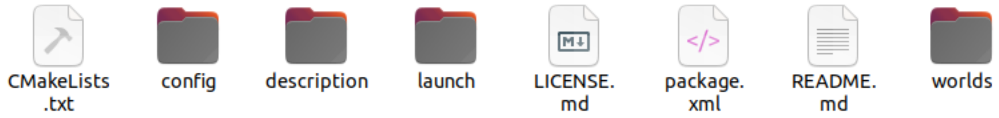

Fig. 3. Components of amr_platform project

The visualization of the created model will be done with the help of the graphic interface RViz[3]. This allows us to visualize and interact with the vehicle model, this application being later used to command and interpret the data provided by the simulation or the physical robot.

To view the vehicle, it must be created using a URDF (Unified Robot Description Format) file. It is written using the XML language and contains the geometric dimensions, mass, inertia, and characteristics of the model.

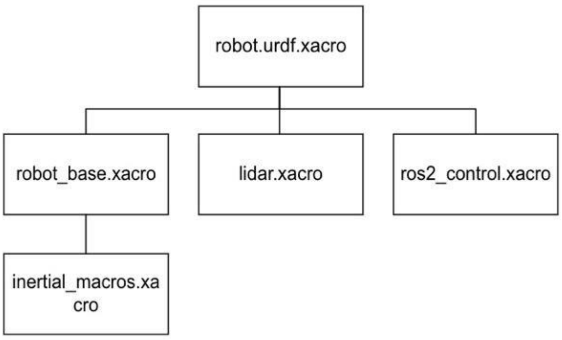

Fig. 4. Structure of the URDF file

The URDF file begins by specifying the "base_link" element.

```
<link name="base_link">

</link>
```

The description of the vehicle chassis can begin and has as a reference point the "base link" created before.

For each element created, we must have a <joint> that contains a <parent link>, a <child link> and an origin. After that, the previously specified child link is described. It is described using the <visual> tag to define its dimensions. The next step is to add the <collision> tag that contains the same coordinates as <visual> to specify to the simulation program which collisions are present on the vehicle. The last step is adding the inertia calculated using the specified mass and dimensions.

```
<visual> <!-- Left Profile -->
    <origin xyz="0.39 -0.28 0"/>
    <geometry>
        <box size="0.7 0.04 0.04"/>
    </geometry>
    <material name="black"/>
</visual>
<collision> <!-- Colision -->
    <origin xyz="0.39 0 0"/>
    <geometry>
        <box size="0.78 0.6 0.04"/>
    </geometry>
</collision>
            <!-- Inertia -->
<xacro:inertial_hollow_frame mass="3.224" x="0.78" y="0.6" z="0.04">
    <origin xyz="0.39 0 0" rpy="0 0 0" />
</xacro:inertial_hollow_frame>
```
Fig. 5. Example of URDF configuration

The URDF file is launched using a launch file[4], and a "/robot_description" node will be generated that publishes the URDF data to be accessed by other programs.

Thus, RViz can be run, and data published in /robot_description can be accessed.

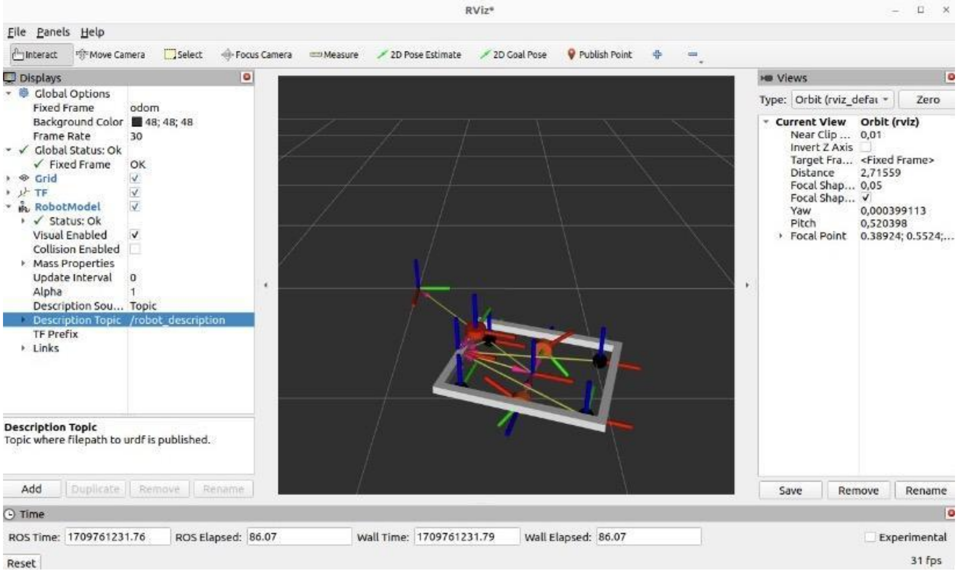

Fig. 6. Viewing the vehicle model in RViz

4. AMR platform simulation and control

Gazebo[5] is the simulation environment in which the functionality of the platform will be tested. This is a powerful simulator that can receive and provide data from sensors, and interactions with the environment are also possible.

The ROS2 Control[6] package is necessary for the program to be able to read the data provided by the encoders on the wheels and to send position changes to the motors. It creates a "generic control loop feedback mechanism" loop.

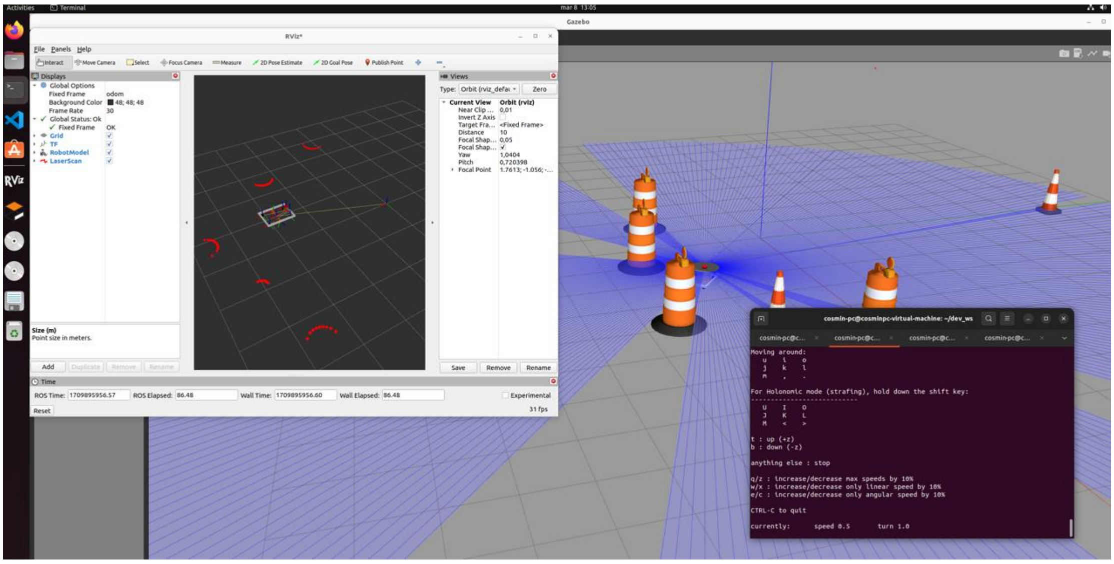

Fig. 7. Gazebo simulation and data received in RViz

SLAM Toolbox[7] is a collection of software tools that allow the creation and integration of SLAM (Simultaneous Localization and Mapping) systems in ROS2 applications. This toolbox offers a set of essential algorithms to allow robots to create a map of their environment in real time, simultaneously with their location on this map.

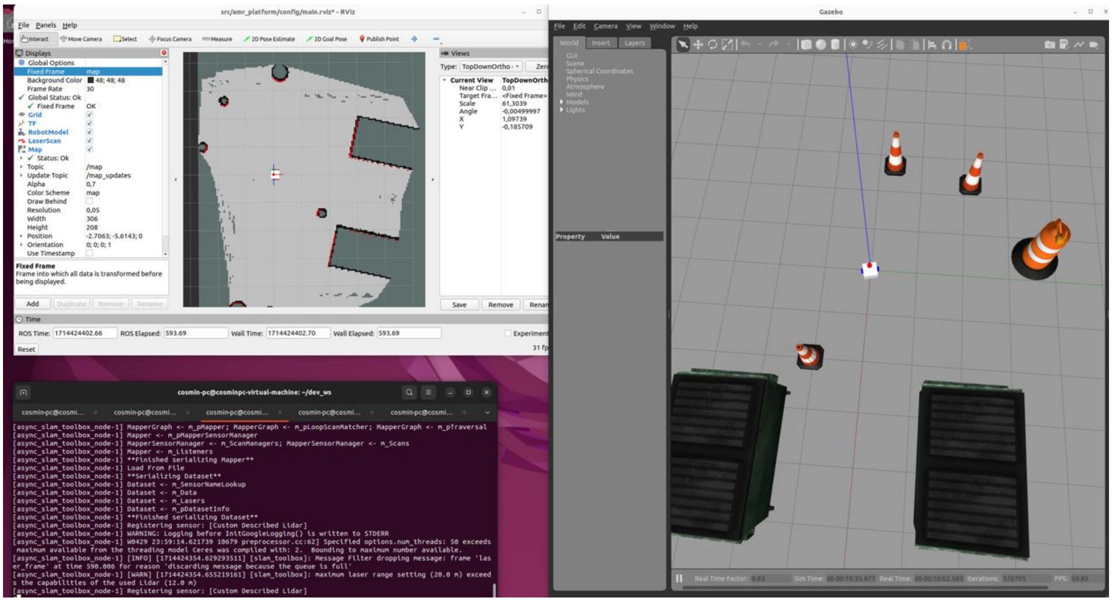

Fig. 8. Simulation mapping

The NAV2[8] package is an advanced library, designed to facilitate the development and implementation of autonomous navigation systems. It provides perception, planning, control, location, and visualization of the vehicle. It will calculate a route from the data received from the sensors, adjust the speed of the electric motors and make changes to the initial route in real time to avoid new obstacles.

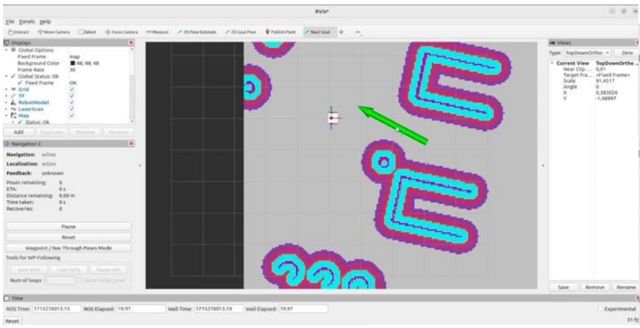

Fig. 9. Specifying the destination

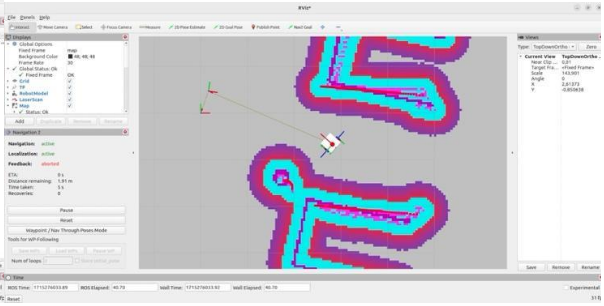

Fig. 10. Final position

6. Conclusions

The paper “DESIGNING AN ALGORITHM AND REALIZING A COMPUTER APPLICATION FOR PROGRAMMING IN THE ROS OPERATING SYSTEM OF AN AMR WITH A ROBOTIC ARM" represents an efficient option for the modernization of autonomous mobile systems. It has been proven that the developed algorithm is efficient and can easily navigate a complex space. The implemented system gives flexibility and adaptability to the application, only small calibrations are needed to implement the program on a different robot.

As robotics technology advances and industrial needs evolve, ROS2 will continue to adapt and provide support for the design and implementation of advanced software solutions for programming and controlling AMRs.

8. Bibliography

[1]. https://docs.ros.org/en/foxy/_downloads/2a9c64e08982f3709e23d20e5dc9f294/ros2-brochure-ltr-web.pdf
[2]. https://docs.ros.org/en/iron/index.html
[3]. https://wiki.ros.org/rviz/UserGuide
[4]. https://docs.ros.org/en/iron/Tutorials/Intermediate/Launch/Launch-Main.html
[5]. https://docs.ros.org/en/iron/Tutorials/Advanced/Simulators/Gazebo/Gazebo.html
[6]. https://control.ros.org/iron/index.html
[7]. https://wiki.ros.org/slam_toolbox
[8]. https://docs.nav2.org/concepts/index.html

DESIGNING AN EXPERIMENTAL ROBOTIC METHOD FOR TOMATO HARVESTING

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ABSTRACT: This project proposes the design of an image processing algorithm for detecting, collecting, and depositing tomatoes inside greenhouses. This objective has been reached using an automatic robotic system, hand arm, equipped with 3D printed mounts, a video camera used for detecting the tomatoes and their peduncle and a cutting system. The proposed method for cutting the tomatoes is that of a precision algorithm used for determining the cutting point of the tomato using its centre, it's top extremity and calculating the position of the peduncle using said data.

KEYWORDS: automatic robotic system, image processing, greenhouse, precision algorithm.

1. Introduction

The project consists of the use of a robotic system, in the form of an articulate robotic arm used in the agricultural field. This project was chosen for optimizing and reducing the work time of agriculturalists during harvest season. For this application a KINOVA robotic arm will be used together with an image processing algorithm, a video camera and a cutting system using sheers for collecting the tomato. The robotic arm will be automated, following the necessary steps for detecting, collecting, and depositing the tomato using the algorithm created with the programming language LabView.

2. Defining the functional module of the robot

In order to achieve the desired results, various studies had to be conducted in order to determine the standards for maintaining and cultivating tomato crops.

Tomato crops are maintained in greenhouses, these being build following the necessary standards. Greenhouses can be constructed in many ways, the most common ones being out of polycarbonate or out of glass. The glass greenhouses are defined as protective spaces, built using a metal skeleton and they can be equipped with machinery used for mechanized processes [1]. These greenhouses can be built to cultivate different kinds of plants, the design however remains the same. The polycarbonate greenhouses are defined similarly to their glass counterpart; however, they are much easier to build [2]. They offer protection for plants only during specific periods of time.

No matter what material is used to build these greenhouses, the architecture is standardized for tomato harvesting. These greenhouses are built using a tubular arch of a diameter between Ø60-76mm, propped up by 80x80mm supporting pillars, tied together using reinforcing rods of a diameter between Ø32-42mm. The access paths are quite large being built between 800-1000mm.

Similarly, tomato cultures are planted using specific standards. The tomatoes can be sowed using two different methods: sowing based on rows or based on groups. The row-based method is used by spacing each row to a distance between 80-100cm and each plant to a distance between 30-40cm [3]. The group-based method is used by grouping two rows, each at a distance between 60-70cm, then leaving an empty space of approximately 90-120cm before sowing the next group. The tomatoes in each row are sowed at a distance of approximately 35-50 cm.

The tomato is defined as a fruit belonging to the Solanaceae family, originating from South America. Tomatoes can be grouped in two distinct categories: determinate and indeterminate tomatoes.

The main difference between the two is the is the growth of the stem; the determinate kind growing to approximately 80-100cm and the indeterminate type growing up to a length of 180cm [4].

Tomatoes have a diameter of anywhere between Ø1.5-7.5 cm, weighing between 100-150g. These fruits grow from a minimum distance of 50-60cm from the soil and 50-60cm from the peak of the stem. The tomatoes are connected to the stem by the peduncle. The peduncle is positioned perpendicular to the main axis of the tomato. The thickness of the peduncle is anywhere between 5.74-6.53mm [5].

To realise this project, the author has separated it into two components: a software component that consists of the image processing algorithm that will detect and identify the position of the tomato, and a hardware component that will consist of the industrial robot with various mounts for collecting and depositing the tomato. The hardware component will also include a video camera used for capturing images and a cutting mechanism used for eliminating the peduncle. The image processing algorithm was made using the programming language LabView [6] and the mounts were made using the 3D modelling software SolidWorks [7] and printed using an additive manufacturing printer Zortrax M300 Plus.

Based on the information previously discussed, the robotic arm will be positioned at a distance of minimum 54 cm from the soil to be able to collect the tomatoes positioned at the top of the stem. For an optimal harvesting process, the robot will be positioned at a distance between 30-40cm from the stem of the tomato plant.

To be able to collect the tomatoes efficiently, the robotic arm will have five distinct positions: a resting position, an initial position where the image capturing and image editing will take place, a position used to align the centre of the robotic end effector with the centre of the tomato, a position used to align the cutting component with the tomato peduncle and a position used to deposit the harvested tomato.

The cutting component will be realised using a pair of sheers connected with the robotic arm using a mount. The sheers will be used by the end effector of the robotic arm and their centre will be aligned with the centre of the robotic arm.

3. Designing the software application

The proposed application will be put together using software and hardware components.

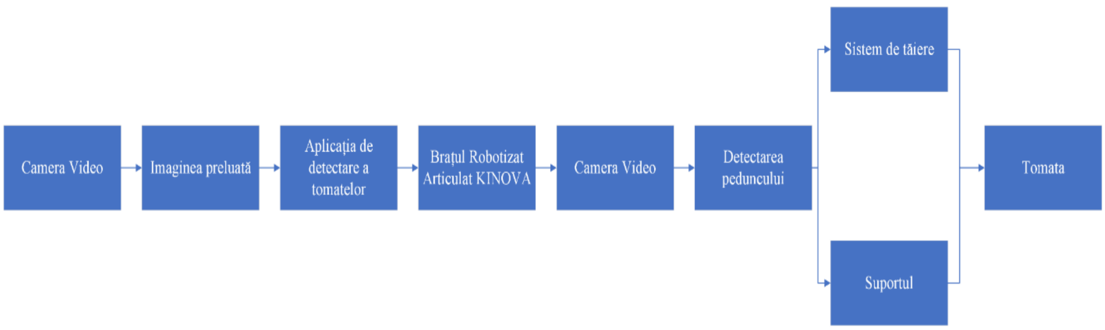


Fig. 1. Scheme of the application

The software application is made up of several VI files, used to detect the tomatoes, position the robotic arm, and determine the distance up to the tomato plant. Because tomatoes have a specific colour of red, the software will eliminate all the unwanted colours.

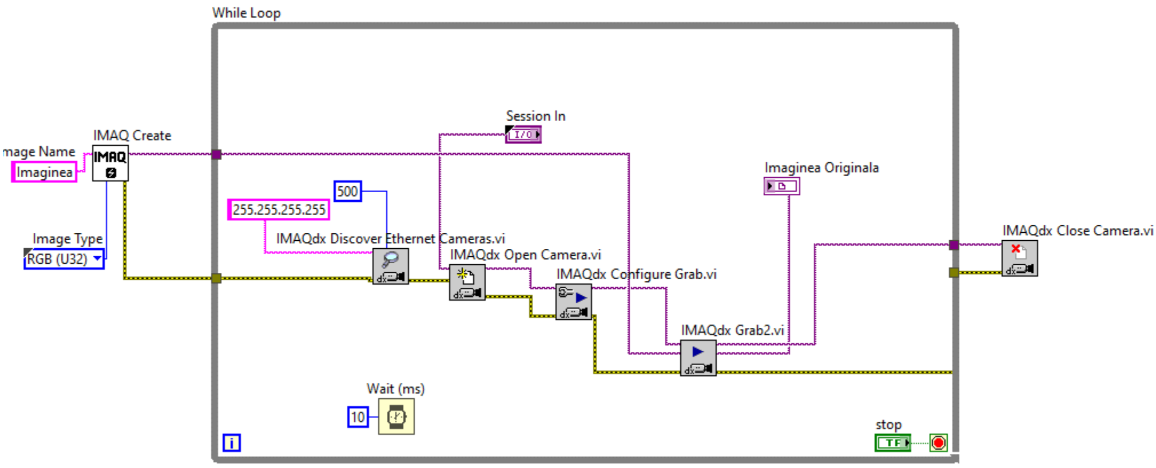


Fig. 2. The Block Diagram of the image capturing process.

The VI presented above is utilized to capture images using the video camera. The function "IMAQ Create" will create a temporary location to save the captured image, it being defined as an RGB(U32) image type. To use the desired video camera, the function "Discover Ethernet Camera" will be used. This function will detect the camera using its IP, which is always 255.255.255.255. The function "Open Camera" will open the video camera mentioned previously, and the functions "Configure Grab" and "Grab" will capture the image. The image will be displayed using an indicator named "Imaginea Originala". After capturing the image, the program will stop automatically, using the function "Close Camera". After capturing the image with the presented VI, the application will be allowed to edit it.

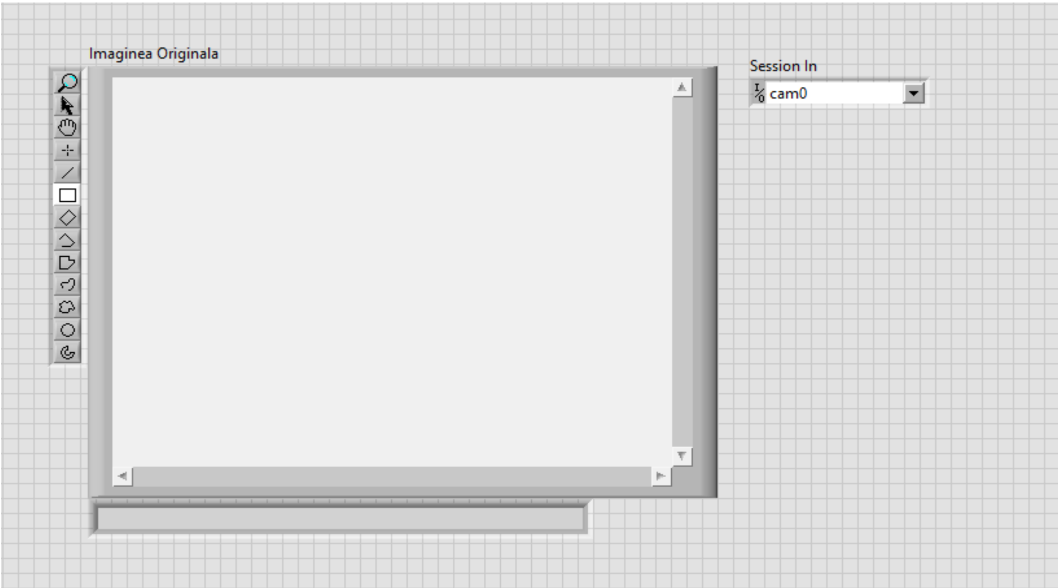


Fig. 3. The Front Panel of the image capturing process.

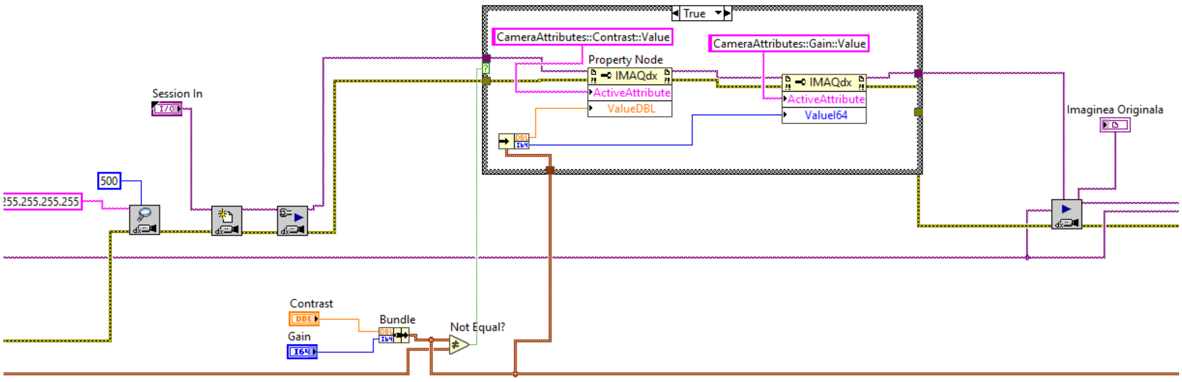


Fig. 4. The Block Diagram of the “Gain” and “Contrast” functions.

Because the intensity of light can affect the colour detection, two functions will be introduced to manipulate the luminosity detected by the camera. Using a “Case” structure, two property nodes will be introduced, these will be able to control the functions for contrast and gain. To be able to manipulate those functions, two numeric input data functions will be introduced, being grouped together using the “Bundle” function. Using the function “Not Equal”, the previous functions will be compared with the initial input data of the image, and if they are not equal, the property nodes will change their respective characteristic. Thus, modifying the contrast function will brighten the image, and modifying the gain function will darken it. After calibrating it, the image will be forwarded to begin the editing process.

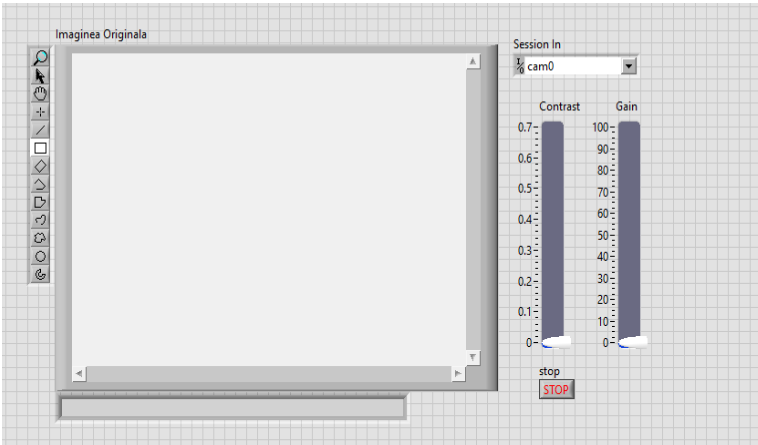


Fig. 5. The front panel of the gain and contrast functions.

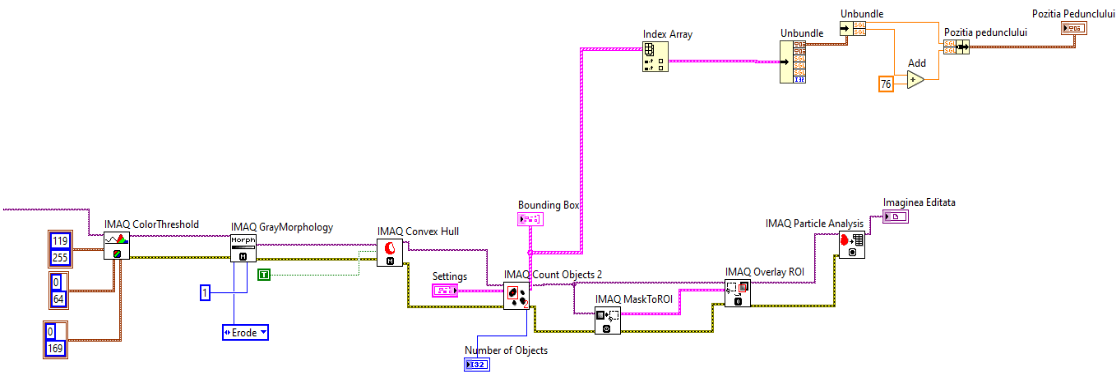


Fig. 6. The necessary operations used to detect the tomato.

After modifying the brightness of the image, the editing of the image will begin. Because tomatoes have a specific complexion of red, the function “ColorThreshold” will be used. This function controls the degree of colours being perceived by the program. Each colour will have a minimum and maximum limit; hence the red colour will have its limits between 119-255, the blue colour will have its limits between 0-169 and the green colour will have its limits between 0-64. This new image will be transformed using the "GrayMorphology" function, which will change the image type from RGB to grayscale. This function is essential to be able to covert the original image in a binary image using the function "ConvexHull". Because the predominant colour in the image is red, the program will only detect objects of that specific colour. Using the function "Count Objects" the program will detect and number the detected tomatoes. The control panel "Settings" will be used to select and define the characteristics used to detect the objects. The tomato will be isolated using the function "MaskToROI" together with the function "Overlay ROI". To analyse the structural composition of the selected object, the function "Particle Analysis" will be used.

To be able to find the centre of the object, the function "Index Array" together with the function "Unbundle" will be used to collect the coordinates from the "Count Objects" function. To be able to detect the peduncle some calculations will be performed using the coordinates of the centre of the tomato.

The indicator named "Imaginea Editata" will display the image after it's been edited by the functions mentioned above, the indicator "Bounding Box" will display the characteristics of the object and the "Pozitia Peduncului" indicator will display the position of the peduncle.

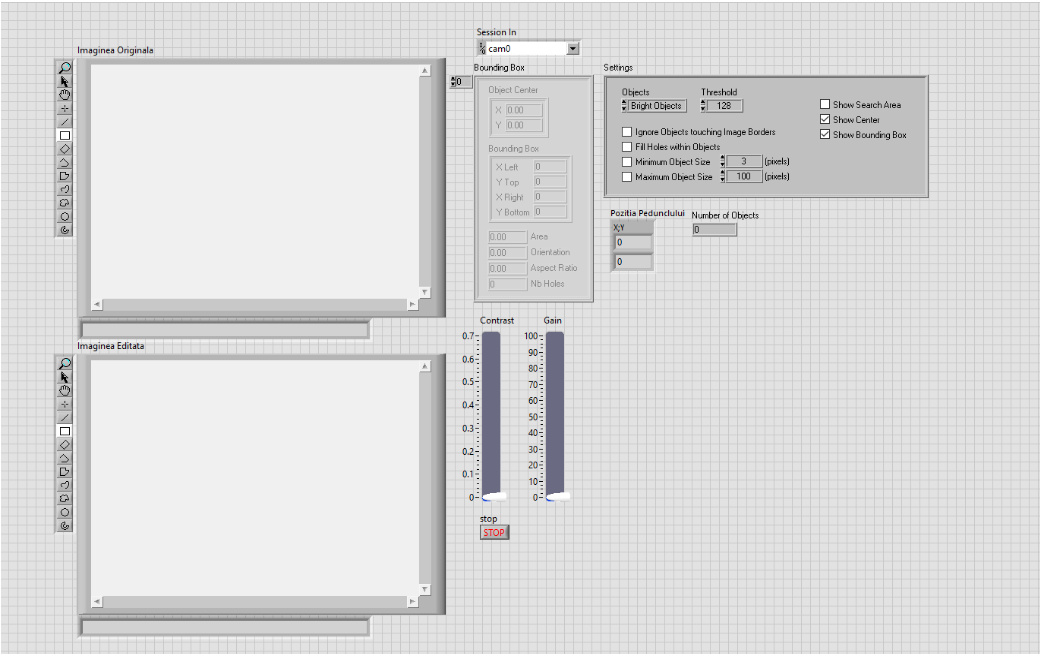


Fig. 7. The front panel of the tomato detection program.

The hardware component is constructed using a robotic arm and a mount used to collect tomatoes. The robotic arm has a maximum reach of 760mm and a maximum payload of 500g. The mount is separated into four components: two fixing collars being used to connect the rest of the mount to the robotic arm using a screw of a diameter of Ø5mm, a main component that will hold the weight of the tomato and a cup that will catch, hold, and transport the tomato after harvesting it. The mount will be printed [8] using additive manufacturing and PLA filaments. The mount will need to sustain a force of approximately 1.5 Newtons. Likewise, the mount will need to be lightweight as to not exceed the maximum payload allowed by the robotic arm.

Fig. 8. The mount assembled on the robotic arm.

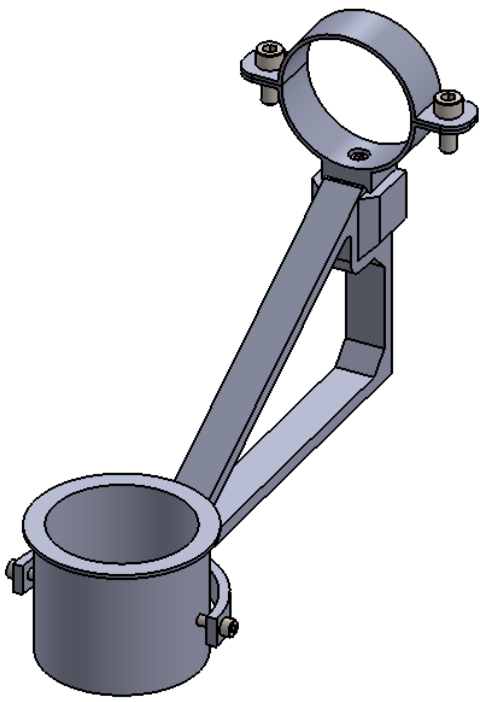


Fig. 9. The mount viewed in the 3D modelling program SolidWorks.

Tabel 1. The mount components

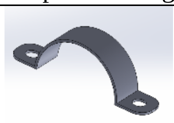
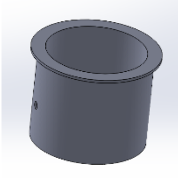
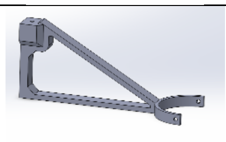
Components	Printable components		
	Component image	Quantity [Nr. Pieces]	Weight [g]
Colar		2	28
Cupa		1	95
Suport		1	93

Table 2. Printing characteristics

Characteristics	Elements
Printer	Zortax M300 Plus
Material	PLA
Support Angle	30°
Nozzle Diameter	0.4 mm
Layer Thickness	0.14 mm
Print Quality	High
Infill density	20%
Seam	Random
Raft Layers	7
Top Surface Layer	8
Bottom Surface Layer	4
Max. Wall Thickness	3.13 mm
First Layer Gap	0.31 mm
Estimated Print Time	1d 15h 30min
Material Usage	216 g

All the elements will be printed at the same time using the same 3D printer. The supports will be generated automatically by the imprinting program.

The tomatoes will be selected using a DFS (Depth First Search) algorithm. After selecting the tomato an algorithm will be used to determine the position of the peduncle. To be able to detect the peduncle equations (1) and (2) will be used, where *c* represents the centre of the tomato, *x;y* represent the extremities of the tomato and *p* will be the peduncle position. The calculations will be performed with pixels.

$$c = \left[\left(\frac{x_{max} + x_{min}}{2}; y_{min}\right); \left(x_{min}; \frac{y_{max} + y_{min}}{2}\right)\right] \ (1)$$

$$c = [c_x; c_y]$$

$$p = [c_x; y_{max} + 76] \ (2)$$

4. Testing of the application.

The software application was tested in a controlled environment, it being able to correctly detect the position of the tomato. The application has correctly detected the position of the tomato because it matches the sizing conditions. Once the tomato has been detected so have its extremities and its centre. The peduncle positions have also been detected after completing the previously acknowledged calculations.

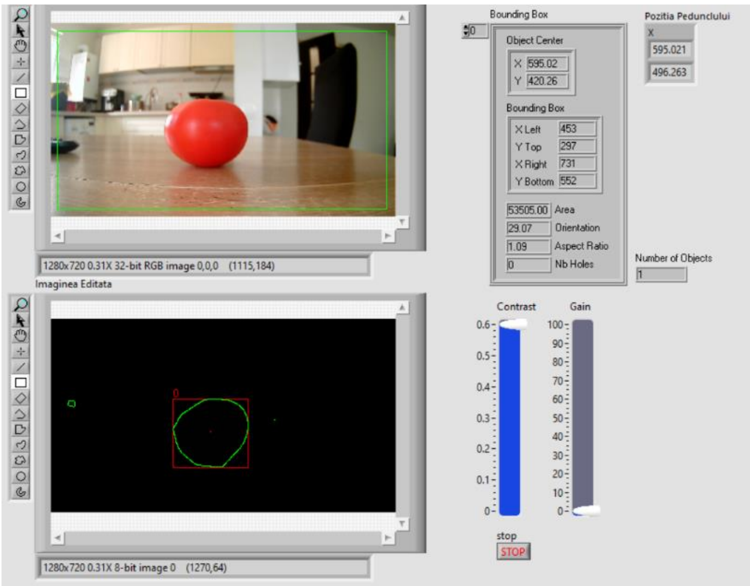


Fig. 10. The VI used to capture and edit images.

5. Conclusion

This document provides a method for detecting and collecting tomatoes using a robotic arm to help agriculturalists during harvesting season. The robotic arm being placed at a fixed distance toward the stem of the tomato plant can detect the position and centre of said tomato using a video camera. The peduncle position can be determined using the centre of the tomato and its extremities. In the future the margin of error to find the peduncle and the repeatability of the robotic arm to fulfil its commands of collecting and depositing tomatoes will be studied and improved upon.

6. Bibliography

[1]. Ioan Băisan (2016), ”Culturi Agricole Protejate”, Universitatea Tehnică ”Gh. Asacchi”

[2]. Gregg D. Short (2012), ”Moldovan Greenhouse Design Manual”, Copyright DAI/USAID

[3]. Teodor N. Stan (2003), ”Legumicultură Volumul III”, Editura ”Ion Ionescu de la Brad”, ISBN 973-98978-9-4, Iași

[4]. Dennis Maina Gatahi (2020), ”Challenges and Opportunities in Tomato Production Chain and Sustainable Standards”, International Journal of Horticultural Science and Technology Volume 7

[5]. Darlene Ana de Paula VIEIRA(2019), ”Mechanical resistance, biometric and physicochemical characteristics of tomato cultivars for industrial processing”, ISSN 0101-2061

[6]. Tom Savu (2020),”Programarea calculatoarelor și limbaje de programare”

[7]. Mihaela Ulmeanu (2021), ”Bazele proiectării asistate de calculator”

[8]. Cristian Doicin (2023), ”Tehnologii și echipamente pentru fabricare aditivă”

DESIGN OF AN ALGORITHM INTEGRATED IN ROS2 FOR THE CONTROL OF AN AUTONOMOUS VEHICLE (AMR) LIFT/LOWER SYSTEM FOR INTRALOGISTICS ACTIVITIES

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ABSTRACT: Topic "Design of a ROS2 integrated algorithm for the control of an autonomous vehicle lift/lower (AMR) system for intralogistics activities" consists of developing an optimized version of the lifting/lowering platform for an autonomous vehicle from the given pre-existing version. The purpose of this platform is to facilitate the transport of pallets/boxes containing semi-finished products, parts or products between stations in different predetermined locations within a production or logistics center. Lifting and lowering is achieved by operating an 'X'-shaped arm assembly which is driven by a motor.

KEYWORDS: AMR, lift/lower, autonomy, ROS2, efficiency

1. Introduction

In the paper "Design of a ROS2 integrated algorithm for the control of an autonomous vehicle lift/lower (AMR) system for intralogistics activities" an optimized solution of an existing autonomous vehicle [1] used for intralogistics activities in a production facility will be presented. This autonomous vehicle is designed to operate without human intervention and can be programmed to follow pre-defined routes or react to information received from the environment via sensors.

2. Definition of the simulation model for intralogistics activities

Intralogistics refers to the optimization, integration, automation and management of logistical flows of information and material goods within a production or distribution center.

General intralogistics flows (production units and distribution centers):

- **Inbound -** receipt of goods and materials
- **Putaway -** transfer of goods and materials to the storage area
- **Picking/Kitting -** collecting and preparing goods and materials for delivery
- **Replenishment -** replenishment of source cells from which picking/kitting is done
- **Line feeding -** delivery of goods and materials to production lines.
- **End of line -** picking of finished products from production lines and delivery to warehouse
- **Outbound -** the outgoing of finished products from the warehouse to the final customer[2]

In terms of intralogistics activities, the model mainly performs activities such as "Putaway", "Line feeding" and "End of line" which will consist of transporting boxes/pallets between various centers within the plant.

An autonomous robot with a predefined hardware configuration will be used in which there will be a lifting/lowering system that should be able to perform the following activities:

1. **Pallet/box loading -** when the AMR arrives at a station, the lift/lower system on the AMR will need to be lowered, the AMR will enter the station, the system will lift the pallet/box until it is

no longer in contact with the station, then the AMR will exit the station and the system will lower the pallet/box. The AMR can then move the load to the next station.

2. **Pallet/box unloading** - when the AMR arrives with the load at a station, the lifting/lowering system on the AMR should be able to pick up the pallet/box, enter the station and lower the pallet/box until it settles on the station. The AMR will then exit the station and move unloaded to the next station.

To create an effective platform, we need to consider several aspects:

- **Load capacity and dimensions**: The system must be designed to support the lifting and lowering of a pallet/box with a pre-determined weight (see figure 1). In the case of Euro pallets or industrial pallets the volume is imposed by their standard dimensions of 1200mmx800mm or 1200mmx1000mm laydown area. For the present topic **a demonstrator lifting system** will be considered which will have a **pallet/box area of 500mmx500mm** (see figure 2) [3]. **The maximum load will be 50kg.**

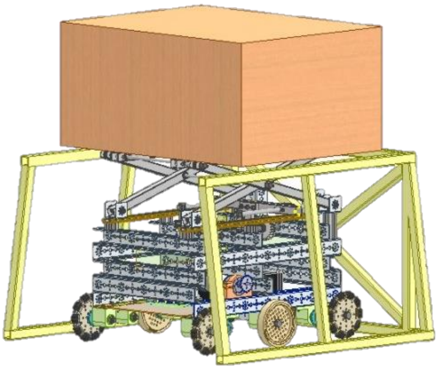

Fig. 1. Example of AMF operation

Fig . 2. Box model

- **Lifting/lowering stroke**: The maximum lifting height will be dimensioned between **50-100mm**.
- **Energy efficiency**: The system will be sized to ensure a **minimum** number of lifts/lowers during a **minimum 2h duty cycle between 2 AMR battery charges**. Calculations and experiments will be carried out for the demonstrator according to the type of motor, drive and computing unit in relation to the other existing consumers on the AMR. Efficient battery usage is a key point in the platform design as increased autonomy is an important feature. To ensure this we will choose low power consumption motors.

3. ROS2 lifting/lowering subsystem design and control

The work process started with the installation of a virtual machine (Oracle VM VirtualBox) through which the necessary ROS2 package installation commands were run in the terminal.

ROS2 (Robot Operating System 2) [4]is an open-source platform that uses software libraries to develop robotic applications. It can be used to develop state-of-the-art drivers or algorithms. Compared to ROS1, ROS2 comes with some additional new functionalities such as: support for multiple platforms and operating systems (including Windows, Linux and macOS), faster communication between nodes (introduction of a new Data Distribution Service (DDS) communication system), and better management of robot hardware and software resources.

RViz is a three-dimensional ROS graphical visualization interface used to visualize and interact with the generated data. It is a useful and popular application used in ROS2, being used for testing and development. Using this program, one can visualize the robot model as well as sensor data [5]

For a thorough understanding, tutorials were followed in which various actions were performed such as: creating a working environment (see figure 2), creating a node, communication between 2 nodes (see figure 3). Thus, for the deepening of the notions, the environment was created containing the following files as shown in the images below [6]:

Fig. 2. "sam_bot_description" working environment and its contents

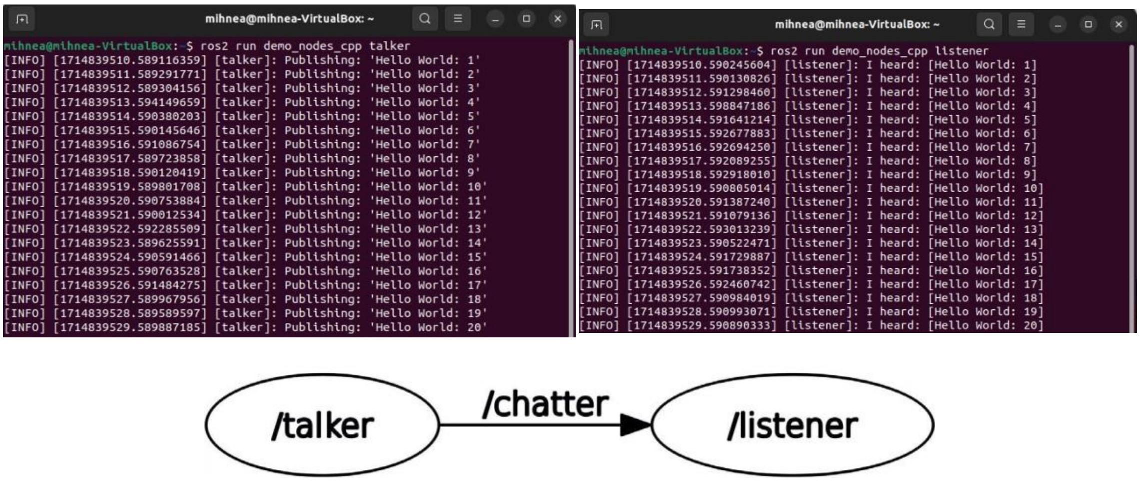

Fig. 3. Communication between 2 nodes - talker and listener [2]

Using the knowledge gained above, you can create for the existing CAD model (see figure 4) of the AMR URDF file that will help us to visualize it in RViz.

The URDF (Unified Robot Description Format) file contains the description and geometric and physical characteristics such as: masses, inertias, and centers of gravity. In addition, the URDF file allows the specification of sensors mounted on the robot, as well as joints and kinematics, thus allowing the simulation of motion in different scenarios. By using this file, we can analyze and optimize the operation by modifying the parameters.

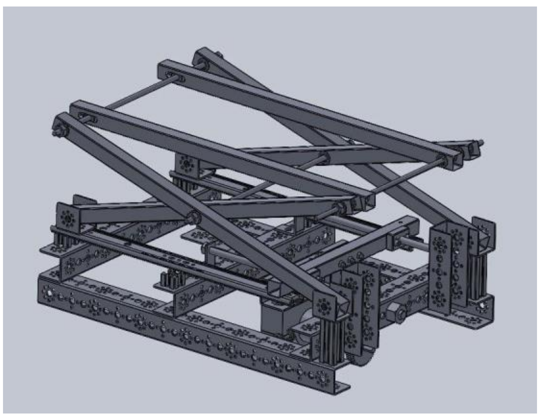
Fig. 4. CAD model of the lifting platform

In a real scenario, the robot will be used in hall CK004 of the Faculty of Industrial Engineering and Robotics where it will be set up with a "HOME" place, a loading station and two centers between which the AMR will transport the boxes/pallets with the parts. It will start from the "HOME" point and go to the first processing center [7] (see figure 5). When it arrives, the platform will lift and pick up the box and the platform will lower down with the load to be stable throughout the journey to the second center. On arrival at the second center, the platform will rise again, drop off the box and descend, and then proceed to the next scheduled location.

Fig. 5. LabCenter 260 CNC machining center

4. Development and testing of the algorithm

In the platform assembly we will also use an AndyMark 2964a [8] motor, a Roboclaw Solo 1x30A[9] controller and a Raspberry Pi 4 Model B/4GB[10] which will be powered from a 12V supply.

As far as the motor control is concerned, tests were carried out to ensure correct operation in one direction and then in the other direction when the mechanical limiter on the top of the bracket was reached (see Figure 6).

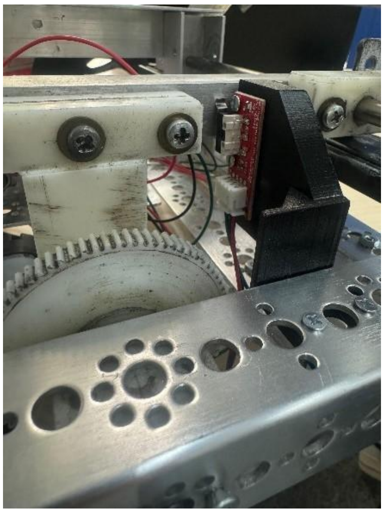

Fig. 6. Activating the stroke limiter when reaching the support

At this stage, the engine can be controlled, but work is underway to improve the algorithm and create an optimal version that can be used in parallel with the weeklies received from the limiters (see figure

7).

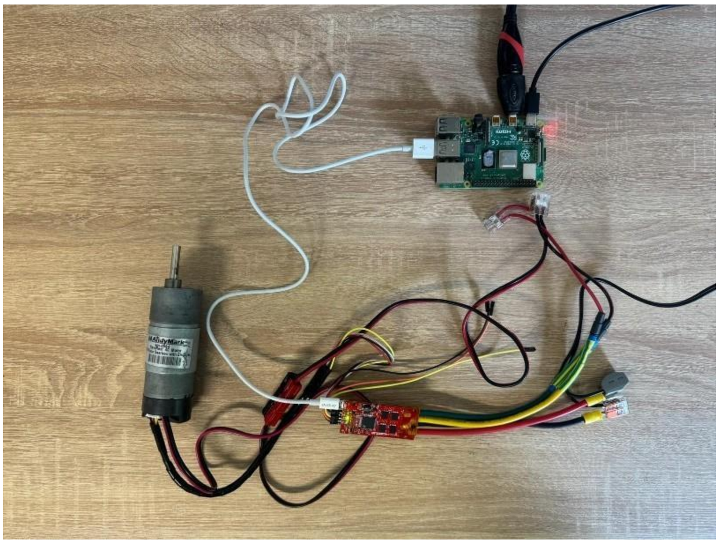

Fig. 7. Physical engine test model

Beforehand, in order for the robot to know its direction, the hall will be mapped using a LiDAR sensor placed on its base. Mapping (see figure 8) the hall is a process of creating a detailed representation of the environment in which the AMR robot will operate. This includes information about obstacles, loading/unloading locations and other details about the environment (see figure 9). Although the mapping is done, the LiDAR sensor will continue to be essential for the safe operation of the robot. This sensor will help the robot to identify its position compared to other scanned objects, giving it accurate information about objects in its vicinity. It will also transmit details from the environment in case of new obstacles not initially identified. This way, it will know how to avoid them or stop if it can't continue.

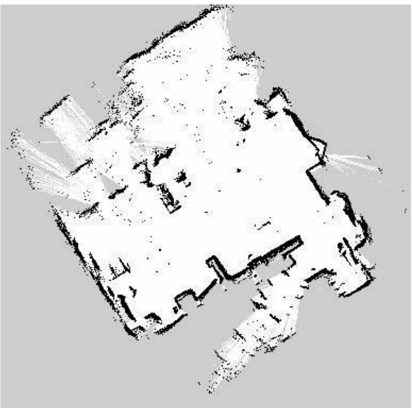

Fig. 8. Mapping of pit CK004

Fig. 9. Robot mapping hall CK004

Upper and lower stroke limitation

To increase safety, two mechanical stroke limiters [11] (see Figure 10) were used to stop the platform at the end of the stroke. These devices are essential to prevent the work platform from lifting or lowering too much, protecting both the robot and the transported parts. Functioning as a safety mechanism, these limiters are designed to intervene if the platform reaches an extreme point. They also help prevent wear and tear prematurely caused by an engine malfunction. Thus, the implementation of these mechanical stroke limiters not only increases the safety of the platform movement, but also contributes to maintaining the reliability of the robot. The figure below shows how the support moves on the lead screw and the contact points of the limiters.

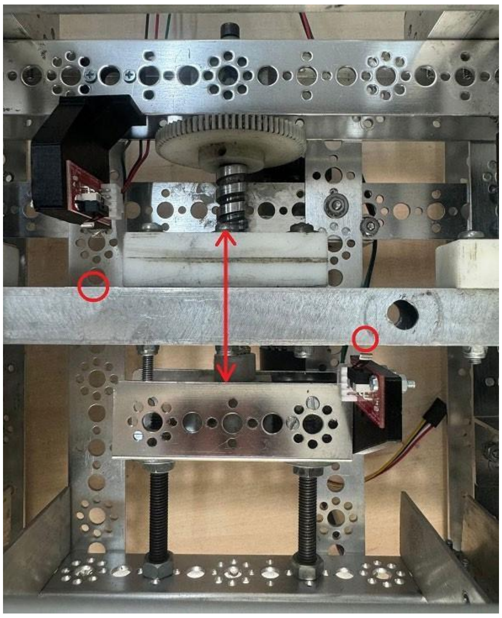

Fig. 10. Fitting mechanical stroke limiters on the robot

To attach these limiters to the AMR body, two supports were designed using SolidWorks taking into account the actual robot dimensions and lead screw movement (see figure 11 and 12).

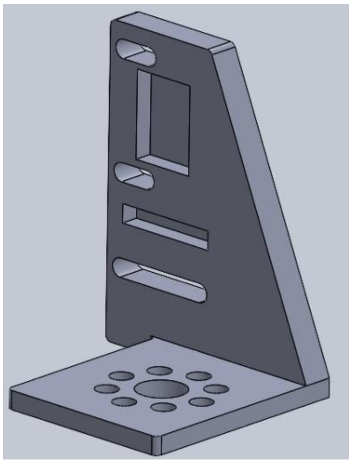

Fig. 11. Lower stroke limiter bracket

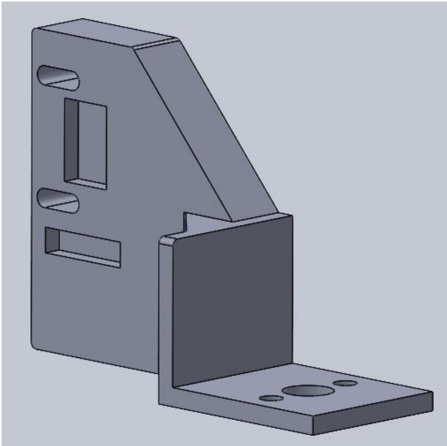

Fig. 12. Upper stroke limiter bracket

ROS2 algorithm design

To create the control software part of the platform, the existing CAD model was used in the first phase, based on which motion constraints were set. Using a plugin called "SW2URDF" available in SolidWorks the URDF file was exported. Subsequently, a working environment was created in the virtual machine where the generated file was added, thus creating a working simulation using RViz (see figure 13).

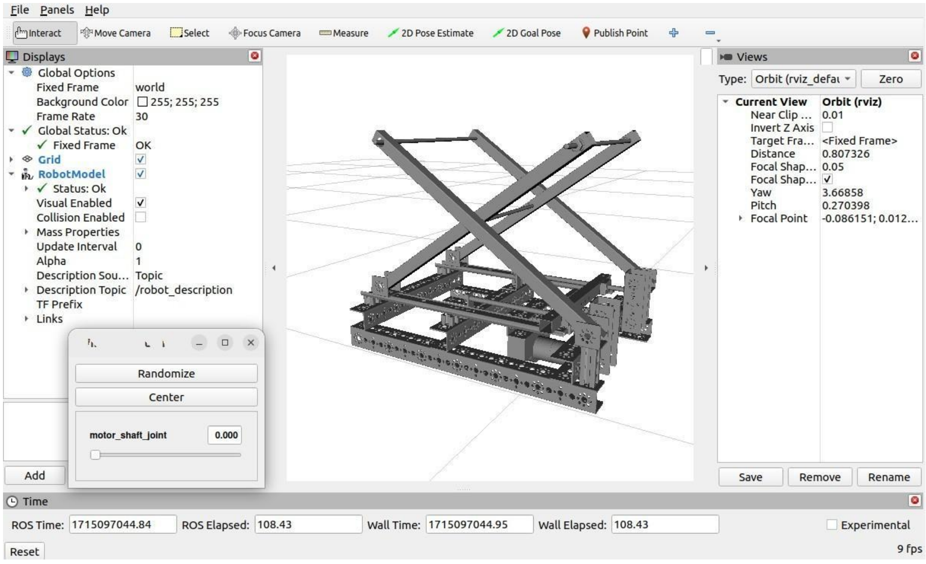

Fig. 13. Platform model in RViz

The generated URDF file contains details about the robot such as: masses, inertias, centers of gravity, and motion kinematics. Starting from the base of the platform and its physical and inertial information, the following code was generated containing the description of the subassembly and the element linking "base_link" to the "world" reference system:

```
        <link name="base_link">
          //mass and inertia
         <inertial>
           <origin xyz="-0.054013918847888635 -0.037824606601193175
0.0313364177845585" rpy="0 0 0"/>
           <mass value="4.766271366186971"/>
           <inertia ixx="0.065528" iyy="0.096601" i z z = "0.041022" ixy="-0.0"
 iyz="- 0.000784" ixz="1e-06"/>
         </inertial>
         //visual aspects: location and orientation of origin
         <visual>
           <origin xyz="0 0 0 0" rpy="0 0 0" />
           <geometry>
             <mesh
 filename="package://amr_robot_description/meshes/base_link.stl" scale="0.001
 0.001 0.001"/>
           </geometry>
           <material name="steel_satin"/>
         </visual>
         //collision information
         <collision>
           <origin xyz="0 0 0 0" rpy="0 0 0" />
           <geometry>
             <mesh
 filename="package://amr_robot_description/meshes/base_link.stl" scale="0.001
 0.001 0.001"/>
           </geometry>
         </collision>
        </link>


        //connection between "base_link" and "world"
```

```
<joint name = "virtual_joint" type = "fixed">

  <origin xyz = "0 0 0.2" rpy = "${PI/2} 0 0"/>
  <parent link = "world"/>
  <child link = "base_link"/>
</joint>
```

Thus, using these files, a system simulation can be created that provides a detailed and complete representation of the structure and characteristics of a robot.

5. Conclusions

The paper "Design of an algorithm integrated in ROS2 for the control of an autonomous vehicle lift/lower (AMR) system for intralogistics activities" represents an optimized solution of an autonomous vehicle used for intralogistics activities in a production facility or in various industrial applications. This project involves the development and improvement of an AMR used to transport boxes/pallets from one work stand to another, thus streamlining the logistics processes on a semi- finished product production line. The implementation of this system offers multiple benefits, including workflow optimization and reduced downtime. There are also further directions for development and improvement of the platform, as well as steps to be completed such as motor control depending on the information received from the mechanical stroke limiters.

6. Bibliography

[1].Ing. George-Sebastian BANU, Eng. Silviu-Daniel DRĂGAN, Ing. Andreea-Alina PĂUN, Ing. Ștefan-Mădălin POPONETE (2022), IMPC 2022 dissertation achievements: Team 1: Development of an Automated Guided Vehicle - AGV

[2] Bogdan Felician ABAZA (2024), "Management of logistics networks", Course 7

[3].https://www.kaiserkraft.ro/ambalaje/cutii-de-carton-pliante/cutie-de-carton-plianta-fefco-0201/cu- 2-straturi-de-carton-ondulat/p/M66546/?articleNumber=605446

[4].https://design.ros2.org/articles/changes.html

[5].https://www.stereolabs.com/docs/ros/rviz

[6].https://github.com/open-navigation/navigation2_tutorials/tree/master/sam_bot_description

S. Macenski, T. Foote, B. Gerkey, C. Lalancette, W. Woodall, "Robot Operating System 2: Design, architecture, and uses in the wild," Science Robotics vol. 7, May 2022.

S. Macenski, A. Soragna, M. Carroll, Z. Ge, "Impact of ROS 2 Node Composition in Robotic Systems", IEEE Robotics and Autonomous Letters (RA-L), 2023;

[7].https://www.knuth.com/en/labcenter-260-cnc-181615

[8].https://www.andymark.com/products/neverest-classic-40-gearmotor

[9]. https://www.basicmicro.com/Roboclaw-Solo-30A-34VDC-Motor-Controller_p_44.html

[10].https://www.optimusdigital.ro/ro/placi-raspberry-pi/8617-raspberry-pi-4-model-b-4gb-765756931182.html?gad_source=1&gclid=Cj0KCQjw6PGxBhCVARIsAIumnWY1Lq21_IISUslXQu IHLkVmb-QTxindRWwIMNVR-9c9vpvtHJs_QTsaAgRUEALw_wcB

[11].https://ardushop.ro/ro/printare-3d/138-endstop-mecanic-pentru-imprimante-reprap.html?gad_source=1&gclid=CjwwKCAjwouexBhAuEiwAtW_ZxxMd3hemdejUy3o9soNDerCpt MQCfoTvtQO47F1v6u27GScc96iDrhoCFWUQAvD_BwE

RESEARCH ON DESIGNING AND IMPLEMENTING AN EXPERIMENTAL MODEL OF A HAPTIC SYSTEM FOR CONTROLLING A ROBOTIC ARM

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Faculty: IIR, Study programme: [1]AIII, [2]IEMA, Year of study: I, email:alexalecu712@yahoo.com

ABSTRACT: The purpose of this scientific paper is to conduct a comprehensive case study on haptic mechanisms. In this context, the starting point is represented by market research, and the main objective is the development of an experimental system for haptic manipulation of objects located remotely, in unfriendly environments for humans.

KEYWORDS: feedback, robots, MBSE, QFD, electronics

1. Introduction

This scientific paper aims to thoroughly examine the strategic marketing of a haptic system, followed by a detailed analysis of its operation. The subject is then extended to systems engineering, with a focus on Model-Based Systems Engineering (MBSE) methods, and Quality Function Deployment (QFD) to highlight the importance of quality in haptic system development. The electronic aspects of the system are then examined, along with the 3D design and programming process, to provide a comprehensive understanding of the entire development and implementation process of the haptic system. This paper aims to provide a comprehensive perspective on the various aspects involved in creating a complex haptic system, illustrating the connections and importance of integrating these aspects to ensure the functionality and efficiency of the system in various applications.

2. Current Stage

The chapter is divided in several components, as follows:

2.1 Strategic Product Marketing

a) Global Market of Haptic Devices

The global market for haptic devices, estimated at $18.9 billion in 2023, is projected to reach a revised size of $47 billion by 2030, growing at a CAGR of 12.1% over the analysis period of 2023-2030. The haptic device market in the United States is estimated at $2.2 billion in 2023. China, the world's second-largest economy, is forecasted to reach a projected market size of $11 billion by 2030. [1]

b) Innovative Products

Companies operating in the haptic technology market are focused on developing innovative products such as high-fidelity haptic systems to meet the ever-evolving needs of consumers. These systems provide realistic and precise haptic feedback, enhancing the overall user experience in various applications. [2]

c) Competing Products

These competing products with their respective specifications can be found in Table 1.

Table 1. Competing Products

No.	Characteristic size	Unit of Measurement	Products			
			Virtuose 6D TAO 	Virtuose 6D RV/V4 	Geomagic Touch X 	Geometric Touch 
1.	Workspace	mm	1020 x 1330 x 575	820 x 1070 x 458	355 W x 228 H x 180 D	431 W x 348 H x 165 D
2.	Refresh Rate	kHz	1	1	4	1
3.	Interchangeable Handle	Yes/No	Yes	Yes	No	No
4.	Degrees of Freedom	-	6	6	6	6
5.	Feedback Degrees of Freedom	-	3	3	3	3
6.	Maintenance and Installation Manual	Yes/No	Yes	Yes	Yes	Yes
7.	Total Weight	Kg	6.4	5.7	3.2	1.4
8.	Maximum Force	N	42	34	7.9	3.3
9.	Continuous Force	N	10	10	1.75	0.88
10.	Power Supply Voltage	V	220	220	220	220
11.	Programming Interface	Yes/No	Yes	No	Yes	Yes
12.	Number of Buttons	-	6	3	0	2
13.	Price	Euro	622	-	11400	2892

2.2 System Modeling

a) Operation Mode, Adaptation according to Koller

A haptic system allows users to feel and interact with virtual or real objects through a range of tactile sensations. The general process of how this system operates begins once the user interacts with the haptic device, such as a joystick or a lever. Haptic sensors measure the movements and forces applied by the user, with the data then transmitted to a control system for encoding and compression. Error correction can take place to compensate for any deviations or delays in measurement, and the corrected information is used to estimate the state of the haptic system and the associated manipulation device. Continuous interaction with the robotic arm, which responds to received commands and generates haptic feedback, is transmitted back to the user to complete the cycle of smooth and precise interaction between the user and the haptic system. [3]

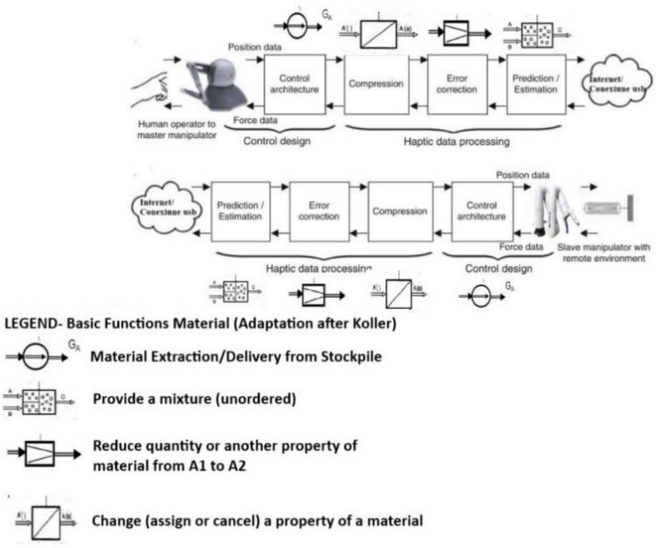

Fig. 1 Adaptation of Haptic System according to Koller [3]

b) Systems Engineering (MBSE)

The Arcadia method emerged in 2007 as part of Thales Airborne Systems: this structured engineering method, which aimed to define and validate the architectural design of complex systems, was immediately followed by the Melody Advance tool, which facilitated its implementation. The method and tool subsequently demonstrated their benefits in all areas of Thales' excellence (Defense, Space, Aeronautics, Ground Transportation, Security, etc.), providing a collaborative working structure for the involved parties, who are often numerous in the system definition phase. [4]

Today's complex systems are constrained by a series of requirements or constraints, often concurrent and sometimes contradictory: functional requirements (the services expected by users) and non-functional requirements (security, operational safety, mass, scalability, cost, etc.). The initial engineering phases of these systems are critical because they condition the suitability of the architecture used to meet customer needs, as well as the appropriate distribution of requirements to the components resulting from the architecture used. To properly manage delays and costs, it is vital to be able to verify the adequacy of the solution in relation to the needs from the system design phase and to minimize the risk of encountering the limits of the solution - thus endangering the architecture - at a more or less advanced stage of development, or even during system integration or qualification. [4]

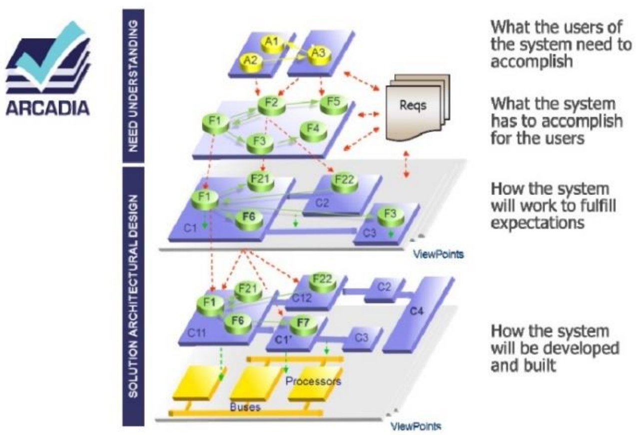

Fig. 2 The main engineering levels of Arcadia [4]

Operational Analysis

The highest level of Arcadia is Operational Analysis ("what future system users need to achieve"). The aim here is to focus on identifying the needs and objectives of the future users of the system to ensure the system's adequacy in addressing these operational needs. [4]

Within the operational analysis of the haptic system presented in the figures below, the roles of the actors (users) and involved entities (robotic arm and object) are highlighted, as well as the activities associated with them. Figures 3 and 4 depict a simplified scenario.

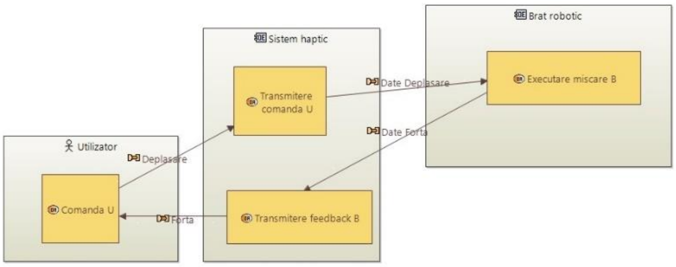

Fig. 3 Capella OAB Haptic system

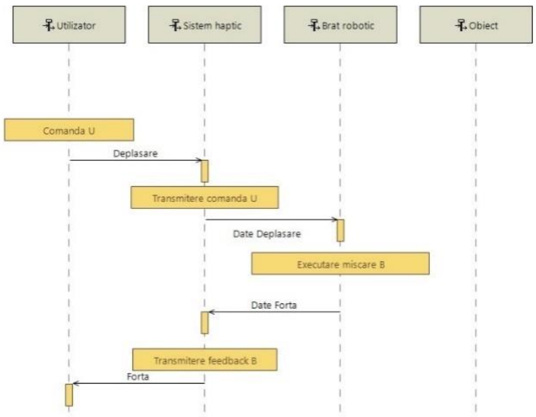

Fig. 4 Simplified Scenario

System Analysis

System analysis involves identifying the capabilities and functions of the system that will meet operational needs ("what the system needs to achieve for users") as shown in Figure 5. [4]

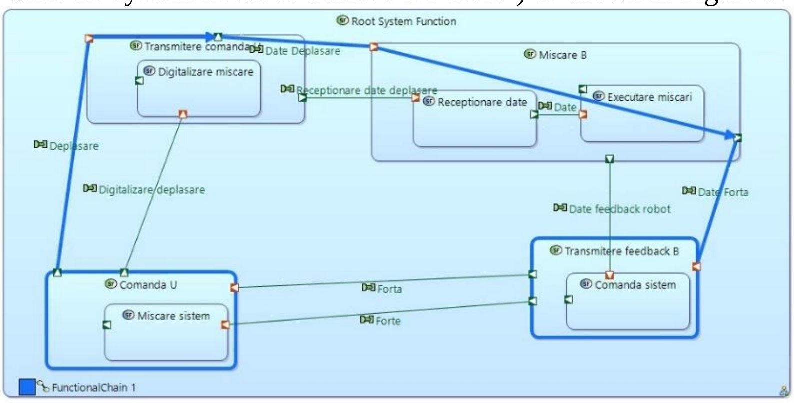

Fig. 5 SDFB Force Simulation

Logical Architecture

The Logical Architecture level aims to identify the Logical Components within the System ("how the system will operate to meet expectations"), their relationships, and their contents, independent of any technology or implementation considerations. [4]

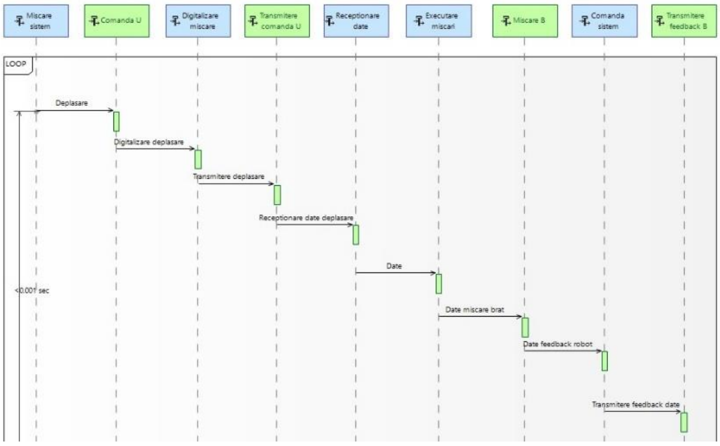

Fig. 6 Detailed Scenario

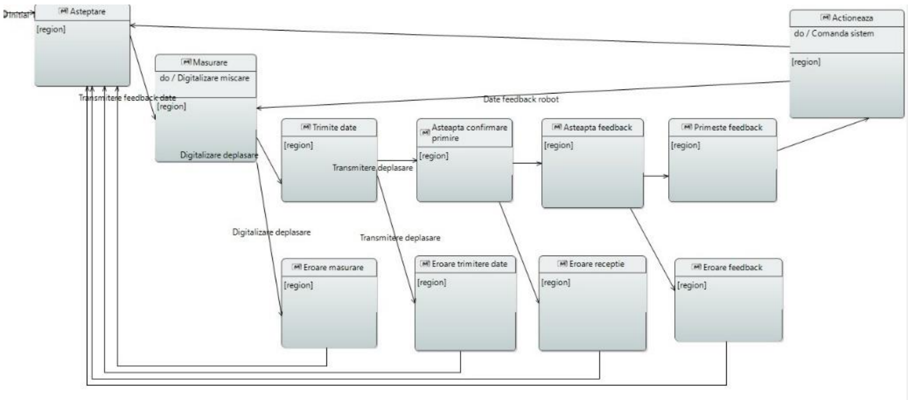

Fig. 7 State machine

A library has been developed that presents the functions and phenomena acting on the haptic system, and Figure 8 illustrates the interaction between them.

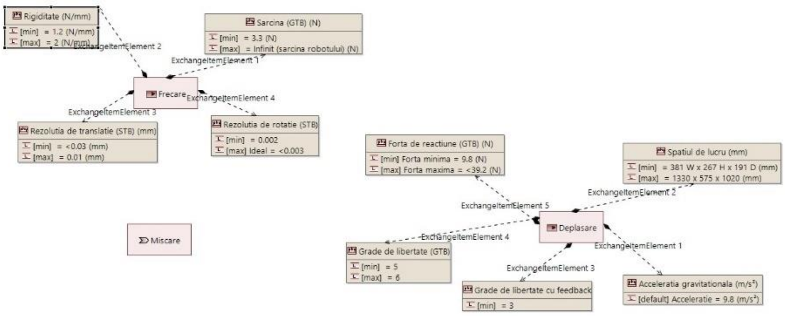

Fig. 8 Phenomena acting on the system

c) Design

Within the Scientific Research 1 discipline, various architectures of haptic systems have been examined, leading to the decision to advance with the following system structure, based on 3 BLDC actuators.

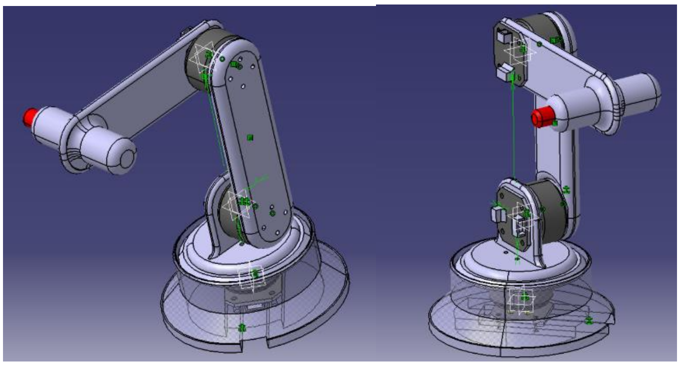

Fig. 9 System Architecture

d) Quality Function Deployment (QFD)

The Quality Function Deployment (QFD) is a method of product and service planning that aims to satisfy customer requirements. It originated in Japan and was initially developed by Yoji Akao in the 1960s. It is illustrated in Figure 10.

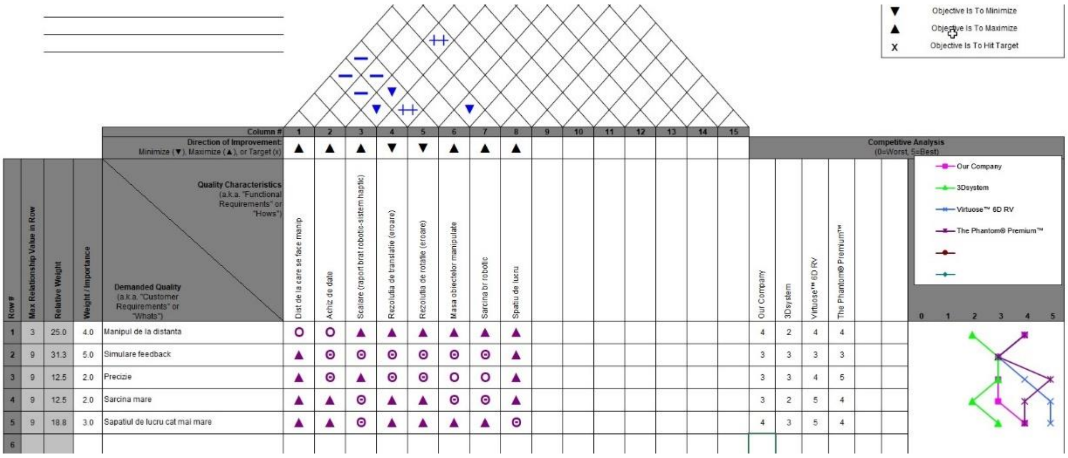

Fig. 10 QFD Haptic System

e) Electrical Diagram

For the electrical diagram of the haptic system, various haptic systems have been analyzed, and as a result, the following components have been selected: 3 BLDC motors (Makerbase MKS SF2804), 3 drivers (SimpleFOC Shield), a PD trigger, and a switch. The connection diagram is presented in Figure 11:

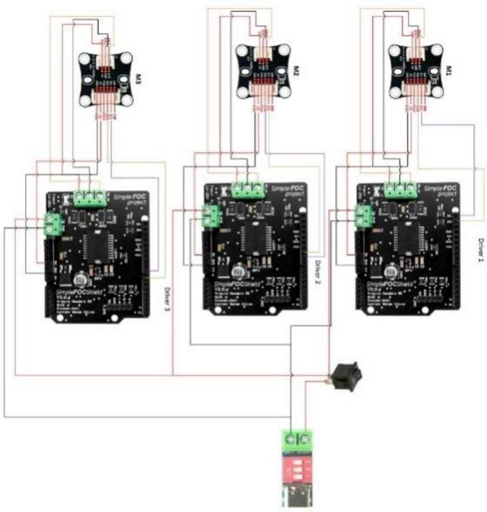

Fig. 11 Electrical Diagram

2.3 Programming

For controlling an articulated robotic arm, there are different levels of abstraction that we can have over it. Low-level and high-level control of a robotic arm represent two different approaches in programming and controlling the arm's movements. Each approach has its advantages and disadvantages, and the choice between them depends on the specific requirements of the application.

Low-level control refers to the direct control of each motor and sensor of the robotic arm, without considering complex tasks or detailed motion planning. This level of control involves sending commands directly for positioning, speed, and acceleration to the motors and sensors of the arm. In contrast, high-level control focuses on fulfilling complex and specific tasks, such as picking up and placing objects in a certain location or navigating in a complex environment. This level of control requires advanced motion planning and decision-making based on available information about the environment and objects.

Regarding the articulated robotic arm Kinova Gen3 Lite [5], high-level control is achieved using the Kinova.Api.Base API, which allows sending commands to the robotic arm's base that are then processed by the robot's control libraries and include functions such as singularity avoidance, zone protection, and movement limitation in both Cartesian and joint coordinates. On the other hand, low-level control means sending a series of small commands to each motor and sensor of the arm using the Kinova.Api.BaseCyclic API, with commands being applied directly at the motor and sensor level without being processed by high-level control libraries, providing more detailed and faster control of the arm's movements.

Given the context of real-time control, a meticulous and rigorous approach to programming is necessary in the low-level control of the robotic arm. This approach must focus on optimizing the system's response time and ensuring the precision of movements in real-time, in accordance with the specific requirements of the haptic application.

To successfully compile the examples provided by Kinova Robotics on Github [6], a series of configurations had to be made based on the compiler (mingw64-posix) and operating system (win64) used for development.

In Figure 12, an example provided within the mentioned API was executed, resulting in a series of files including one with the extension ".exe" and one ".dll".

A Dynamic Link Library (DLL) file represents a collection of functions and resources that can be shared and used by multiple applications simultaneously. These functions can be called from other programs to perform specific operations or to provide certain services (e.g., controlling an articulated robotic arm).

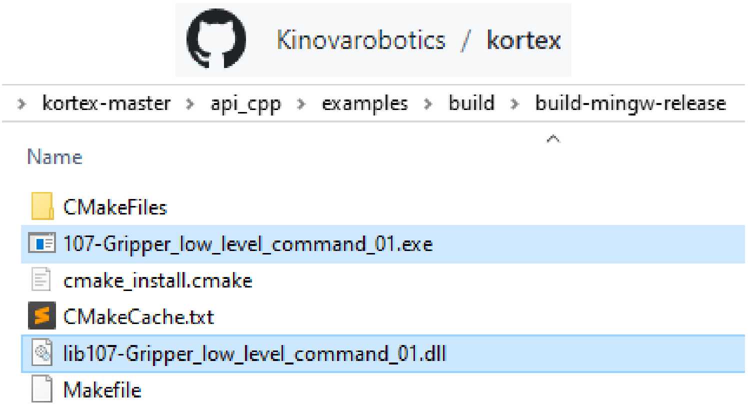

Fig. 12 Compiling the example "Gripper_low_level_command_01"

In Figure 13, the use of dynamic loading tools for a DLL file (e.g., lib107-Gripper_low_level_command_01.dll) in the LabVIEW programming environment is demonstrated. The "Call Library Function Node" block allows calling functions from the DLL file directly from the block diagram [7], enabling the passing of parameters (ip_address, username, password) used in the C++ control file (.cpp). This facilitates low-level control of the end effector and implicitly of the articulated robotic arm.

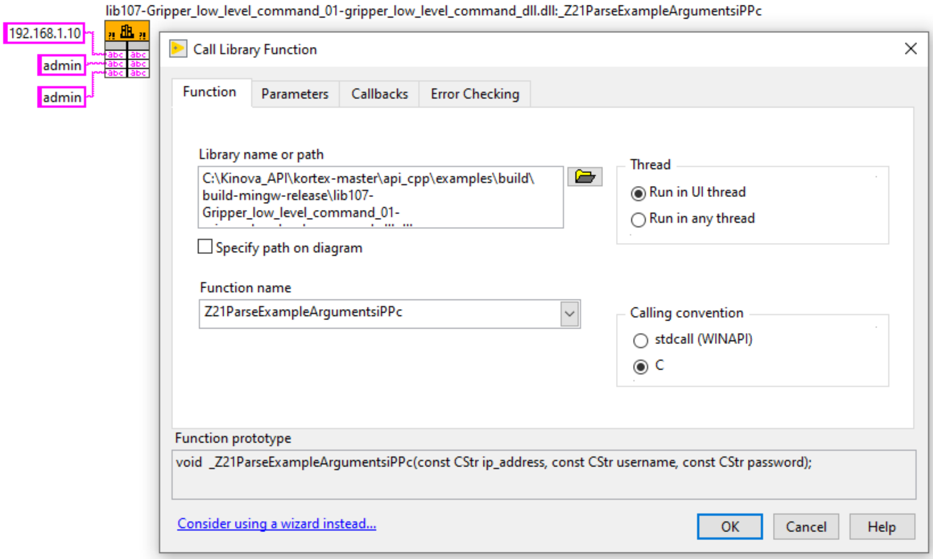

Fig. 13 Example of using lib107-Gripper_low_level_command_01.dll in LabVIEW

3. Conclusions

This paper investigated the design and implementation of an experimental haptic system for controlling a robotic arm. We began by examining the market for haptic devices and innovations in the field. Then, we focused on systems engineering, using Model-Based Systems Engineering (MBSE) methods and Quality Function Deployment (QFD) to ensure quality and customer satisfaction. We detailed the operation of the haptic system, adapting existing concepts, and analyzed the programming required for its implementation. Finally, we designed and implemented the electrical schematic of the system, ensuring it is suitable and functional. This paper provides a comprehensive perspective on the development process of a haptic system and the importance of quality in this process.

4. Bibliography

[1]. G. I. (2024, mai). Haptics - Global Strategic Business Report. (accesat la data 8.05.2024) https://www.researchandmarkets.com/ (accessed at 08.05.2024)

[2]. T. B. (2024, februarie). Haptic Technology Market Is Expected To Grow At A Rate Of 11% https://www.globenewswire.com/ (accessed at 08.05.2024)

[3]. Jae-young L, Shahram P (2015). Haptic Teleoperation Systems. Editura Springer

[4]. Pascal Roques (2018). Systems Architecture Modeling with the Arcadia Method. Editura Elsevier Ltd, ISBN 978-1-78548-168-0

[5]. Kinova Robotics. (2021) Kinova® Gen3 Lite robot - User guide https://artifactory.kinovaapps.com/ (accessed at 06.04.2024)

[6]. Kinova Robotics. (2023) KINOVA® KORTEX™ API Reference https://github.com/ (accessed at 18.03.2024)

[7]. National Instruments. (1998) LabVIEW User Manual https://engineering.purdue.edu/ (accessed at 18.03.2024)

MICROWAVE PASTEURIZATION INSTALLATION

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ABSTRACT:The paper deals with the finite element numerical simulation of the microwave pasteurization process. Information is presented on the state of the pasteurization process and the facilities dedicated to it. The results obtained from the numerical simulation are consistent with the experimental results, based on this fact, but also duet o the needs of the customers, a microwave pasteurization installation was 3D modeled in the work. The microwave pasteurization process is very effective in removing pathogenic components from food in a short time.

KEYWORDS: installion, microwave, pasteurization, numerical simulation, customers.

1. Introduction

Pasteurization is the process by which the growth of microorganisms in food is slowed down. The process is named its creator, the chemist and microbiologist Louis Pasteur.The first pasteurization test was performed by Louis Pasteur and Claude Bernard on April 20, 1862.The process was originally conceived as a way to prevent the acidification of wine and bear.[1]

Microwaves are thought to inactivate enzymes and kill microbes mostly through conventional thermal mechanisms.[2] For long-term preservation, the products are subjected to the thermal process in a pressurized chamber.[3]The thermal treatments to which the products are subjected are: thermalization, low pasteurization of milk LTLT, high pasteurization of milk HTST, ultrapasteurization, sterilization, sterilization in containers.[4]

2. Strategic Marketing

The segmentation of the product market is based on the specific requirements regarding the quality and structure of the offer, the affirmation and manifestation of the demand from buyers, the frequency, and the average size of the purchase, etc. In any type of enterprise, the role of marketing is to contribute to a better understanding of its audience in order to adapt to the external environment and achieve maximum efficiency. [5]

2.1. Identifying Market Opportunities

a. Portfolio of Customer Needs

Three primary needs are identified, numbered N1, N2, and N3:

- N1: The need to ensure food safety.
- N2: The need to extend the shelf life of food products.
- N3: The need to reduce processing time and costs.

b. Opportunities / Products

"Today's competition is more than ever based on product development capabilities." [5]

The products that fully or partially satisfy these needs are represented by microwave pasteurization installations (MPI). These are specialized products designed to provide efficient and rapid pasteurization of food using microwave technology.

Market opportunities for the developed microwave pasteurization installation are represented by the increasing demand for safe and healthy food products.

c. *Customers for Product Distribution*

Selecting customers involves identifying actual and potential customers who could benefit from the microwave pasteurization installation.

The equipment is aimed at the following types of customers:

1. Food industry enterprises, especially SMEs that process and produce various types of food.
2. Research and educational institutions:
   - ➢ Students – occasional use
   - ➢ Professors – occasional use
   - ➢ Laboratories – relatively frequent use

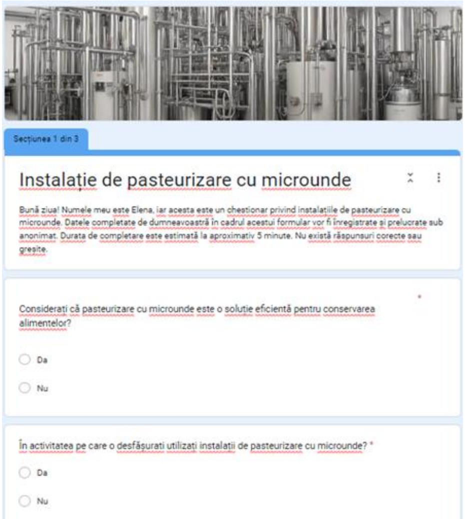


Fig. 2. Online Questionnaire [6]

1.2.Formulating the Mission for the Selected Product Development

- Customer Selection Matrix

The customer selection matrix is presented in Table 1.

Table 1. Customer Selection Matrix

	Top Users	Average Users	Occasional Users	Centers
Category 1	7	2	2	1
Category 2	1	6	2	
Category 3	2	2	5	

The guide for conducting interviews to identify customer needs for the microwave pasteurization installation is presented in Table 2.

Table 2. Guide for Conducting the Interview to Identify Customer Needs for the IPM Product

Client: **Address:** **Phone:** **Would you like to collaborate? Yes No**	**Interviewers:** **Date:** **Current Uses:** **User's Occupation:**	
Question	Client's Statement	Interpreted Need
1. Do you consider microwave pasteurization an effective solution for food preservation?	a) Yes b) No	
2. In your current activity, do you use microwave pasteurization installations?	a) Yes b) No	
3. How often do you use the microwave pasteurization installation in a week?	a) Daily b) Several times a week c) Occasionally d) Rarely	
4. What are the main reasons you use the microwave pasteurization installation? (multiple answers possible)	a) Speed of the process b) Nutrient preservation in food c) Food freshness maintenance d) Reduced contamination risk e) Others	
5. Are you satisfied with the performance of the microwave pasteurization installation?	a) Completely satisfied b) Mostly satisfied	

	c) Not very satisfied d) Not satisfied	
6. Do you believe a microwave pasteurization installation can help maintain hygiene standards in food processing?	Da, într-o mare măsură 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ Nu, deloc	
7. What are the main criteria you consider when choosing a microwave pasteurization installation? (multiple answers possible)	a) Process efficiency b) Installation capacity and size c) Food safety d) Product reliability and durability e) Installation cost f) Others	
8. Are you willing to pay a higher price for a microwave pasteurization installation that offers advanced features or superior performance?	a) Yes b) No	
9. Do you think a microwave pasteurization installation can help reduce the microbiological contamination risk of food and extend its shelf life?	a) Yes b) No	

3. Establishing specifications

The main characteristics of a microwave pasteurization installation (MPI) are: power, operating frequency and volume. The optimal operation of the installation directly depends on the proper correlation of these technical parameters.

3.1. Technical Characteristics of a Microwave Installation

Useful power is the indicator of the power developed by the installation during the food pasteurization process. The greater it is, the faster the pasteurization process. Usually, useful power is directly proportional to the chamber volume. Maximum consumed power indicates the electrical energy consumption required for operation.

The operating frequency determines the effectiveness of how energy is absorbed and distributed within the oven. Using inappropriate frequencies can lead to uneven heating of the food, damage to the installation, injury to the operator, and interference with other devices.

Since the human body can absorb microwaves, microwave installations are structurally equipped with protective devices to avoid harm of the body (shielding of the resonant cavity, magnetron lock device when the door is opened). A larger pasteurization chamber volume allows for more uniform distribution of microwaves inside the oven, leading to better process results.

3.2. Matrices Used to Determine Technical Characteristics

To identify the optimal operating parameters of the installation, several existing products on the market were compared. The matrix of competing products is presented in Table 3.1.

Table 3.1 The matrix of competing products

Size/Characteristic	Units	Products					
		Myria MM720 [7]	MGB 25332 [8]	SMW 6021 [9]	MOC201 [10]	LHMS [11]	MLHS [12]
Oven power	W	700	900	800	700	2000-15000	75000-200000
Nominal power	W	1050	1450	1200	1100	3000-20000	90000-240000
Dimensions (L x h x l)	mm	44x33x25,8	40x38,8x59	45x38x26	24x47x34	83x30x97	84x61x249

Weight	kg	10,7	18,5	12	9,4	-	-
Operating frequency	MHz	2450	2450	2450	2450	2450	915
Volume	L	20	25	20	20	-	-
Type	Built-in / standalone	Standalone	Built-in	Standalone	Standalone	Standalone	Standalone
Control type	Mechanical / digital	Mechanical	Mechanical	Digital	Digital	Digital	Digital
Application	Domestic / industrial	Domestic	Domestic	Domestic	Domestic	Industrial	Industrial

Later, a size requirements matrix was created to determine the objective characteristics. A correspondence is established between each primary requirement and the measurable size that characterizes it.

The size-requirements matrix is represented in Table 3.2 below.

By analyzing Table 3.2, the target parameters of the pasteurization installation are established in Table 3.3.

Table 3.2 The size-requirements matrix

Requirements		Sizes/Characteristics													
		Importance of Requirement	Oven Power	Noise Level	Nominal Power	Dimensions (L x h x l)	Weight	Operating Frequency	Volume	Type	Control Type	Material	Energy Efficiency	Reliability	Ease in maintenance
			1	2	3	4	5	6	7	9	10	11	12	13	14
1	MPI can be used on an industrial scale.	4	●		●				●						
2	MPI does not overheat.	5	●		●			●				●	●	●	
3	MPI has a large volume.	3				●			●						
4	MPI does not consume excessive energy.	4			●								●		
5	MPI ensures safety during	5			●			●			●			●	
6	MPI operates stably.	3	●		●			●							
7	MPI is resistant to mechanical actions.	3				●	●					●		●	●
8	MPI is not noisy.	2		●											
9	MPI present minimal danger to the operator.	5	●		●			●							
10	MPI uniformly heats the food.	5	●					●							
11	MPI can be transported.	2				●	●			●					●
12	MPI is made of durable	4					●					●		●	●
13	MPI is easy to clean.	3							●			●			●

Tabel 3.3 Target parameters

Nr	Size	Characteristics type	Rel. Imp.	Units	Limit values	Target values
1	Chamber volume	GTB	5	L	>20	25
2	Type of processed food		5	Liquid/solid	Liquid+solid	Liquid+solid

3	Oven power	GTB	5	W	>700	800
4	Quality of pasteurization	GTB	5	-	best	best
5	Ensures operator safety		4	yes/no	yes	yes
6	Overall dimensions	GTB	4	mmxmmxmm		
7	Special tools for maintenance		3	yes/no	no	no
8	Power consumption	STB	5	W	<2000	1200
9	Total weight	STB	4	kg	<20	10
10	Operating noise level	STB	3	dB	<70	60
11	Maintenance manual		4	yes/no	yes	yes
12	Cleaning time	STB	4	min	<20	10

*GTB = Greater The Best
*STB = Smaller The Best

4. Conceptual design

The general function of a microwave pasteurization installation (MPI) is to heat food/liquids to a temperature where they no longer present a danger to human health due to the elimination or inactivation of microorganisms, bacteria and viruses from the chemical composition through the process of pasteurization.

In table 4.1. general function, component function, main functions and critical functions of MPI are presented.

Table 4.1. MPI functions

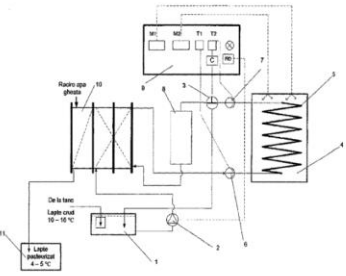
No. crt.	The function type	Function description
1	General function	Inactivation of microorganisms in the composition of food products by microwave pasteurization.
2	Component function	Recovery of energy accumulated from microwaves during pasteurization to be used to preheat the next liquid to be pasteurized.
3	Main function	a. Introduction of the food/liquid for pasteurization b. Introduction of microwaves for pasteurization c. Carrying out the pasteurization process of the products d. Collection of pasteurized food/liquids
4	Critical function	The introduction of microwaves for pasteurization, the heating time and the temperature from which the process starts; Realization of the food/liquid pasteurization process

4.1. External research to identify new constructive solutions

In order to be able to identify new constructive solutions, we have analyzed several invention patents on this topic.The main patents we have studied are the following:

- *Process and installation for thermal processing of milk– No. patentt RO 125073 B1*[3]

  The invention refers to an installation for carrying out the process of thermal processing of milk the help of microwave energy with a frequency of 2450MHz, characterized by the fact that it includes a peristaltic pump (2), necessary for the circulation of milk through the double-circuit heat exchanger (10), which preheats the milk, in order to pasteurize, by passing through the spiral (5) found in the microwave enclosure (4), a heat-insulating holding vessel (8) two temperature transducers(6,7), a control panel of control (9), a recirculation head (3), controlled by a switch (C), through the temperature transducer (7), a flow regulator (RD) in the panel (9) to ensure the variation of the milk flow until reaching and maintaining the pasteurization temperature, circuit elements and connections, a raw milk supply vessel (1) and a pasteurized milk storage vessel.[3]



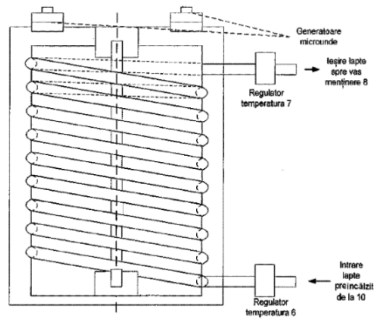


Fig. 3 General diagram of the pasteurization installation, according to the invention[3]

Fig.4 Scheme of the spiral through which the milk circulates in the microwave enclosure, according to the invention[3]

- *Method and apparatus for microwave processing of planar materials – No. patent US 6546646 B1*[13]

This invention relates to a process and apparatus for removing moisture from a material without substantially spoiling the material. Described herein are a process of and apparatus for microwave irradiation heating, drying, dehydration, curing, disinfection, pasteurization, sterilization or vaporization of any one or any combination of one or more of these processes in the processing of materials which are typically in planar form or able to be arranged so as to be in planar form.[13]

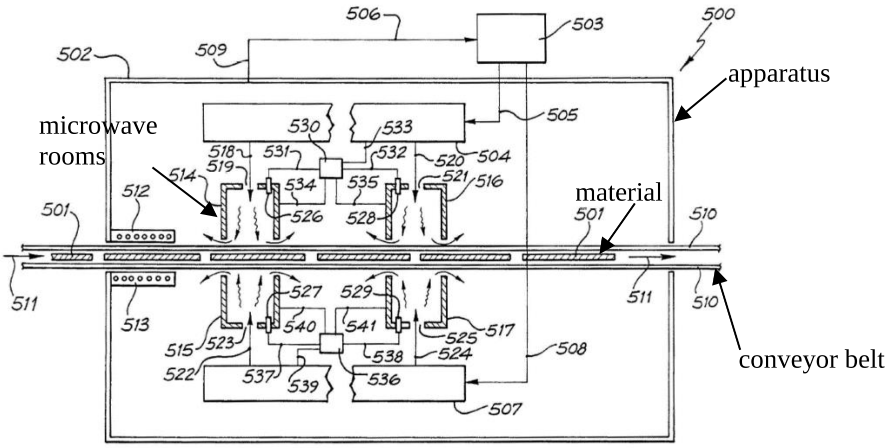


Fig. 5 Apparatus for removing moisture from a material[13]

- *Post package pasteurization for meat products – No. patent US 2007/0065551 A1*[14]

A technique for treating packaged solid meat products by applying microwave energy at an elevated operating frequency such as 2450MHz.This frequency is sufficiently high such that energy penetration depth is limited, and thus it only causes rapid heating of the outer surface of the product.The result is thus much like searing in which the meat product is only heated to minimum depth. Because the exterior surface of the meat is heated only to a minimum depth, the interior surface of the meat product retains its desired doneness, color and texture. Only minimal cooling efforts need to be taken afterwards.[14]

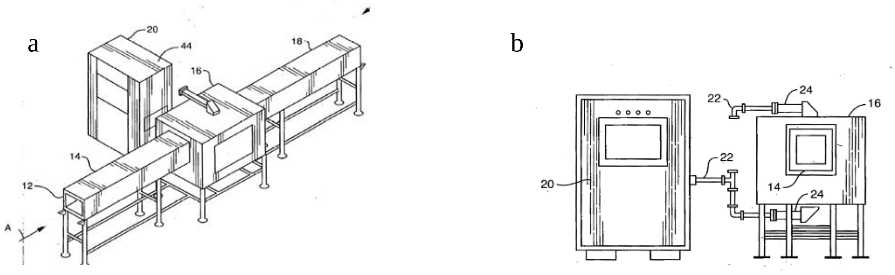


Fig. 6 Isometric views of a packaged meat pasteurization system constructed and operating in accordance with the invention[14]

- *Microwave sterilization or pasteurization transport carriers – No. patent US 10681923 B2*[15]
- *Microwave-assisted sterilization and pasteurization system using synergistic packaging, carrier and laucher configurations – No. patent US 10966293 B2*[17]

4.2. Constructive solutions

The constructive solutions that have been identified are presented in table 4.2.

Table 4.2. Constructive solutions

No. crt.	The constructive solution	Execution
1	Modular and flexible design	Use of standardized modules
2	Efficient microwave distribution system	Using antennas or cavities with optimized design
3	Precise control of temperature and processing time	Using temperature sensors and an advanced control algorithm
4	Safety systems and quality monitoring	Safety systems that monitor critical parameters (temperature, frequency)
5	Energetic efficiency	Use of insulating materials to reduce heat loss
6	Automation and digital control	Implementation of automation and digital control systems
7	Easy cleaning and maintenance	Use of corrosion-resistant materials and ease of access to components for maintenance and repair

4.3. Block diagram of the microwave pasteurization installation

The block diagram of the microwave pasteurization installation is represented in figure 8.

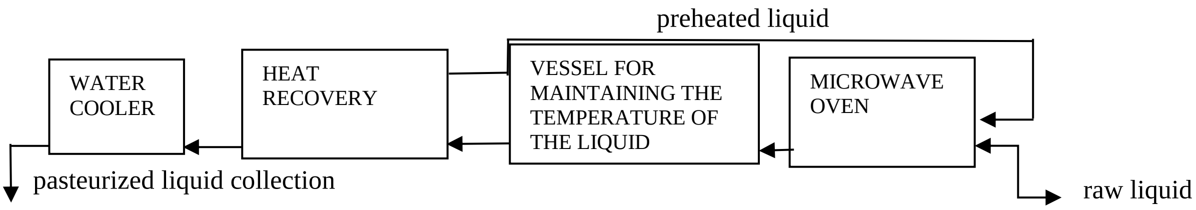


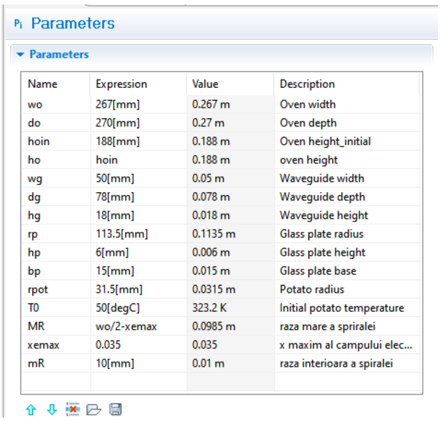
Fig.8 MPI Block diagram

4.4. Modeling-simulation of the microwave pasteurization installation

In order for this MPI to be physically realized, a simple modeling and simulation (finite element method) was carried out in the Comsol Multiphyisics 4.2. program. From this modeling-simulation it emerged that the MPI can be physically realized as it will meet the required conditions.

The numerical simulation of the microwave pasteurization process was carried out for the food liquid – milk. The steps of the numerical simulation were as follows:

1. Choosing the calculation module– Microwave Heating Frequency-Transient;
2. Parameterization of the model presented in figure 9;



Parameters

Name	Expression	Value	Description
wo	267[mm]	0.267 m	Oven width
do	270[mm]	0.27 m	Oven depth
hoin	188[mm]	0.188 m	Oven height_initial
ho	hoin	0.188 m	oven height
wg	50[mm]	0.05 m	Waveguide width
dg	78[mm]	0.078 m	Waveguide depth
hg	18[mm]	0.018 m	Waveguide height
rp	113.5[mm]	0.1135 m	Glass plate radius
hp	6[mm]	0.006 m	Glass plate height
bp	15[mm]	0.015 m	Glass plate base
rpot	31.5[mm]	0.0315 m	Potato radius
T0	50[degC]	323.2 K	Initial potato temperature
MR	wo/2-xemax	0.0985 m	raza mare a spriralei
xemax	0.035	0.035	x maxim al campului elec...
mR	10[mm]	0.01 m	raza interioara a spiralei

Fig.9 Parameterization of the model[16]

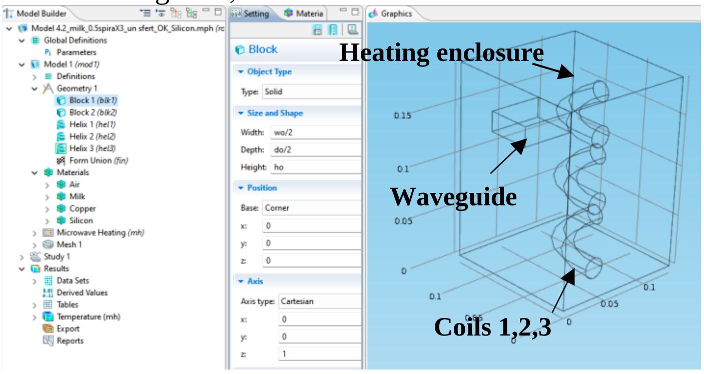


Fig.10 Creating geometry[16]

3. Geometry of the model – the microwave heating enclosure will be made. It is composed of the following elements: the heating enclosure, the waveguide and the 3 coils, shown in figure 10.

4. Allocation of materials for the furnace, waveguide and coils 1,2,3 as follows: air for the interior of the furnace and the waveguide, milk for the walls of the furnace and silicon for the walls of the coils.These materials have properties specific to the chosen calculation model.

5. Boundary conditions – these refer to the initial milk temperature T0=50[°C], the condition of electromagnetic wave propagation without the usual heat transfer inside the oven, the wave emission port, the impedance condition, the conductor condition perfectly magnetic. Some of these conditions are represented in figures 11,12,13,14 and 15.

6. Discretization of the model – for discretization, free tetrahedral elements with fine discretization are used inside the heated material, figure 16.

7. Running the model and evaluating the results – the maximum value of the electric field intensity in a cross section along the Oz axis close to the section made to simplify the geometry is 14196 V/m for milk. The maximum, respectively minimum value of the temperature on the surface of the coils is 72,417[°C], respectively 50,005[°C]. The obtained results are presented in figures 17, 18, 19.[16]

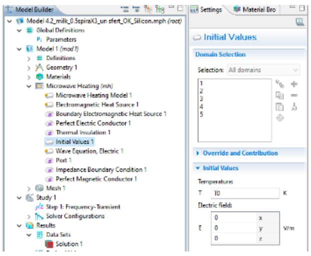


Fig. 11 Setting the initial temperature[16]

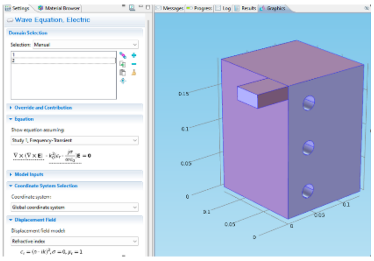


Fig.12 The condition of propagation of electromagnetic waves[16]

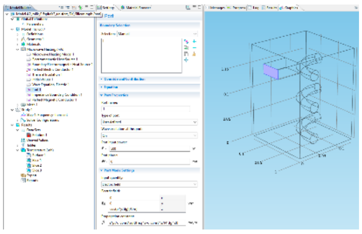


Fig. 13 Wave emitting port[16]

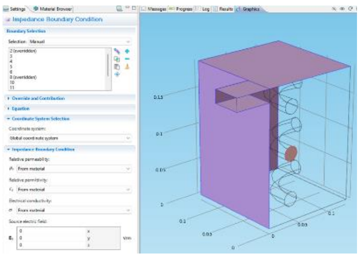


Fig. 14 The impedance condition[16]

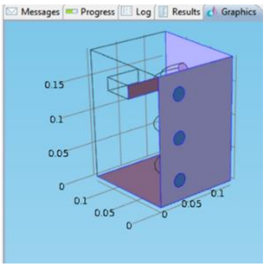


Fig. 15 The condition of a perfect magnetic conductor[16]

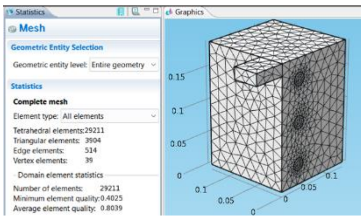


Fig. 16 Discretization, statistics

and model quality[16]

Time	Temperature (degC)
0	50.0065
1	54.4263
2	58.5033
3	62.2854
4	65.8263
5	69.2192
6	72.457

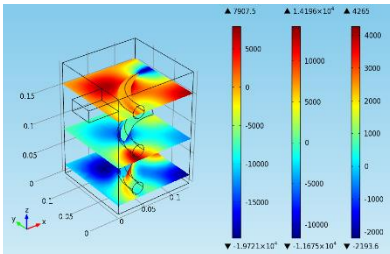


Fig. 17 Field distribution electrical and its values in milk [16]

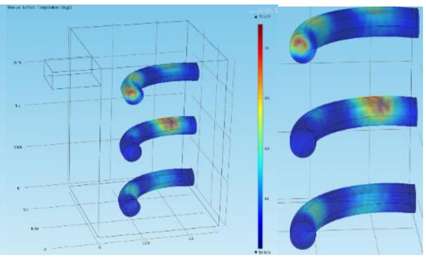


Fig. 18 Temperature distribution (milk pasteurization) after a 6s exposure, isometric view[16]

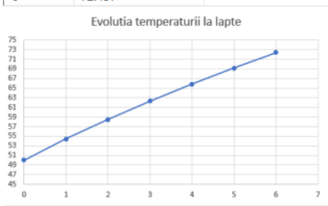


Fig. 19 Maximum temperatures at different time periods[16]

5. Detailed design

In this chapter, the microwave pasteurization system will be presented at the conceptual level. This is shown in Figure 20.

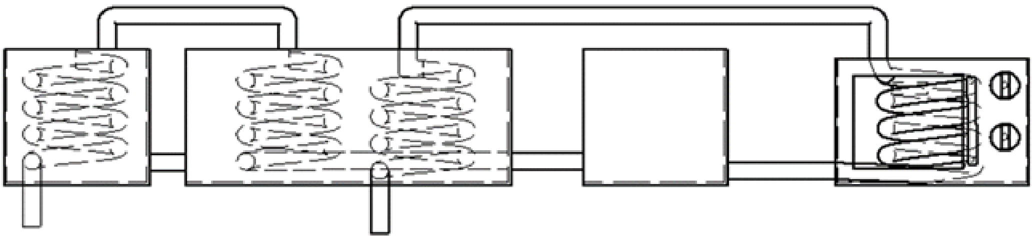


Fig. 20 Microwave pasteurization system at the conceptual level

Figure 21 shows the assembly of the microwave pasteurization system. It also describes the pasteurization process of liquids, specifically for the food liquid – milk.

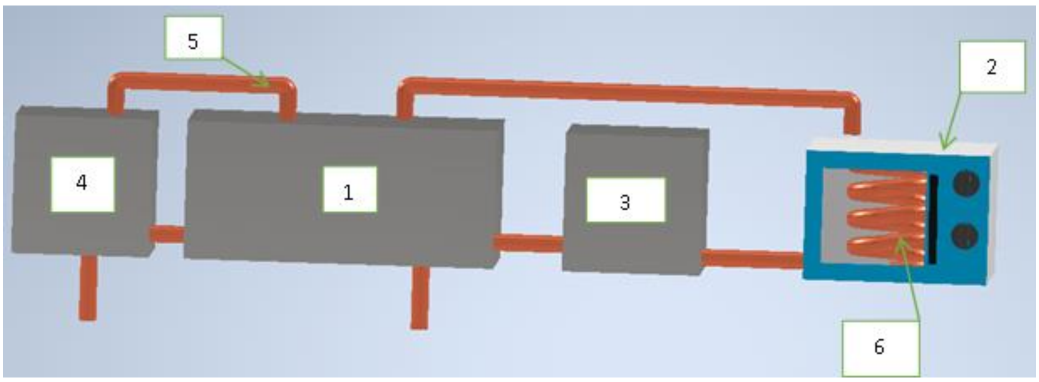


Fig. 21 The assembly of the microwave pasteurization system

Process description: The raw milk is preheated as it ascends in the heat exchanger (1) with the help of a pump. The preheated milk then enters the microwave oven chamber (2) and is subsequently transferred to the holding tank (3). Once in the holding tank, the milk re-enters the heat exchanger (1) and is then transported to the cooling tank (4), thus being prepared for collection as pasteurized milk. This entire milk circuit is carried out using a network of pipes (5) that facilitate the preservation of the transported liquid's properties. The coils (6) through which the liquid passes help to keep the milk in the microwave chamber for the necessary duration to complete the pasteurization process.

6. Conclusions

The contributions of the work consist of the following elements regarding the addressed research topic: identification of market opportunities related to needs, grouping of customers by category, development of a questionnaire to identify needs on the market; establishment of product specifications with the help of the matrix of competing products, sizes-requirements on the basis of which set objective specifications; conceptual design elements, general, component, main and critical function were developed, an external research was carried out analyzing a series of patents, some constructive solutions were developed, a block diagram of the plant based on the results of finite element modeling of the process for heating some liquids from the food industry (milk and apple juice); a preliminary model of the microwave pasteurization installation was designed.

7. Bibliography

[1]. Constantin, A. M. and Csaltos, C. (2011), "Research on the Use of Microwaves for Antibacterial Treatment of Milk", Brașov.

[2]. Tajchakavit, S. (1997), "Microwave Heating of Fruit Juices: Kinetics of Enzyme Inactivation/Microbial Destruction and Evaluation of Enhanced Thermal Effects", Vol. 1, pp. 86-110, ISSN 0-612-44605-0.

[3]. ICPE S.A., Ica Research & Development S.R.L., et al. Process and Installation for Thermal Processing of Milk, Romania, RO-1250731-B1, 2010.

[4]. Gavrilut, Cristina, Alternative Methods of Milk Treatment: Journal of Meat and Dairy Industries Specialists. Available at: https://www.meat-milk.ro/tetra-pak-metode-alternative-de-tratare-laptelui/ (Accessed: May 2, 2023).

[5]. Ghiculescu, L.D., Ionescu, N., Creativity and Intellectual Property, Moodle Platform, Bucharest, 2024. Available at: https://curs.upb.ro/2023/my/courses.php (Accessed: April 15, 2024).

[6]. *** https://forms.gle/WcrmWbww3d1prfDX9 (Accessed: April 23, 2024).

[7]. *** Myria Microwave Oven MM720W, Available at: http://myria.ro/ro/cuptoare-cu-microunde/1095/cuptor-cu-microunde-myria-mm720w-700w-20l-alb.html (Accessed: March 20, 2024).

[8]. *** Microwave Oven User Manual MGB25332BG, Available at: https://www.beko.ro/cuptor-cu-microunde-mgb25332bg (Accessed: March 20, 2024).

[9]. *** Microwave Oven User Manual Sencor SMW 6021, Available at: http://www.sencor.ro/cuptor-microunde/smw-6021 (Accessed: March 20, 2024).

[10]. *** Microwave Oven User Manual MOC201102W, Available at: https://www.beko.ro/cuptor-cu-microunde-beko-moc201102w (Accessed: March 20, 2024).

[11]. *** 6kW Liquid Heating Microwave System, Available at: https://industrialmicrowave.com/microwave-systems-liquids-fluids-heating/6kw-microwave-system/ (Accessed: March 20, 2024).

[12]. *** 915MHz Liquid Heating Industrial Microwave System Brochure, Available at: https://industrialmicrowave.com/resources/915-mhz-liquid-heating/ (Accessed: March 20, 2024).

[13]. Thomas, S. D., Method and Apparatus for Microwave Processing of Flat Materials, United States, US-6546646 B1, 2003.

[14]. Alton, W. J., Post-Packaging Pasteurization for Meat Products, United States, US-2007/0065551 A1, 2007.

[15]. Tang, J., Liu, F., Transport Supports for Microwave Sterilization or Pasteurization, United States, US-10681923 B2, 2020.

[16]. Alexa, L.V., Unguroiu, M.M., Numerical Simulation of the Microwave Pasteurization Process, Scientific Session May 2023, Faculty of Industrial Engineering and Robotics.

[17]. Raider, M., Behringer, D., et al., Microwave-Assisted Sterilization and Pasteurization System Using Synergistic Packaging, Carrier, and Launcher Configurations, United States, US-10966293 B2, 2021.

EQUIPMENT FOR HYBRID EDM-ECM+US TECHNOLOGY

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ABSTRACT: This paper presents the concept of equipment for hybrid technology of electrical discharge machining (EDM) and electrochemical machining (ECM) in an ultrasonic field (US). For this purpose, an analysis of competing products was conducted with a role in the conceptual design and detailed design of the equipment. Potential buyers were identified and an economic analysis model was approached.

KEYWORDS: Hybrid technology, EDM, ECM, US.

1. Introduction

Considering the advantages brought by unconventional technologies, they are increasingly encountered in the industry. Electrical discharge machining (EDM), wire electrical discharge machining (WEDM), and electrochemical machining (ECM) are applied for processing conductive materials with high hardness, non-corrosive, and wear-resistant properties [1,2]. EDM and WEDM belong to the category of thermal erosive processes, where the material is removed by melting, vaporizing, and boiling, phenomena that occur due to electrical discharges between the electrode and the workpiece. The melted material is evacuated from the processing gap by the circulation of the dielectric fluid. The disadvantage of these processes is low productivity [1].

Electrochemical machining is carried out through controlled removal of electrically conductive material from a workpiece by anodic dissolution in an electrolytic cell, with the workpiece being the anode and the tool the cathode. The disadvantage of ECM is the difficulty in controlling the precision of the machined [3].

The introduction of ultrasonic vibrations with a frequency greater than 20 KHz into the EDM, WEDM, and ECM processes brings numerous advantages, such as increased productivity, relatively reduced volumetric wear, improved machined surface quality, and dimensional accuracy—parameters that are very important in machine construction. In electrical discharge machining, ultrasonic vibrations enhance process performance by breaking the gas bubble that impedes the circulation of the dielectric fluid to the melted material. In the case of inducing ultrasonic vibrations in ECM, there is an intensification of electrochemical processes, increasing the rate of electrochemical dissolution [3].

The purpose of this paper is to develop hybrid EDM-WEDM-ECM + US machining equipment, consisting of subsystems with different machining mechanisms, assisted by the induction of ultrasonic vibrations.

2. **Competitive Product Analysis**

Currently, there is no simultaneous EDM-WEDM-ECM-US machining equipment available, but separate machines for each individual process can be considered as competitive products (Figures 1, 2, 3). The specifications of the analyzed machines are presented in Table 1.

Fig. 1 Solid Electrode Electrical Discharge Machine (EDM) CNC-D2535 [4]

Fig. 2 CNC Wire Electrical Discharge Machine (WEDM) Wi-430S [4]

Fig. 3 Electrochemical Machining (ECM) Machine HO-ECDM-01 [5]

Table 1. Machine Specifications

Machine Specifications:		
-Machine Dimensions: 1620x1140x2325 mm -Machine Weight: 1000 kg -Table Dimensions: 600x300 mm -Maximum Workpiece Weight: 300 kg -Machining Diameter Range: 0.1-6 mm -X/Y Axis Travel: 345x245 mm -Z1/Z2 Axis Travel: 400x300 mm -Maximum Drilling Speed: 60 mm²/min -Maximum Power Consumption: 3.5 KVA -Maximum Discharge Current: 30A -Orientation: 8 axes	-Machine Dimensions: 3100x2200x2150 mm -Machine Weight: 2100 kg -Table Dimensions: 640x500 mm -Liquid Reservoir Capacity: 570 liters -Maximum Workpiece Weight: 500 kg -Wire Diameter Range: 0.1-0.3 mm -Maximum Taper Angle: 22.5º -Maximum Workpiece -Thickness: 100 mm -X/Y Axis Travel: 400x300 mm -Z Axis Travel: 300 mm -U/V Axis Travel: 100x100 mm -Working Axes: X/Y/U/V – 4 axes	-Table Dimensions: 450x450 mm -X/Y/Z Axis Travel: 100x100x100 mm -Resolution: 1 µm per axis -Positioning Accuracy: 5 µm per axis -Speed: 0.1-8 mm/s on all axes -Rotation Speed: 10-2000 rpm -Output Voltage: 0-300 V

3. Conceptual Design of a Hybrid Machining Equipment EDM+US, WEDM+US și ECM+US, EDM-ECM+US

3.1. Defining general function

A machining equipment combining solid electrode electrical discharge machining in an ultrasonic field (EDM+US), electrochemical machining in an ultrasonic field (ECM+US), and wire electrical discharge machining in an ultrasonic field (WEDM+US) has the general function of processing materials using both the phenomena of traditional EDM, ECM, and WEDM processes in combination with ultrasonic vibration, which causes the removal of gas bubbles, resulting in high productivity of the machining process and, simultaneously, superior quality of the machined surface.

3.2 Highlighting Critical Issues

There are several conditions for optimizing working parameters to achieve certain technological performances. [6]

(1) Condition of stability for EDM and ECM processes:

$$A_y < s_F \quad [\mu m] \qquad (1)$$

where: Ay is the maximum amplitude of longitudinal oscillations with ultrasonic frequency of the tool [µm]; sF is the size of the frontal gap [µm].

If this condition is not met, short-circuit phenomena may occur during the EDM process, affecting the quality of the machined surface. These short circuits can lead to increased relative volumetric wear and decreased processing efficiency due to the retraction and approach movements of the working head in response to the electroerosive feed system.

(2) Maximization condition of the frontal gap size (smax):

By increasing the breakdown voltage (uo) in the electroerosion process, the possibility of generating discharges in a larger frontal gap is extended. This measure improves the conditions for evacuating processed particles.

(3) Minimization condition of discharge energy:

In finishing EDM regimes, it is necessary to process with minimum values of impulse energy (We).

(4) Maximization condition of the number of controlled impulses (nic) in an oscillation period (Tus):

At the end of an ultrasonic oscillation period, the phase of cumulative microjets appears, generated by the simultaneous implosion of gas bubbles formed in the EDM machining gap. In this phase, the pressures become extremely high, and the direction of the microjets is oriented parallel to the machined frontal surface.

(5) Cavitation condition:

The power consumed by the ultrasonic chain drive (PcUS) must be large enough to generate the acoustic pressure (pac) required to exceed the cavitation threshold in the dielectric fluid used. However, in the EDM finishing process, the main objective is to minimize the roughness of the machined surface

(6) Minimization condition of the acoustic chain drive power:

To reduce the roughness of the machined surface, the aim is to minimize the cumulative microjet pressure and, implicitly, the acoustic pressure (pac), simultaneously with achieving the cavitation condition. In the absence of this balance, there is a risk of deteriorating the quality of the machined surface.

(7) Resonance condition:

This condition requires that the natural frequency of the acoustic chain (f0) during equipment operation be within the ultrasonic frequency range (fUS) provided by the US generator. Also, to achieve this condition, it is necessary for the natural frequency of the transducer to be equal to that of the rest of the acoustic chain.

(8) Reduction condition of the electrode-tool wear:

This requirement necessitates the use of controlled impulses with a long duration (ti) in the stretching semi-period. Discharges with a long duration also facilitate the deposition of the carbon layer on the frontal surface of the electrode-tool. This resistant layer is the result of the decomposition of dielectric liquid molecules containing carbon.

3.3 Highlighting Applicable Natural Phenomena

a) Applicable natural phenomena for (W)EDM+US

The pressure in the gas bubbles, developed around the plasma channel produced by the discharge, limits the cross-sectional area of the plasma channel, influencing the density (J) inside it. The dynamics of the gas bubbles comprise four stages: (a) very high pressure (pib) in the gas bubbles, (b) gradual decrease in pib pressure due to the increase in the bubble's volume; (c) sudden drop in internal pressure; (d) sharp increase in internal pressure. [7]

The analysis of the four stages leads to corresponding phases of relative volumetric wear dynamics, taking into account the effect of polarity.

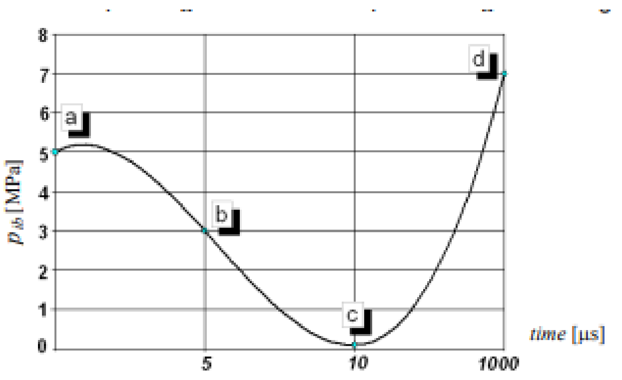

Fig. 4 The variation of pressure inside the gas bubble for a pulse time of 10 µs, EDM finishing. [7]

The deposition of carbon, in the form of a surface layer on the tool electrode when using a dielectric liquid composed of hydrocarbons with a high carbon content, is a well-known phenomenon. Considering the very high melting point of this deposited material, it is necessary to analyze this phenomenon closely in relation to tool wear. The total wear in this region is lower at the beginning of the machining process and gradually increases to a value that depends on the machining conditions and material.

Experimentally, in finishing/superfinishing modes with a processing time of 10-15 minutes, very low volumetric wear, even negative, is observed.

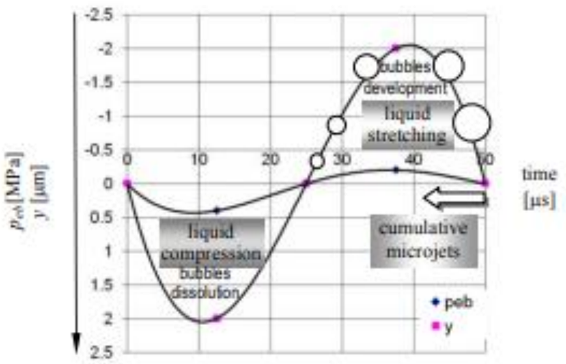

Fig. 5 Phenomena of ultrasonically induced cavitation in EDM+US. [7]

The oscillation period, TUS, in EDM assisted by longitudinal vibrations (normal to the machined surface) of the tool electrode comprises two half-periods with distinctive cavitation phenomena, which influence electrode wear (Fig. 5).

n the first half-period, lasting from 0 to 25 µs (at the frequency of 20 kHz), the dielectric liquid in the working frontal gap is compressed, leading to the occurrence of capillary phenomena.

b) Natural Phenomena Applicable to ECM+US

In conventional ECM, the variation of the working gap dx/dt is determined at each moment by the difference between two velocities - the tool electrode's feed rate (s) and the machining velocity (vp) - as a result of the anodic dissolution process.

The working gap is sensitive to the type of liquid in which the processing takes place and the material being processed, as well as the potential difference between them. Generally, the potential difference (ΔU) is less than 24 V when using liquids with good conductivity, resulting in an average current density (J) of less than 1A/cm2 at the end of the process. The ECM deburring process is a type of static machining, based on the assumptions of Tipton's model: the conductivity of the working liquid remains constant along the OX direction; the conductivity of the tool electrode and the workpiece is much higher than that of the liquid, so the electrodes are considered at the same electrical potential; phenomena comply with Ohm's law; assembly properties are maintained uniformly along the OZ direction for each unit of distance (dz = 1).

The main improvement brought by electrochemical machining in an ultrasonic field (ECM+US) is that the vibrations of the tool electrode, transmitted into the electrolytic liquid, prevent the formation of a passive layer on the surface of the workpiece, leading to an increase in material removal rate..

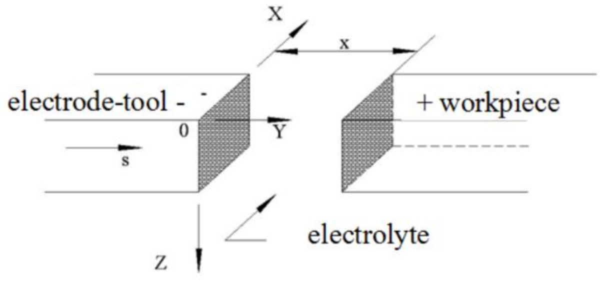

Fig. 6 Tipton Model[7]

Ultrasonic frequencies can also induce cavitation phenomena in the electrolytic liquid, exceeding the required pressure limit for this.

vibrations can also cause the pumping effect, as the volume of electrolyte is incompressible; the tool electrode squeezes the electrolyte while vibrating up and down in the machining space. The electrolyte is sucked and discharged from the machining space. [8]

c) Simultaneous EDM-ECM+US processing

In addition to classical ECM processing at lower voltages below 24 V, there is also the possibility of processing at higher voltages exceeding 80V, which offers the advantage of using low-concentration, inexpensive, environmentally friendly, easily manipulable and prepared electrolyte solutions such as NaCl solution.

The processing mechanism is characterized by the presence of a stable envelope of vapors and gases on the surface of the workpiece, which separates the workpiece from the electrolyte and leads to intense chemical and electrochemical reactions between the workpiece material (anode) and the electrolyte vapors - the Wien effect. Faraday's laws of electrolysis, specific to classical ECM processing, are no longer followed.

4. Detailed design of a processing equipment for EDM+US, ECM+US, and WEDM+US;

In Figure 7, the preliminary model of the processing equipment for EDM+US, ECM+US, and WEDM+US is presented..

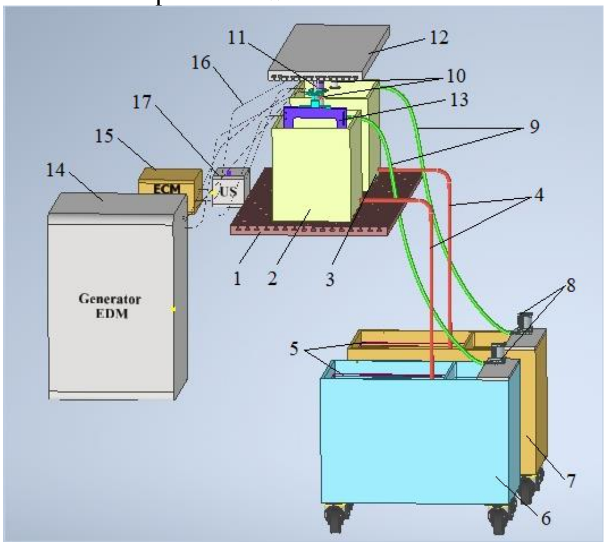

Fig. 7 Hybrid technology equipment assembly (W)EDM-ECM+US

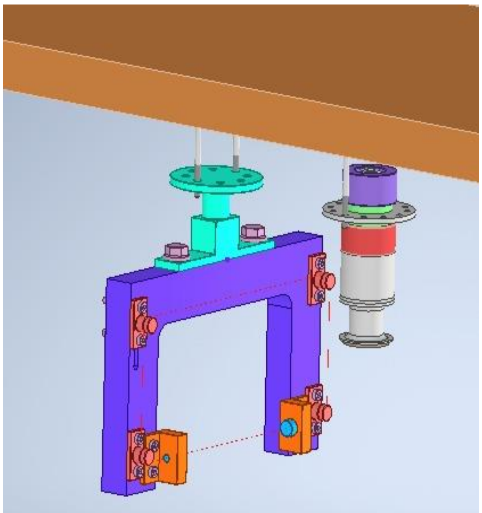

Fig. 8 Subassembly WEDM+US

On the machine table 1, equipped with T channels, the tank with dielectric fluid 2 for EDM+US and WEDM+US processing and the tank with electrolytic fluid 3 for ECM+US processing are fixed. The dielectric fluid used has lower viscosity, suitable for WEDM. The filtration of the processing fluid from the two tanks is performed continuously by evacuating the fluid with particles through the tubes 4, being filtered through the two sieves 5, one equipped with 0.2 mm holes and the other with 0.02 mm holes. For finishing and superfinishing processes, a third filtration with higher fineness 0.002 can be added. The filtered fluid is transported from the mobile tanks 6 and 7 with the help of pumps 8 through the tubes 9 back into the working tanks.

The processing is carried out in an ultrasonic field through the ultrasonic chain 10 consisting of a reflecting bushing, piezoceramic plates, nodal flange, radiant bushing, assembled by a hexagonal screw, concentrator, at the end of which the copper electrode is located. The US chain is attached to the working head of the EDM machine by the threaded rods 11, which slide on the T-channel plate 12.

The EDM generator 14 provides voltage pulses, which produce successive discharges (current pulses), the ECM generator (DC power supply), the US generator, which provides voltage oscillations exceeding 1000V with US frequency >20000Hz.

Additionally, the wire cutting equipment 13 can be observed in Figure 8.

5. Commercialization of the product

Among the main reasons why EDM technology is increasingly used in various industries are: high precision (in the order of microns), the ability to process hard materials, flexibility in creating complex shapes, reduction of stress and material deformations, and excellent surface finishing. As such, the main industries using EDM processing include: mold manufacturing industry, automotive industry, aerospace industry, medical industry, and electronics industry. EDM processing can be easily introduced into these sectors and beyond, and the buyer market is focused on the Bucharest area and its surroundings. [10].

Companies in the aerospace industry use EDM machines to produce critical aircraft components such as turbine blades, engine components, and landing gear parts. Potential buyers in this sector include: Romaero, Turbomecanica, INCAS, Avionics Services, IMAS Aero-Technologies, Honeywell Aerospace Romania..

Several concrete examples of engine components used in the aerospace industry can be seen in Figure 9. In the figure, turbine blades 1, bearing housing 2, compressor 3, compressor casings 4, diffuser 5, combustion chamber 6, nozzle guide vanes (NGV) 7, thermal shields 8, exhaust housing 9, sealing segments 10, turbine discs 11, compressor blades 12, and gears 13 can be observed..

Fig. 9 Componente produse prin EDM, ECM [11]

In the automotive industry, EDM technology is particularly used for components such as: engine blocks, transmission parts, interior components, some bodywork components, as well as interior and exterior parts with intricate details. Among the potential buyers in the automotive sector are: Dacia (Renault Group), Faurecia Romania, Star Assembly SRL, Garrett Motion.

In the mold industry, EDM technology is an advanced processing method used for manufacturing molds and forms required in industrial production processes. Companies in Bucharest specialized in molds that use EDM as a manufacturing process include: Tera Plastics & Electronic, Metalica Expert, VDA Hard-Metal S.R.L.

In the medical field, EDM machines are used for the precise manufacturing of various components of medical equipment, implants, and surgical devices. For example, they are used for producing prosthetic components, dental implants, and surgical instruments.

In the electronic field, EDM machines are utilized for manufacturing various components such as templates and molds for producing printed circuit boards (PCBs). The EDM process allows for the creation of precise details and fine holes required in electronic component production. Among the electronic companies using EDM are: Siemens Romania, Dell EMC Romania, ICPE (Electrotechnical Research and Design Institute).

Product placement will be done only on a order basis, depending on the buyer's needs. The request for quotation will be placed directly with the manufacturer, and the offer will be made according to the customer's needs. In this way, the buyer has access to three types of electroerosion processing: EDM, WEDM, ECM.

6. Economic analysis

6.1 Development of a product cost model

In the specialized literature [12,13], there are several methods for cost calculation (global method, standard-cost method, direct-cost method, Georges Perrin method - Rate - hour - THM machine, Activity Based Costing method, etc.). For determining the cost of the hybrid EDM-ECM-US system, considering factors such as the structure of the hybrid EDM-ECM-US system and its production in small series, or even as a unique unit, a mixed method has been chosen for calculating the manufacturing cost of the hybrid EDM-ECM-US system as follows: in relation to the activities necessary for manufacturing the three subsystems, the Activity Based Costing (ABC) method was chosen, which is based on determining the cost of each group of activities [14], and for determining the cost of each subsystem, the direct-cost method was chosen, which is based on determining the cost components (materials, labor, overhead expenses, depreciation, etc.). Thus, the total production cost (CT) of the hybrid EDM-ECM-US system can be determined by the following relationship:

$$C_T = C_{EDM} + C_{ECM} + C_{US} \quad (2)$$

Where C_T = Total cost of the hibrid technology EDM-ECM-US, C_{EDM} = The cost of the electroerosion subsystem, C_{ECM} = The cost of the electrochemical processing subsystem şi C_{US} = The cost of the ultrasonic subsystem

6.2 Determining the price and profit using non-cooperative game theory

To determine the final selling price under competitive conditions, the Non-Cooperative Game Theory can be applied, as outlined in [15]. This theory can be employed when the profits of each economic agent, considered as players in the market, depend not only on their own actions but also on the actions of other competing firms (players). This theory assumes that players are rational, attempting to maximize their profits using their own interpretations of how other players (firms) will act. The outcome of the game will ultimately depend on the actions of all players. Given the type of product and the main competitors, it is reasonable to consider applying the non-cooperative game theory under oligopoly conditions, where there is a relatively small number of firms, and none of them can prevent others from having a significant influence on the market. The goal is to determine the best response of our firm based on the Cournot-Nash equilibrium theory [15]. The Cournot-Nash model has the following basic characteristics [15]:

1. Context: a. Market served by n company; b. Homogeneous products - from the consumers' point of view, the goods produced by all firms are perfect substitutes; c. Competition through quantity; d. Simultaneous choice - the n firms must choose their outputs simultaneously, without knowing the choices of competitors.

2. ***The normal form of the game:*** $i = 1, 2,..., n$ (Company); Output-ul of every company $x_i \geq 0$, like $x_i \in [0, \infty)$, $i = 1,2,...,., n$; Profit of company i (our) corresponding to the combination of strategies (x_i, x_{-i}) is:

$$\Pi_i(x_i, x_{-i}) = p(x_i + x_{-i}) \cdot x_i - C_i(x_i) \quad (3)$$

where $\Pi_i(x_i, x_{-i})$ is profit of our company, p – price, $C_i(x_i) = d + c \cdot x_i$, d – fixed costs, c – variable costs.

Given the strategy profile (x_1, x_2, …, x_n) which can also be written as (x_i, x_{-i}), we said that $\Pi_i(x_i, x_{-i})$ is the profit of our company associated with any combination of strategies in which our company produces x_i systems while other firms together produce x_{-i}, systems, with the total x_{-i} distribution among the other *n–1* company. In Cournot oligopoly games, it is said (Aguirre, 2021) that $\left(x_{1,}^{*} x_{2,}^{*} \dots, x_{n}^{*}\right) \equiv (x_{i,}^{*} x_{-i}^{*})$ is a Cournout-Nash equilibrium if $x_i^* = f_i(x_{-i}^*)$, $(\forall)i,\ i = 1, 2, \dots, n$, where $f(x_{-i}^*)$ is the best response function to all combinations and strategies of the other company that have the total output .l x_{-i}. To estimate the profit, it is necessary to establish the inverse demand function according to the relationship (Aguirre, 2021) $p(x) = a - b \cdot x$, where p s the price of the product and x is the number of units. Thus, relationship (2) becomes:

$$\Pi_i(x_i, x_{-i}) = [a - b \cdot (x_i + x_{-i})] \cdot x_i - (d + c \cdot x_i) \tag{4}$$

Based on equation (2), the issue of profit maximization arises, namely

$$\frac{\partial \Pi_i\,(x_i, x_{-i})}{\partial x_i} = a - c - 2b\, x_i - b\, x_{-i} = 0 \tag{5}$$

Based on the Cournot-Nash equilibrium condition, it follows

$$x_i = f_i(x_{-i}) = \frac{a - c - bx_{-i}}{2b} \tag{6}$$

In a symmetric equilibrium $x_i^* = \overline{x^*}$ şi $x_{-i}^* = (n-1)\overline{x^*},\ i = 1, 2, \dots, n$, thus, the equilibrium condition becomes

$$\overline{x^*} = f_i((n-1)\overline{x^*}) = \frac{a - c - b(n-1)\overline{x^*}}{2b} \tag{7}$$

Results:

$$x_i^* = \overline{x^*} = \frac{a-b}{b(n+1)}\ \text{buc} \tag{8}$$

Output-ul of total balance will be:

$$x^* = n\overline{x^*} = \frac{n(a-b)}{b(n+1)}\ \text{buc} \tag{9}$$

Using equation (4), the Cournot price is:

$$p^* = p(x^*) = \frac{a+nb}{n+1}\ \text{Euro/buc} \tag{10}$$

The equilibrium profit will be:

$$\Pi_i = \frac{a+nb}{n+1} - c_i\ \text{Euro/buc} \tag{11}$$

Using equation (5) or (9) + (11), the total equilibrium profit for firm i (our company) can be determined:

$$\Pi_i(x_i, x_{-i}) = \frac{a-b}{b(n+1)} \cdot \left[\frac{a+nb}{n+1} - c_i\right] \tag{12}$$

7. Conclusions

The contributions of the work to the researched theme include: the development of a hybrid processing equipment EDM-WEDM-ECM + US, consisting of subsystems with different processing mechanisms.

In this way, competing products with their associated performances were identified, and conceptual design elements of the hybrid technology equipment (both general and secondary functions) were developed.

The natural phenomena applicable to the processes associated with hybrid technology (both successive and simultaneous) were described.

A preliminary version of the hybrid technology equipment was designed, which can be implemented on a classic EDM machine.

Several potential clients from the automotive, aerospace, mold manufacturing, electronics, and medical fields were identified.

For calculating the cost of realization/manufacturing of the EDM-ECM-US hybrid system, the ABC method (Activity Based Costing) was chosen, based on determining the cost of each group of activities, and for determining the cost of each subsystem, the direct cost method was chosen, based on determining cost components (materials, labor, overhead, depreciation, etc.).

To establish the final selling price under competitive conditions (which in most cases may differ from the one previously established), the Non-Cooperative Game Theory can be applied.

8. Bibliography

[1]. Abu Zeid, O.A. (1997). On the effect of electro-discharge machining parameters on the fatigue life of AISI D6 tool steel. J. Mater. Process. Technol., vol. 68, p. 27-32

[2]. Merdan, M.A.E.R., Arnell, R.D. (1991). The surface integrity of a die steel after electro-discharge machining, 2. residual stress distribution. Surf. Eng., vol. 7, p. 154-158

[3]. Balan, A.S.S.; Giridharan, A. "A progress review in wire electrical discharge machining process." Int. J. Autom. Mech. Eng. 2017, 14, 4097–4124

[4] *** Proma , Masini de electroeroziune, Available at https://www.proma.ro/masini-prelucrare-metal/masini-de-electroeroziune.html, accessed at: 09.05.2024

[5] *** Holmarc Available at https://www.holmarc.com/electrochemical_discharge_machining__system.php, accessed at: 09.05.2024

[6]. Ghiculescu, D. (2021), "Computer-assisted engineering and manufacturing in the field of unconventional machining.", Course in Romanian, Production Engineering Dept., University Politehnica from Bucharest, Romania.

[7]. Ghiculescu, D. (2016), "Contributions to Development and Innovation of Ultrasonically Aided Nonconventional Machining", Habilitation Thesis, Production Engineering Dept., University Politehnica from Bucharest, Romania.

[8]. Shen, Z. Y., Tsui, H. P., (2021), "An Investigation of Ultrasonic-Assisted Electrochemical Machining of Micro-Hole Array", Department of Mechanical Engineering, National Central University, Taoyuan 32001, Taiwan.

[9]. Ghiculescu, D. (2021), „Advanced Electrochemical Discharge Machinning Methods", Course in Romanian, Production Engineering Dept., University Politehnica from Bucharest, Romania.

[10]. Elman C. Jameson. (2001). "Electrical Discharge Machining". Edo Society of Manufacturing Engineers Dearborn, Michigan

[11] *** ONA for aeronautics & turbine industries, Available at ONA EDM: EDM Machines for aeronautics and turbine sector, accessed at: 10.05.2024

[12]. Neagu, C., Roşu, M., Mamgiridis, M., Melnic, L., (2008) "Calculation model of production costs for batch-organized manufacturing case, Review of Management and Economic Engineering", Bucharest, Romania.

[13]. Neagu C (2004) "Ingineria si Managementul Sistemelor de Productie", Bren, Bucharest, Romania.

[14].***Bâtcă-Dumitru Corina-Graziella, Sahlian Daniela-Nicoleta , Șendroiu Cleopatra, Managementul performanței - Măsurarea performanței prin metoda Activity Based Costing, 2019, Available at https://www.ceccarbusinessmagazine.ro/masurarea-performantei-prin-metoda-activity-based-costing-i-a5784/, accessed 10.04.2023

[15]. *** Aguirre Iñaki, Notes on Market Power and Strategy, Department of Economic Analysis, University of the Basque Country, 2020 – 2021, Available at https://www.ehu.eus/iaguirre/, accessed 05.09.2024

RESEARCH AND CASE STUDY ON DEVELOPMENT OF SOME DEVICES FOR CNC AND CLASSIC MACHINING TECHNOLOGICAL SYSTEMS

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ABSTRACT: For the realization of technological processing systems, the development of devices represents a main part. In the construction of the orientation and fixing devices, several technical - acceptable solutions can be developed, and it is necessary an economic analysis to select the optimal variant. A very important criterion that is considered in the design process is the reduction, as much as possible, of the deformation of the workpiece under the action of the fixing forces. Modulated devices represent a solution for reducing the time required for the design process. There are presented data and results obtained from the experimental research on the development of a multifunctional device for operations in CNC and classical machining technological systems.

KEYWORDS: multifunctional device, technological operation, CNC technologocal system, conventional technologocal system.

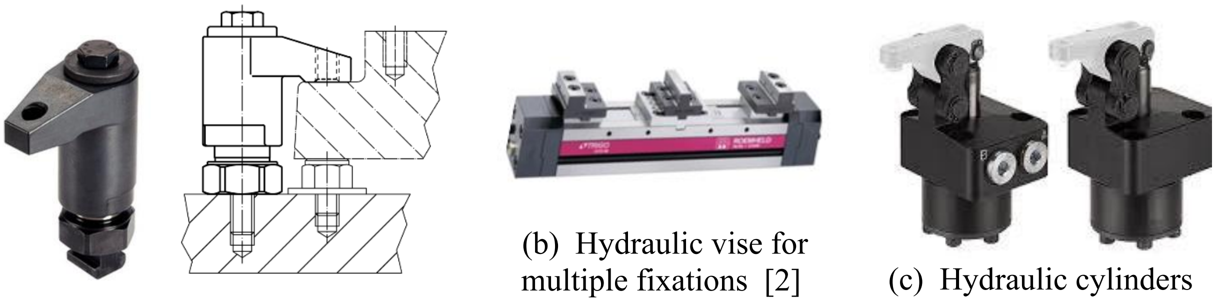
1. Introduction

There are various methods of part orientation and fixing within technological systems, which include mechanical, magnetic, hydraulic or pneumatic actuation. Part characteristics, such as the shape and dimensions of spaces for orientation and fixture elements, tool guides, etc. influence the design of devices. The use of computer-aided design can reduce design costs and time. Computer-aided device design includes algorithms, finite element analysis, etc.

2. General considerations

Devices design and their manufacture is an important part of the preparation process for technological machining, and the costs associated with these are considerable. The geometrical errors of the part, the geometrical errors of the orientation elements and the fixing error are factors that influence the orientation and fixing system of the workpiece [1]. Thus, errors represent the reason why a machined feature is outside the tolerance field.
Constructive characteristics of the parts such as general shape, wall thicknesses, dimensions of the spaces possible for fixing, etc., also represent elements of influence regarding the ways of machining and/or orientation and fixing within the technological systems. It is necessary that the component elements of the devices to be determined by careful analysis of all factors that can influence this process.
Mechanisms with wedge, eccentric, screw-nut, pneumatic motor, hydraulic motor and clamp, plunger, pressure plate or vacuum are just some of the fixing mechanisms in the structure of technological machining systems, and those with jaws, with elastic bush(es), with levers or prisms are for orientation-fixation [1]. From the point of view of the types of technological fixing mechanisms with hydraulic actuation, we mention rotary clamps, hydraulic vises for multiple fixations and cylinders with lever mechanisms.
In the case of medium-volume and medium-variety manufacturing systems, significant production costs are represented by the design and manufacture of various orientation and fixing devices, amounting to up to approximately 20% of the total production costs. An increase in the variety of products which are manufactured in a production

system leads to an increase in the costs of orientation and fixing devices. The modulate orienting and fixing systems can be quickly adjusted and reconfigured to fit a variety of products and components [9].
In the construction of devices, multiple technically acceptable solutions can be developed; however, it is necessary to conduct an economic analysis to choose the optimal variant. The most important criterion considered in the design process of a device is minimizing the deformation of the workpiece under the action of clamping forces.
Clamping of medium and large-sized workpieces within technological systems can be achieved using hydraulically actuated mechanisms (Fig. 1). The hydraulic fixing system is more efficient compared to other fixing systems because it has lower energy consumption and, compared to manual tightening, ensures a constant clamping force on the workpiece and speeds up the fixing process [4]. These mechanisms operate on a relatively simple principle, where hydraulic pressure is first converted into downward force, and through a wedge-plunger mechanism, fixing forces are generated (Fig. 2).



(a) Rotating clamps [2]

(b) Hydraulic vise for multiple fixations [2]

(c) Hydraulic cylinders and lever mechanisms [6]

Fig. 1. Various fixing mechanisms with hydraulic actuation

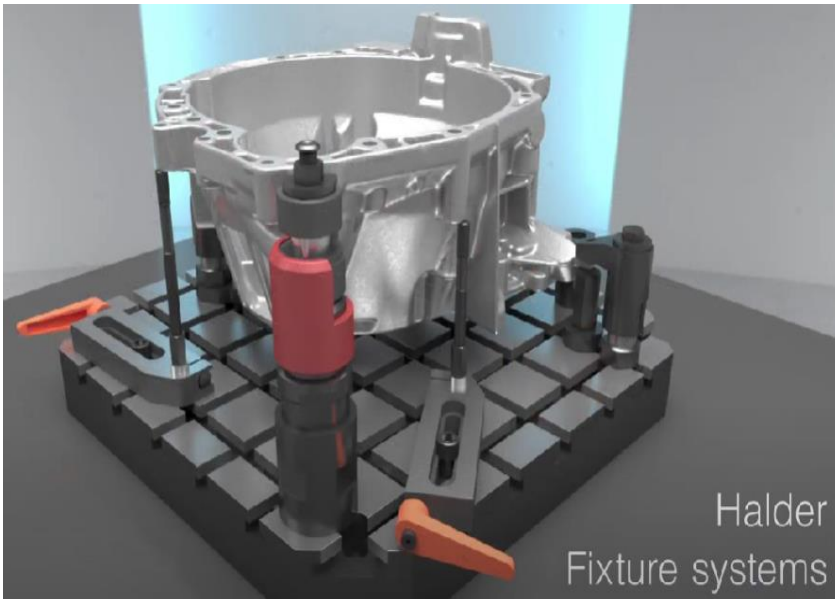
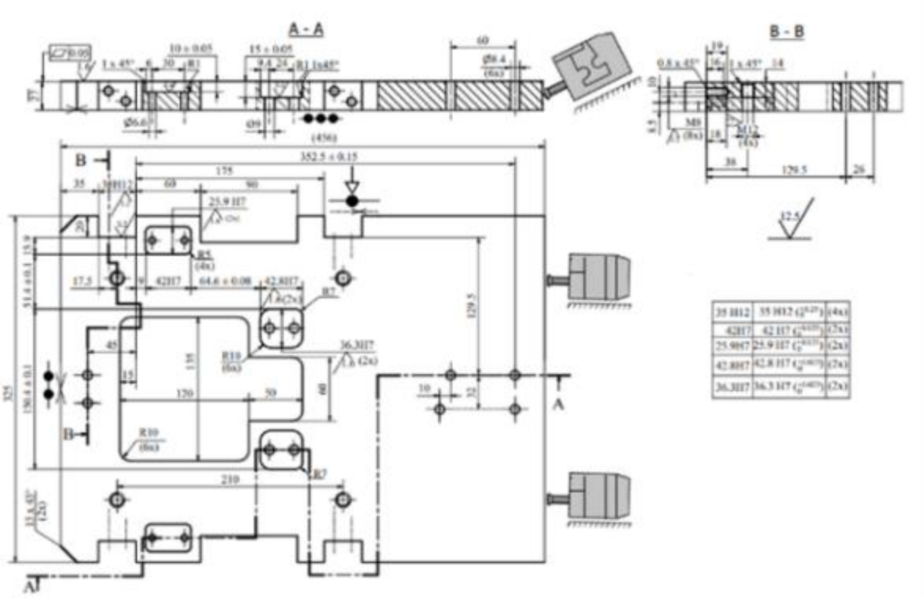
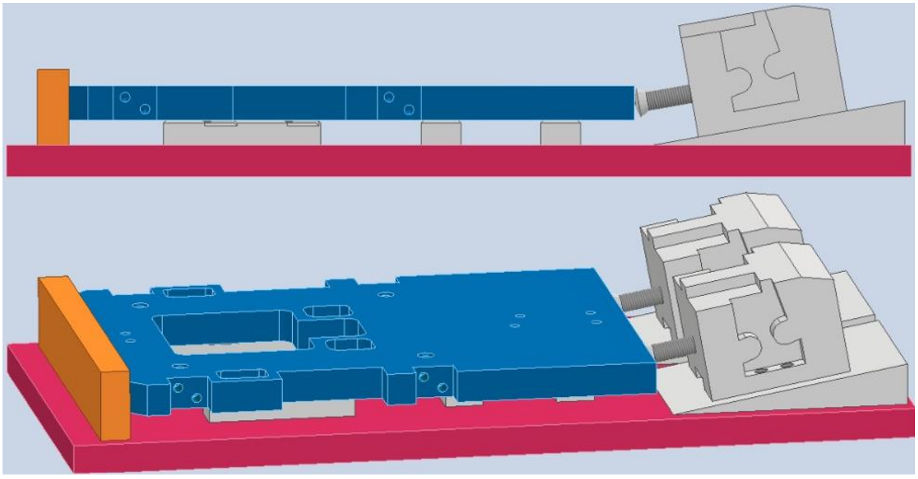


Fig. 2. Fixing mechanisms with hydraulic actuation [4]

Another example refers to the use of hydraulic clamping modules for orienting and fixing a workpiece with a complex geometric shape, on which milling, drilling, and threading machinings are performed (Fig. 3).



(a) Workpiece simplified fixing scheme



(b) 3D model of the hydraulic fixing modules

Fig. 3. Workpiece simplified fixing scheme through hydraulic modules [12]

3. Development of some multifunctional devices

The design of a multifunctional device is carried out in three stages [5]:

- analysis and selection of an existing design solution for the device
- modification of the selected solution to meet current needs
- design of a new solution (if no acceptable variant exists)

For selecting an existing design solution for the device, a classification is necessary. Thus, it is possible to identify final or partially-final devices that can be directly used in the construction of another device [3].

3.1. Multifunctional device with modulated elements

For the construction of two types of devices, the same "base device" was used, consisting of: a base plate, a rotary table, a modulate block, and the necessary connection to allow the rotation of the

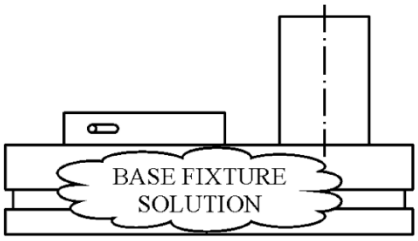


Fig. 4. Base fixture [3]

table. By replacing or adjusting certain component elements, other new design solutions were developed, as shown in Fig. 4. For each type of construction, two other orienting and fixing solutions are presented. The rotary table allows the processing of holes by rotating the workpiece to a certain required angle [3]. This type of device is used for cylindrical workpieces with a predefined range of diameters and heights. The orientation and fixing of the workpiece to be processed (Fig. 5) is achieved through a vise. The elements subject to change are the guide bushing and the bushing holder plate. If the workpiece has a large diameter, it is necessary to change the orientation and clamping part, which represents the second variant of the device [3]. The workpiece is clamped using a screw-nut-washer assembly on the flat outer surface (Fig. 6). The bushing holder plate and the bushing are changed according to the diameter of the hole to be processed.

In the case of all devices derived from the base device, the modulate block element can also be changed to allow adaptation to workpieces with different heights [5].

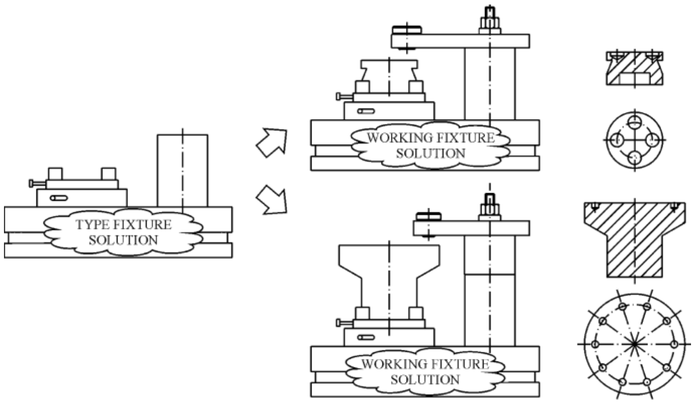


Fig. 5. Jig with fixing mechanism type of vise [3]

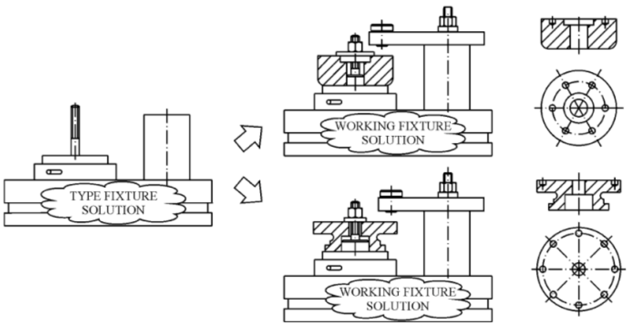


Fig. 6. Jig with modulated elements [3]

3.2. System structure – solution generation through automation

The first step in automating this process is structuring the system modules. The input data module involves the interactive entry of information that will be used later in the design process and for generating a code that will be used as input data for the device selection module [3].

The device selection module establishes the connection between the required device and the existing one in the database. A complete overlap between requirements and results is necessary, with exceptions for the characteristics used for coding: machine tool type, clamping elements, dimensions of the worktable T slots, height, and diameter of the workpiece, clamping force, etc. [3].

After searching the database and determining the level of match between the classification code of the required device and the existing design solutions in the database, an analysis of technically acceptable devices is generated. The modification module involves selecting the device that will form the basis of the necessary solution. This device will be modified by adding or removing certain clamping elements. The output data module takes the previous information and generates the output documentation. The working solution (assembled device) is saved in the database, and output information is generated, as shown in Fig. 7 [3].

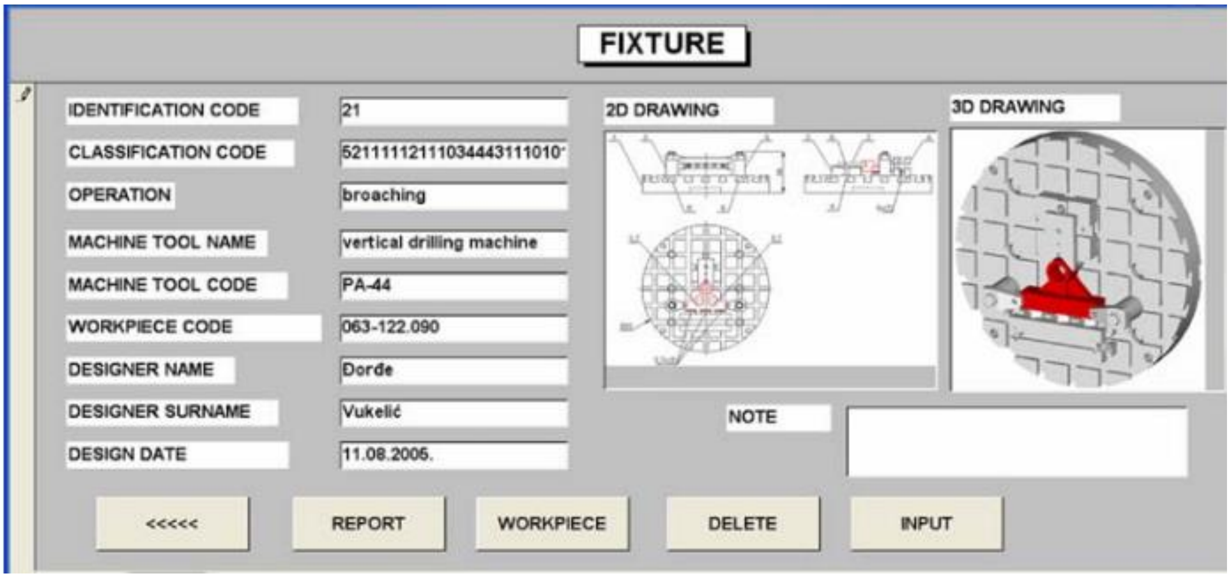


Fig. 7. Generated soluțion [3]

4. Case study on the development of a multi-functional machining device

Let us consider the complex product/ workpiece of which model is presented in Fig. 8

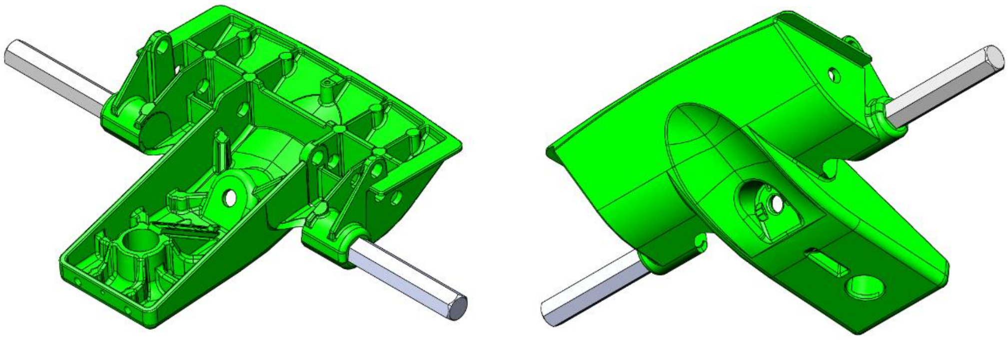


Fig. 8. Part 3D model [9, 11]

Following the analysis of the initial data, technically acceptable variants of the technological machining process are developed, in which three groups of holes positioned successively at 90° are executed within different technological operations. Corresponding to the elements in the sketches of the technological operations, a multifunctional machining device, DMP 01.00.00, was designed and produced [9], so that to be usable within a CNC or conventional machining technological system where the considered operation takes place.

The multifunctional machining device DMP 01.00.00 is shown in Fig. 9.

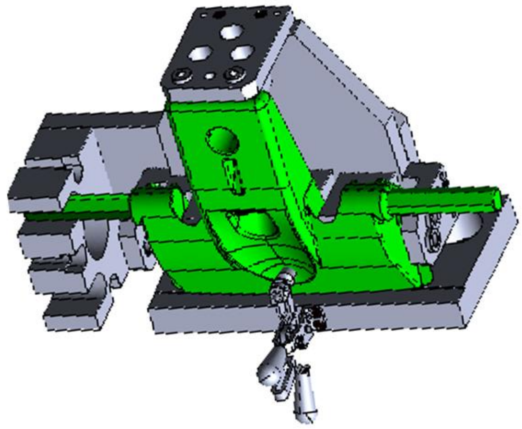


Fig. 9. Multifunctional machining device DMP 01.00.00 (based on [9])

The usage technically acceptable variants of the DMP 01.00.00 device (VT-A D1, VT-A D2, ...) are achieved through well-defined configurations (Cf1, Cf2, ...) of the DMP 01.00.00 device. This is done by modifying the position of some component elements or by assembling/ disassembling certain component elements within the DMP 01.00.00 device. Accordingly, the devices DP 01.01.00, DP 01.02.00, ..., result

for use in the actual CNC or conventional machining operation/system 1, 2, ..., as shown in equation (1) and
Fig. 10, and in equation (2) and Fig. 11, respectively.

VT-A D1 ⇔ Cf1 - DMP 01.00.00: DP 01.01.00, for tehnological operation/ system CNC 1,
VT-A D2 ⇔ Cf2 - DMP 01.00.00: DP 01.02.00, for tehnological operation/ system CNC 2,
VT-A D3 ⇔ Cf3 - DMP 01.00.00: DP 01.03.00, for tehnological operation/ system CNC 3,
VT-A D4 ⇔ Cf4 - DMP 01.00.00: DP 01.04.00, for tehnological operation/ system CNC 4 (1)

VT-A D5 ⇔ Cf5 - DMP 01.00.00: DP 01.05.00, for tehnological operation/ system classical 5,
VT-A D6 ⇔ Cf6 - DMP 01.00.00: DP 01.06.00, for tehnological operation/ system classical 6,
VT-A D7 ⇔ Cf7 - DMP 01.00.00: DP 01.07.00, for tehnological operation/ system classical 7,
VT-A D8 ⇔ Cf8 - DMP 01.00.00: DP 01.08.00, for tehnological operation/ system classical 8 (2)

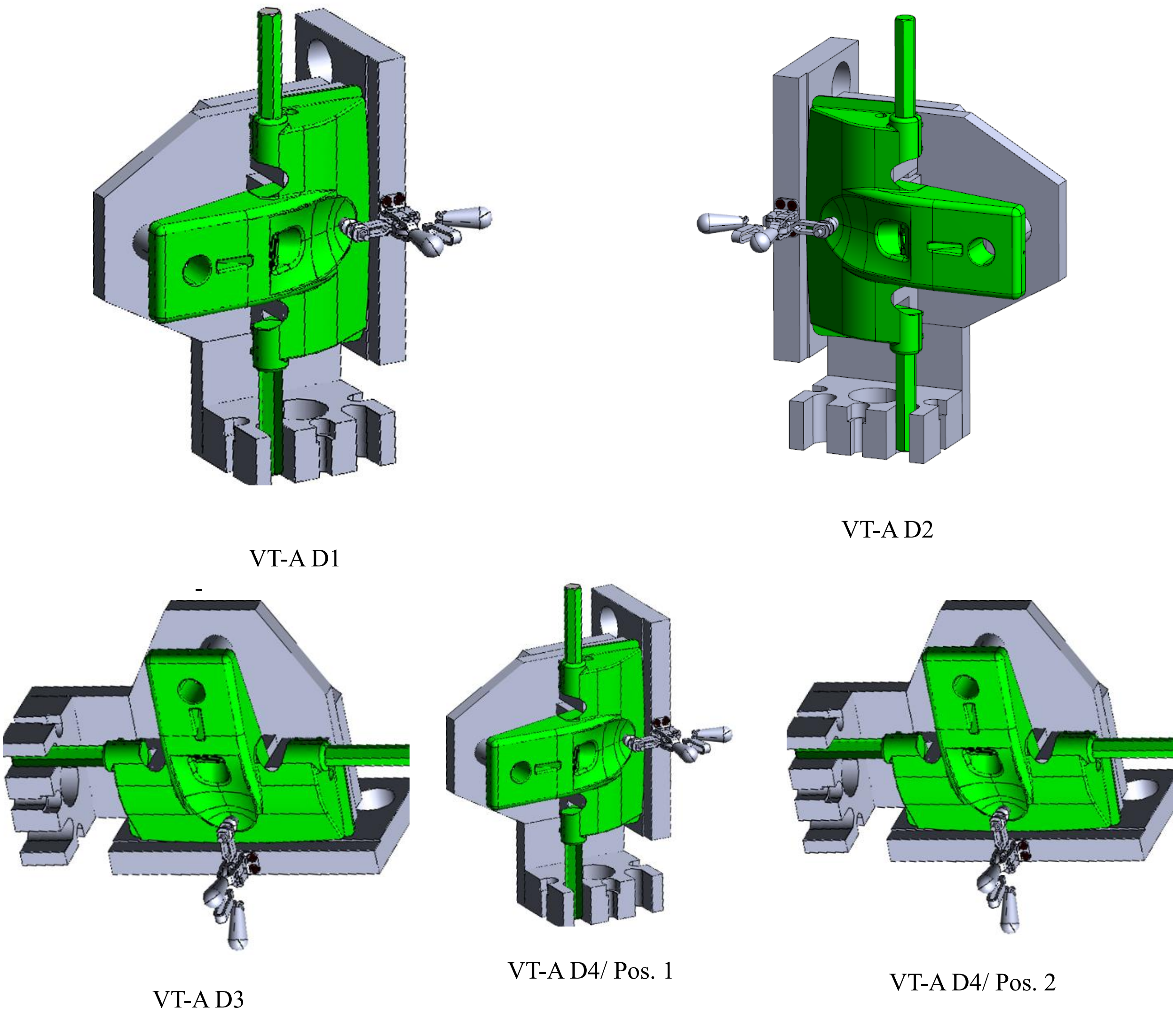


Fig. 10. Technically acceptable variants of the multifunctional device DMP 01.00.00 for use in actual CNC technological machining operations/ systems (based on [9])

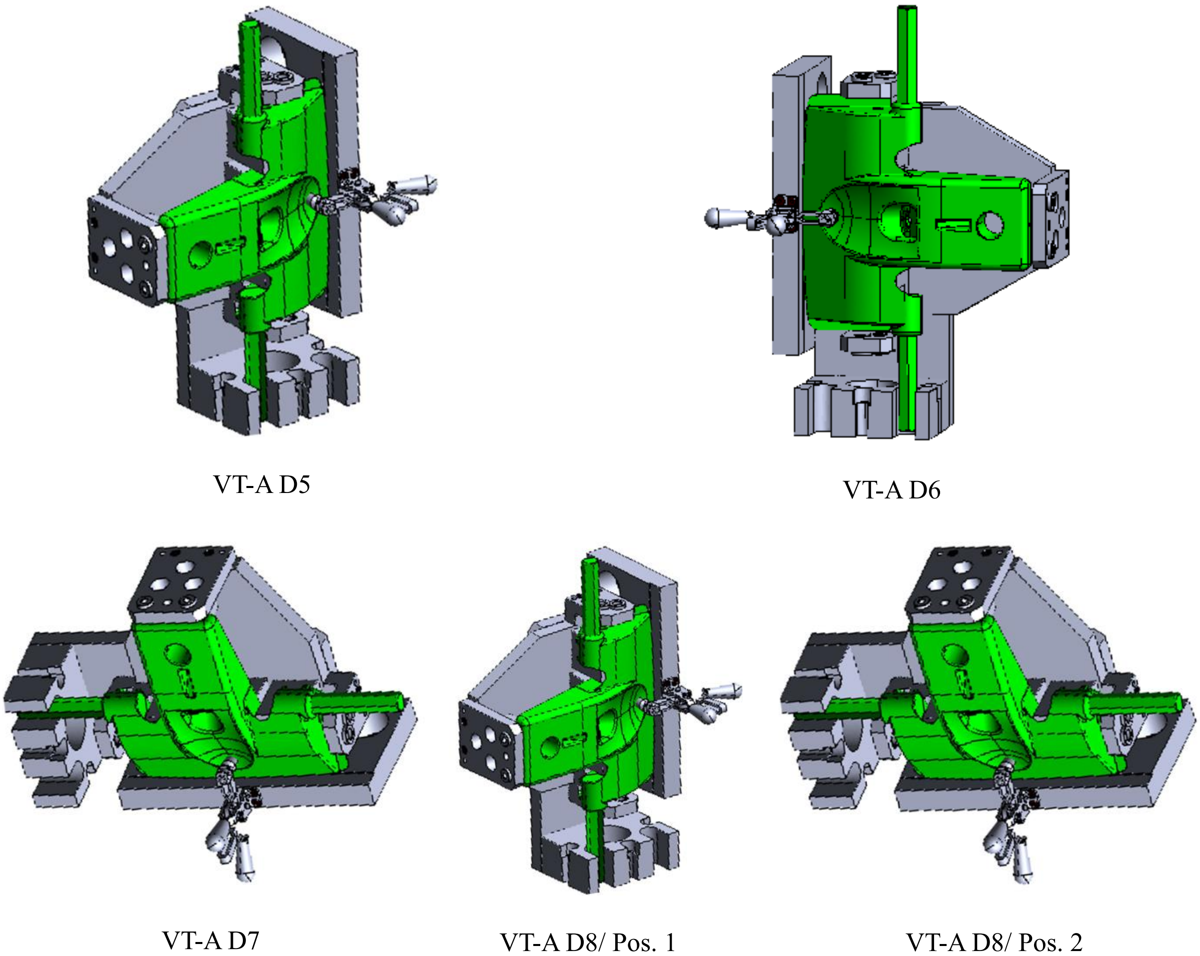


Fig. 11. Technically acceptable variants of the multifunctional device DMP 01.00.00 for use in actual classical technological machining operations/ systems (based on [9])

5. Conclusions

For the orientation and fixing of complex workpieces within machining technological systems, it is necessary to analyze various orienting and clamping schemes and mechanisms in relation to a series of specific characteristics of the workpieces - general shape, wall thicknesses, etc.

In the context of competition and constant changes in customer needs, companies are seeking ways to adapt quickly and efficiently to new market requirements. A growing trend is product diversification, and in this context, industry specialists are emphasizing the development of devices that offer increased flexibility and versatility.

Modulate devices are important in the manufacturing industry because they provide flexibility and adaptability to changes in the production environment. The adaptability of devices is a key feature in reducing costs, diversifying the product range, increasing process efficiency, and fostering innovation and continuous development.

The case study on the development of a multifunctional machining device highlights the main elements concerning the design of a multifunctional machining device, as well as its use through technically acceptable configurations, making it a component of an actual CNC or conventional machining system where a specific machining operation takes place.

In perspective, it is envisaged the development of a multifunctional platform to allow the assembly, under the conditions of Industry 5.0, of devices for CNC and classic technological operations/ systems, respectively.

6. Bibliography

[1] Gheorghe M., “Manufacturing processes 2”, Course notes , UPB, 2021-22.

[2] ***, https://parconfreiwald.ro/menghina-hidraulica-hilma-dcs-80-h-l360mm, accessed on 20.04.2024.

[3] Vukelic D., Uros Z., Janko H., “Complex System for Fixture Selection, Modification, and Design”, Faculty of Mechanical Engineering, University of Maribor, Slovenia, published online: 24 March 2009.

[4] ***, Erwin Halder, Modular Fixture Systems, https://www.youtube.com/watch?v=xz7fHwF8uVk&t=12s, accesat la 24.04.2024.

[5] Pei Xian Lam, Joshua Prakash, Koon Chun Lai, “Setup Time Reduction in a CNC Production Facility Through Redesign of Jigs and Fixtures”, Faculty of Engineering and Green Technology, Universiti Tunku Abdul Rahman, Perak Campus, Jalan Universiti Bandar Barat, Kampar 31900, Perak, Malaysia, AIP Conference Proceedings 1902, 020061 (2017).

[6] ***, Direct Industry, https://www.directindustry.com/industrial-manufacturer/hydraulic-hinge-clamp-84798.html, accessed on 24.04.2024.

[7] Claudio Costa, F. J. G. Silva, Ronny M. Gouveia, R.P.Martinho, “Development of Hydraulic Clampimg Tools for the Machining of Complex Shape Mecanical Components”, ISEP - School of Engineering, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal, 28th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2018), June 11-14, 2018, Columbus, OH, USA.

[8] Tohidi H., AlGeddawy T., “Planning of Modular Fixtures in a Robotic Assembly System”, University of Minnesota Duluth, Duluth, Minnesota, USA, 48th CIRP Conference on Manufacturing Systems - CIRP CMS 2015.

[9] ***, Industrial documentation, SC Dr. Kocher, 2023, https://www.drkocher.ro/.

[10] ***, Technic AS, https://www.technicasms.ro/, accessed on 27.04.2024.

[11] Cocoloș Ana-Maria, Ciocan Cristian, Timonia Andrei, “Research Report 1” (In Romanian), NUST Politehnica Bucharest, January 2024.

[12] Cocoloș Ana-Maria, Gheorghe M., Gannam N., “Research on development of hydraulic fixing modules of parts in industrial CNCtechnological systems”, Student Scientific Communications Session, May 2023, NUST Politehnica Bucharest, 2023.

AUTONOMOUS VEHICLE FOR LUGGAGE TRANSPORT

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ABSTRACT: Through this work the aim is to develop a prototype of a autonomous robotic system that is used for transporting and storing passengers' luggage at the airport, until they board the airplane. The system's role is to facilitate efficient handling and management of passengers' luggage in the airport environment, thereby enhancing travelers' experience by providing an innovative and reliable technological solution.

KEYWORDS: robot, autonomous, transport, luggage

1. Introduction

The subject of the paper is represented by the design and establishment of the initial specifications of a robotic system for the transport and storage of passengers' luggage at the airport. This paper explores the design of a robotic system dedicated to transporting and storing passengers' luggage in an airport.

The essential goal is to create a technological solution capable of efficiently and accurately managing complex baggage flows at an airport.

The objectives pursued within the work are: achieving the current state of the market, establishing the initial specifications, operating principle and prototype design, presenting the main modules of the system.

2. Current market status

In order to identify the best method of implementing the robotic system, a market study was conducted to analyze the existing autonomous vehicle models and fully understand the current industry context. At the moment there are numerous systems for the transport of luggage, this type of system being in continuous development, including those in the table below.

Table 1. Current market status

	
Fig. 1 Omron LD Mobile Robot [1]	*Fig. 2 Omron mobile robot models[1]*

Fig. 3 BAGXONE High-Speed AGV [2]

Fig. 4 FLEET [3]

3. Establishment of system functions, initial specifications and prototype design

Following the study carried out on the current market status, an analysis of existing products on the market was made, in order to determine a general structure of the composition of the robotic platform. Thus, the type of construction of the robot and the main functions it performs were analyzed, depending on the targeted application.

This analysis helped to establish how the system works and thus the main assemblies of the system were established, so that it is able to perform the following main functions illustrated in the following figure.

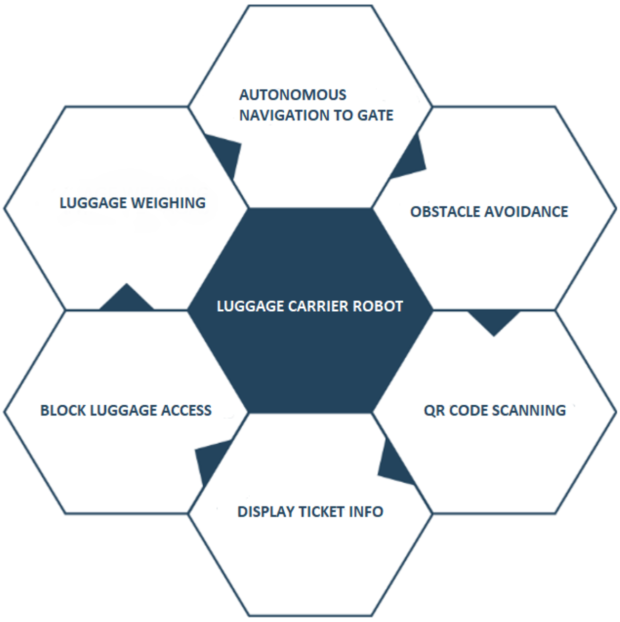

Fig. 5 – Main functions of the baggage carrier robot

The main modules of the system and the type of components that can be used to perform the functions have been established.

In the diagram in the following figure we can see the grouping of components by subsystems that fulfill different roles. Several possible variants of the components have been established and will be presented in the following sections.

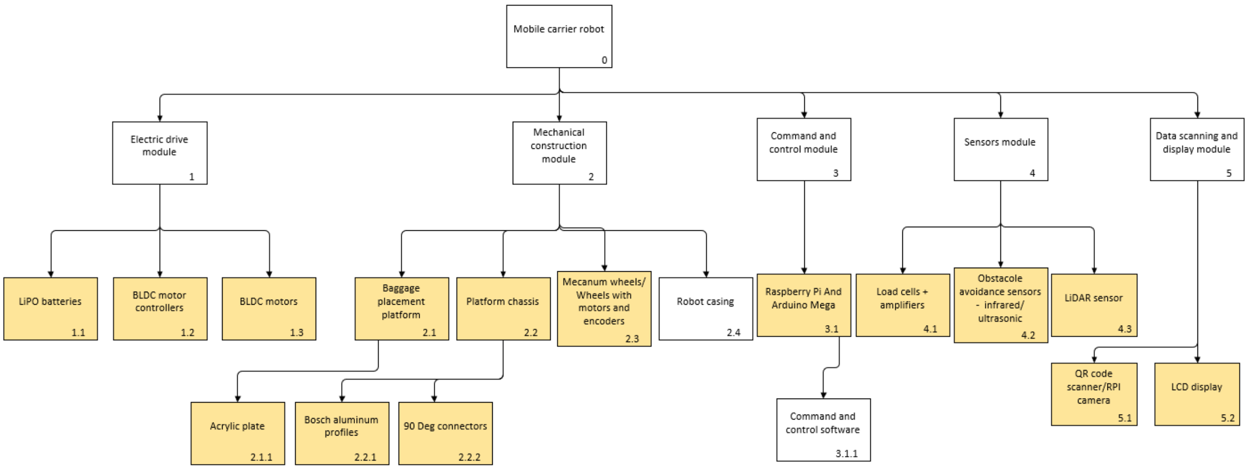

Fig. 6 Diagram of baggage carrier robot modules

The following initial specifications have been established for the autonomous vehicle:

- **Overall dimensions (LxWxH)**: 850 x 500 x 300 mm (850 x 500 x 1000 mm - with screen support)
- **Ground clearance:** min. 28 mm
- **Total robot weight:** max. 35 kg
- **Maximum speed:** 0.4 m/s
- **Payload:** 50 kg
- **Operating autonomy:** 4-5 h

Based on the diagram and initial specifications, an autonomous vehicle prototype was designed:

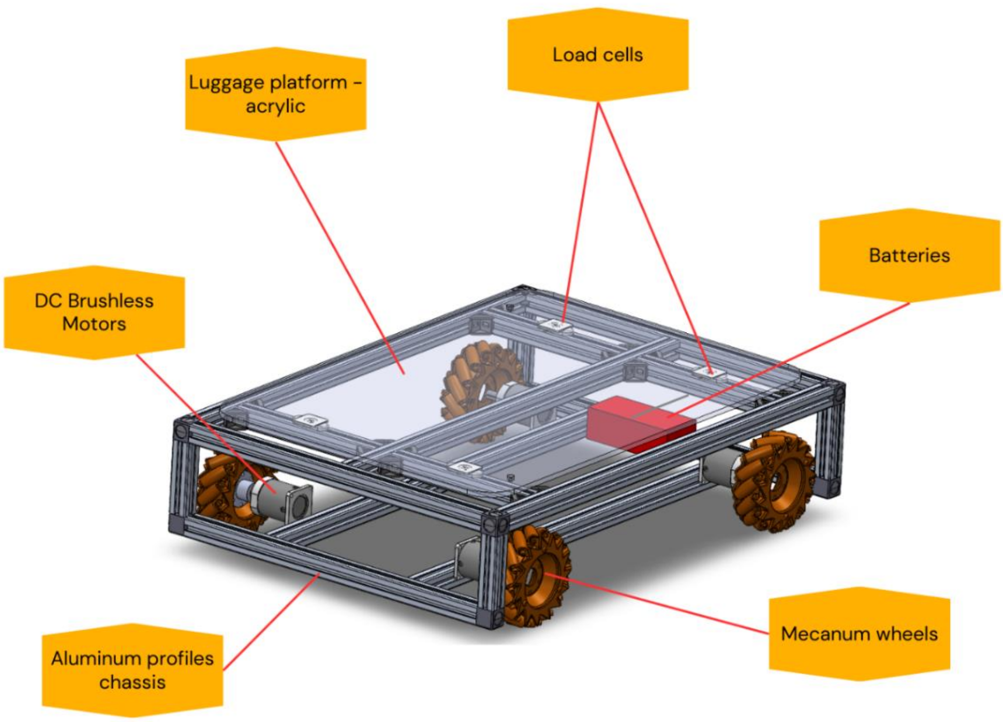

Fig. 7 Autonomous transport vehicle prototype design

4. Electric drive module; Data scanning and display module

In order to make it possible to both move the vehicle and to communicate with the passenger who wants to transport his luggage, it is necessary to establish components for the electrical drive of the platform so that it moves in the desired direction. At the same time, in order to start moving, the system must be switched on and controlled; this is done by scanning the QR code on the ticket and displaying the passenger details.

Given the initial specifications of the system, it is necessary to purchase elements that make up the electrical drive of the vehicle, such as:

- **Wheel drive motors -** Energy-efficient and compact electric motors providing sufficient power and torque to propel the vehicle to a maximum speed of 0,4 m/s. These motors should be adapted to ensure smooth and precise movement of the vehicle inside the airport.
- **Motor Controllers –** The right motor control module to manage and control electric motors according to the desired speed and steering requirements. These control modules should be compatible with the specifications of the engines used and provide accurate and reliable operation.
- **Batteries -** A high-capacity, energy-efficient parallel-linked battery system is needed to power electric motors and other vehicle electronics. The batteries should be chosen in such a way as to provide the desired operating autonomy of 4-5 hours and comply with the imposed total mass and size limits. An example of suitable batteries are: LiPo 6S batteries.

Fig. 8 LiPo 6S batteries [4]

- **Command and control systems -** Control systems that allow the control of different vehicle components and facilitate communication with airport infrastructure or other autonomous vehicles. These systems should provide a stable and secure connection for the transfer of data and commands. Possible examples to use are: Arduino Mega control unit or Raspberry Pi 4 control unit.

Fig. 9 Arduino Mega control unit [5]

Fig. 10 Raspberry Pi 4 control unit [6]

In order to perform the scanning of the QR code on the passenger's ticket and display the relevant details, the following elements will be needed:

- **QR Code Scanner –** A scanning device integrated into the vehicle, equipped with an image sensor or a dedicated laser sensor able to read QR codes off of passengers' tickets. This scanner must be able to decode QR codes quickly and accurately.
- **Image processor/QR code recognition system –** An image processor or QR code recognition system that interprets the data in the scanned QR code and transforms it into information usable by the display system.
- **User interface –** A touch screen or LED display to display details relevant to passengers. This could include flight number, boarding gate, departure time and other travel-related information.

Fig. 11 QR code scanner [7]

- **Connectivity –** A connectivity module (such as WiFi, Bluetooth or LTE) to enable communication between the vehicle and the airport ticket management system. This would allow flight information and other travel details to be updated in real time.
- **Security and encryption systems –** Security and encryption measures to protect scanned and displayed passenger data. Those systems should ensure the confidentiality and integrity of travel information and prevent unauthorised access to sensitive data.

5. Sensors module

- **Load cells and amplifiers -** To measure luggage weight in an automated transport system, load cells are an efficient and accurate option. To ensure efficient operation of a baggage weight measurement system, an arrangement of 4 load cells shall be used, each with a minimum measuring capacity of 15 kg. To achieve greater accuracy in measuring baggage weight, load cells with a higher measuring capacity of up to 50 kg each will be used. This choice of load cells with a capacity greater than the maximum weight of luggage helps to avoid overloading and offers strength and durability in use.

Fig. 12 Strength cell 50kg [8]

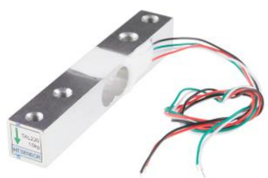

Fig. 13 Load cell 10 kg straight bar [9]

In addition to load cells, amplifiers must also be purchased, that are used to increase the electrical signals received from the cells.

Fig. 14 Load amplifier HX711 [10]

An obstacle avoidance sensor is essential in an autonomous system, such as a vehicle designed to carry luggage at an airport, for several important reasons:

- Safety: An obstacle avoidance sensor is crucial for the safety of the vehicle and passengers or other nearby objects. It helps detect objects that are in the vehicle's path and avoid unwanted collisions.
- Efficient navigation: an autonomous system must be able to navigate in a dynamic environment where objects can appear or move in the path of the vehicle. An obstacle avoidance sensor helps determine clear paths and select optimal routes for travel.
- Automation: with the help of an obstacle avoidance sensor, the vehicle can operate without human supervision, making quick decisions and adapting to changes in the environment to avoid collisions.

For our model, it was found that in order to ensure rapid and effective detection of obstacles, the vehicle must be able to detect obstacles at a minimum distance of approximately 50 cm. At this distance, the infrared sensor can detect obstacles early enough to allow the vehicle to take corrective measures, such as stopping or avoiding. The following model shows: DC working voltage 3.3V-5V and detection range: from 1mm to 60 cm – adjustable. [11] These shall be mounted on the vehicle so as to cover all important areas.

The following ultrasonic sensor model features [12]:

- Very small design for use in small spaces
- Programmable normally open/normally closed output function
- Clearly visible LED for switching status and echo indication
- Switching distance [mm] 40...300; (Target: 200 x 200 mm)
- Operating voltage [V] 10...30 DC

Fig. 15 Obstacle avoidance module, infrared, 4 channels [11]

Fig. 16 Ultrasonic sensor [12]

A LIDAR sensor can be used for obstacle detection and navigation.

Table 2. LIDAR sensor features [13]

Mapping and trajectory identifying module: LD06 Lidar 360° DTOF	• Measuring radius 12 m; • Resistance of 30000 lux to strong light • Measuring frequency 4500 HZ; • Scanning radius 360°; • Laser safety (Class I); • Lifetime 10000h	

6. Mechanical construction module

In order to ensure efficient and reliable operation of the baggage transport robot in the airport environment, it is crucial to build every aspect of the platform with care and precision. The platform shall be designed to withstand varying loads and difficult working conditions, while ensuring safe and efficient handling of passengers' luggage.

- **Baggage placement platform -** In order to ensure a solid and stable surface for placing and transporting passengers' luggage, an acrylic plate seating platform can be used. This material can be chosen because of its impact and deformation resistance, as well as because of its excellent transparency and aesthetic properties. The acrylic plate provides a smooth and even surface, ideal for supporting and transporting different types of luggage. In addition, the durability and ease of processing of this material can facilitate the construction process, allowing for achieving a robust and reliable platform with the possibility of placing it over the weighing cells.

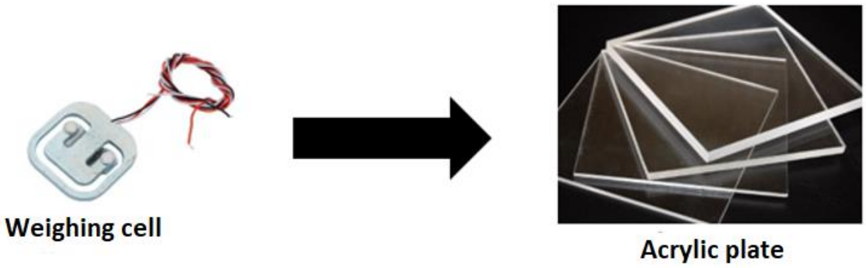

Fig. 17 Baggage weighing platform

- **Platform chassis -** High-quality aluminum profiles can be used to make the frame of the baggage robot platform. These profiles have excellent impact and corrosion resistance, and are easy to process and assemble.

Fig. 18 Aluminium profiles [14]

The use of aluminum profiles offers the opportunity to build a robust and durable frame that can withstand various loads and demanding environmental conditions in the airport environment. The flexibility and versatility of these profiles allow the frame design to be easily adapted to the specific requirements of the project, while ensuring a solid and reliable structure for the other components of the robot.

- **Mecanum wheels -** In order to ensure optimal maneuverability and efficient travel capacity in the crowded environment of airports, one can opt for the use of mechanum wheels. Mecanum wheels are equipped with rollers steerable at an angle of 45 degrees to the wheel axis, which allows them to perform lateral and diagonal movements.

Fig. 19 Mecanum wheels [15]

This distinctive feature of mecanum wheels gives the robot a unique ability to easily navigate tight spaces and avoid obstacles accurately. Also, mecanum wheels allow the robot to perform complex maneuvers, such as turning in place and skidding sideways, without the need for additional manual maneuvering.

7. Conclusions

Future research for the making of the automatic baggage transport system will be carried out taking into account the specifications of similar products existing on the market and the operating schemes presented in this paper. The necessary calculations will be made to establish the exact variants of the products to be purchased and the design of the mechanical assembly will continue, followed by the actual building of the platform, by sizing and mounting aluminum profiles and by making the housing components. Subsequently, after installing the components, the necessary wiring will be made and the robot's navigation algorithm will be designed.

8. Bibliography

1. https://automation.omron.com/en/us/products/family/LD
2. https://alstefgroup.com/baggage-handling/baggage-handling-products/bagxone-agv/
3. https://www.vanderlande.com/news/fleet-all-systems-go-at-rotterdam/
4. https://www.ampow.com/products/2packs-ovonic-120c-4s-2200mah-lipo-battery?variant=42940952543476
5. https://www.robofun.ro/arduino-62/arduino-mega2560-v3.html
6. https://www.robofun.ro/raspberry/placa-raspberry-pi-4-model-b-4gb.html
7. https://www.dualstore.ro/gadgeturicastiincarcatoare-si-cabluri-usb-49/scaner-yhd-9800-cod-de-bare-1d-2d-qr-cu-fir.html
8. https://roboteh.ro/456-celula-de-sarcina-50-kg-1000448.html
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11. https://www.emag.ro/modul-detectie-obstacol-cu-4-canale-ir-oky3518/pd/DYJNKRMBM/
12. https://www.ifm.com/ro/ro/product/UGT209
13. https://smartrobot.ro/produs/ld06-lidar-360-dtof/
14. https://www.dicsaautomation.com/copie-de-extrusion-d-aluminium
15. https://www.servocity.com/140mm-mecanum-wheel-set-70a-durometer-bearing-supported-rollers/

STUDY ON THE DEVELOPMENT OF AN EXPERIMENTAL MODEL FOR REMOTE CONTROL OF MOBILE EQUIPMENT UNITS

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ABSTRACT: *The present work refers to a series of experimental researches regarding the thermal stress of electronic equipment found in the UMC assembly and the determination of the necessary airflow for optimal operation under normal conditions of use. For this research, specialized CAD software was used, specifically Autodesk Fusion, and also for the mentioned simulations, Autodesk Fusion [6]. These researches were reinforced by conducting physical trials as close to reality as possible, in order to demonstrate the compatibility of the chosen solutions to meet the need for an ergonomic, resistant, and reliable product development, adapted to current specialty standards.*

KEYWORDS: UMC, temperature, thermal visualization

1. Introduction

In recent years, the development of robotic technology has led to a variety of innovations in the field of remote control mobile units. These include both hardware developments such as sensors and control devices, and software developments such as navigation algorithms and data processing.

During the interwar period, the development and testing of unmanned aircraft continued. In 1935, the British produced a number of radio-controlled aircraft intended for use as targets for training purposes. It is believed that the term "drone" began to be used during that period, inspired by the name of one of these models, DH.82B Queen Bee. Radio-controlled drones were also manufactured in the United States and used for shooting practice and training. [1]

The ground-based Unmanned Vehicle Control Station (UMC) is a land- or sea-based control center that provides facilities for human control of unmanned aerial vehicles (UAVs or "drones"). [2]

UMC hardware refers to the complete assembly of ground-based hardware systems used for UAV control. This typically includes the man-machine interface, computer, telemetry, video capture board, and antennas for control, video, and data links to the UAV. [2]

UMC software typically runs on a ground-based computer used for mission planning and execution. It provides a map display where the user can define waypoints for flight and track mission progress. It also serves as a "virtual cockpit," displaying many of the same instruments as manned aircraft. [2]

Fig. 1 Portable Ground Control Station for Unmanned Aerial Vehicles (UMC for drones).[2]

A control station (Fig. 2) typically consists of a set of screens and consoles that allow operators to remotely visualize data and control the system. With the help of advanced technologies such as data analytics, artificial intelligence, and high-speed communication technology, the control station can be configured and customized to meet the specific needs of each user.

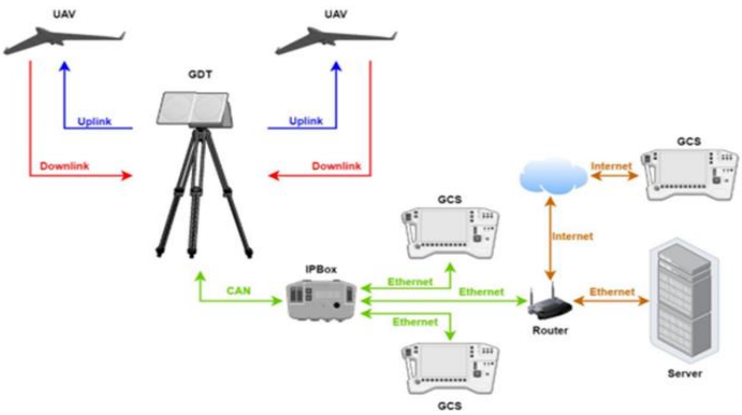


Fig. 2 Multi-UAV, Multi-GCS with internet connection [4]

2. Current Stage

The development process must fully incorporate ergonomic aspects into the UMC optimization approach, considering that this perspective will ensure seamless system integration for human requirements. This holistic approach will essentially reflect the principle of ergonomics, which emphasizes that every aspect of the system, whether it's equipment, interface, or the surrounding environment, must be designed with the human user as the central focus.

In the initial studies, the development process concept for UMC was realized. Once the design was developed, ergonomic design underwent radical changes. We implemented new general functions, subject to analysis, resulting in the main function, with secondary functions resulting from the interaction of the main functions and the environment in which it operates, representing external interactions.

The conceptual design of the product, as well as its architecture, is developed based on the sizes and characteristic values of competing products. The remote mobile control unit represents an assistance and control unit for a wide range of moving systems that provides the operator with the freedom to control devices from anywhere. Thus, in order to highlight the main modules found in the current configuration, the creation of a block diagram presented in Fig 3 has been proposed.

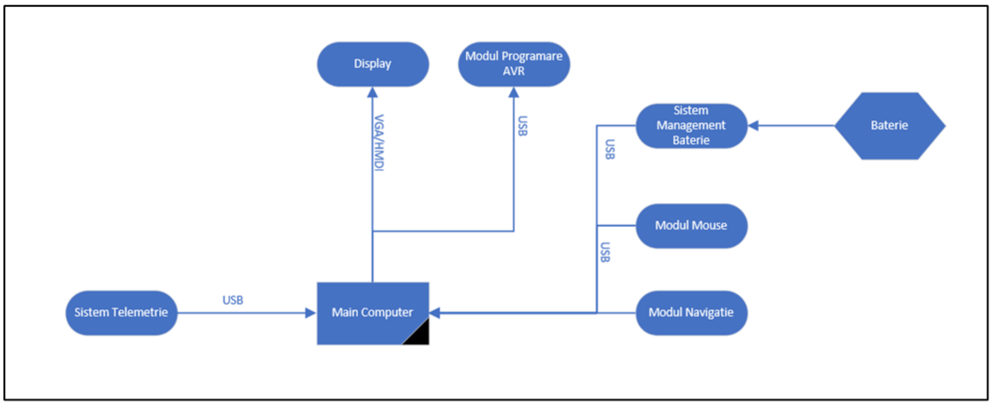


Fig. 3 Block diagram of the modules comprising the UMC

To determine the functions of the UMC product, the following recommendations had to be followed:

- To ensure a good connection with associated devices.
- To be able to work with any operating system installed on the devices it connects to.

- To have programmable buttons.
- To be ergonomic, with buttons and touchpad comfortable for any palm size.
- To be able to operate for a long period without constant need for battery replacement.
- To easily connect to external devices.
- To be easily powered from other external energy sources, even with different electrical voltages.
- To be able to provide easy illumination using RGBW installation with minimal consumption.
- To be able to capture and display meteorological parameters through the built-in mini weather station.

Both based on ergonomics and design constraints and based on mechanical strength constraints of UMC component elements, the product design was directly influenced to meet the user's interaction needs with UMC. As a result, the mechanical part was designed and assembled to 90% completion.

A USBAsp module was developed as part of the Atmel microcontroller programming function, using an ATMega8 and a USB driver exclusively in the firmware. The connection scheme is based on Atmega8 with an external 12MHz oscillator, with indicator lights indicating power and programming status.

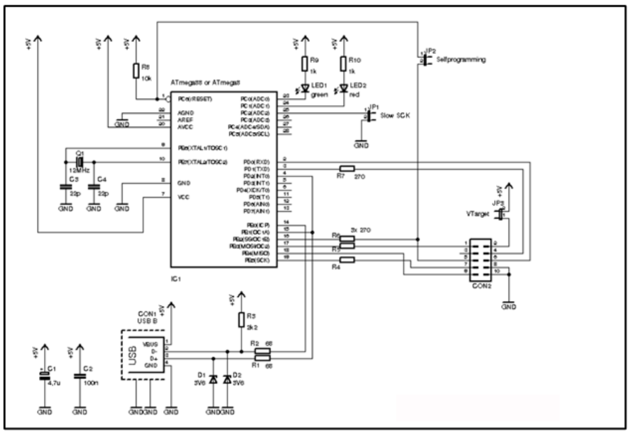


Fig. 4 AVR Programming Module Connection Diagram [3]

The real-time display of battery parameters (Voltage, Current, Power consumption, remaining battery capacity, battery temperature) can be found both at the software level (in the UMC interface) and hardware level (by displaying key parameters using a display (Fig. 5)).

Fig. 5 Displayed parameters of the management system

The circuitry of the battery management system was designed using specialized software, Eagle, provided by Autodesk. The system is divided into 2 subsystems: the battery optimization system (Fig. 6), which interrupts the power supply to the UMC when it is not in use, and the battery monitoring system (Fig. 7), which continuously displays battery status parameters and also performs continuous monitoring of the charging cycle.

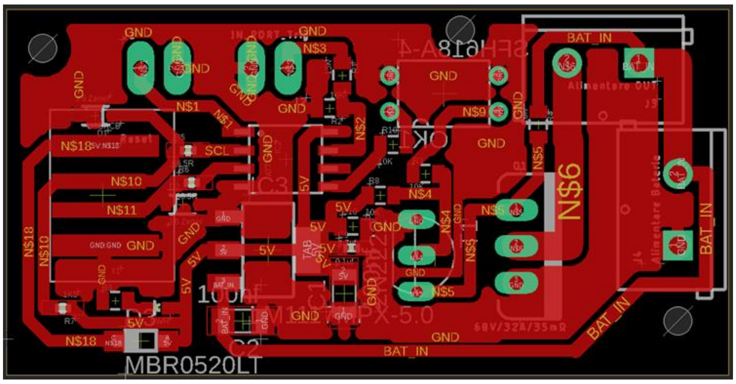


Fig. 6 Battery Optimization System Diagram

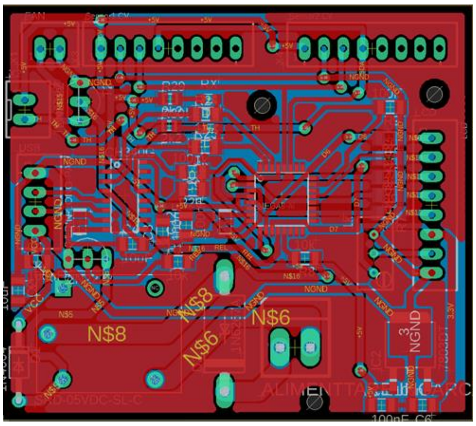


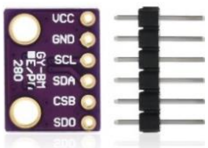
Fig. 7 Battery Monitoring System Diagram

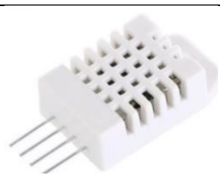
2.1. Weather Station

For the successful implementation of the proposed activities with the help of UMCD, knowledge of essential meteorological parameters is vital. Thus, the design of a proprietary system of specific sensors is desired to transmit the measured parameters to UMCD via Bluetooth signal, using an application and a Bluetooth modulator.

We will use sensors for air temperature and humidity, atmospheric pressure sensor, and wind speed sensor. (Table 1)

Table 1 - Meteorological Parameters Sensors Used

Sensor Used	Observations
	BMP280 - Atmospheric Pressure Sensor

	DHT22 - Air Temperature and Humidity Sensor
	Anemometer - Wind Speed Sensor

3. Static analysis regarding the determination of operating temperatures and airflow

3.1. Defining the experimental model, input data, and constraints

To perform a static analysis of temperature evolution following the exposure of the UMC to general environmental conditions (ambient temperatures ranging from 20-40 degrees, air humidity <70%), dedicated software is required (in this case, Fusion360 software was used). The necessary steps for thermal simulation are as follows:

The first step is defining the working/ambient temperature. This factor is crucial in simulation since the heat exchange between the external environment and the UMC is a decisive factor in conducting the simulation. (Fig. 8)

Fig. 8 Defining the operating temperature for the UMC

The second step is defining the constraints. In the case of thermal simulations, the zones where air will enter or evacuate are defined. The UMC will have the front slot on the control panel defined as the air intake zone, while the left side area will be defined as the air evacuation zone (hot air will be forcibly pushed outwards using axial fans). (Fig. 9)

Fig.9 Definition of constraints for the UMC

The third step involves defining the thermal consumption constraints. In this step, the areas of interest generating heat will be selected. For the UMC, the most heat-generating component of interest is the system processor. Due to its low power consumption characteristics, the dissipated heat power is 40 W. (Fig. 10)

Fig.10 Definition of thermal consumption constraints for the UMC

The last step is defining the temperature constraints on each element of the UMC. For optimal operation, the overall maximum temperature should not exceed 50 degrees Celsius. An increase of approximately 25% from the maximum temperature will affect heat-sensitive components such as voltage regulators / reference sources / EEPROM memories. (Fig. 11)

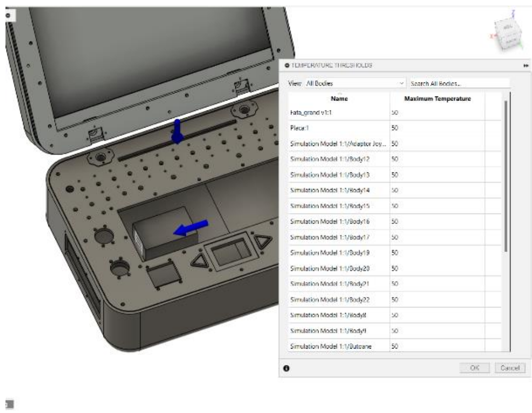
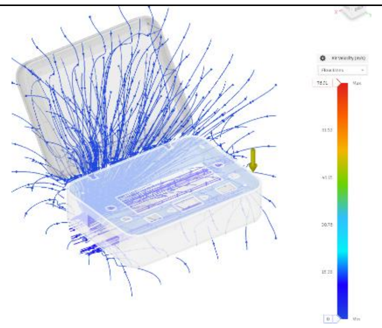
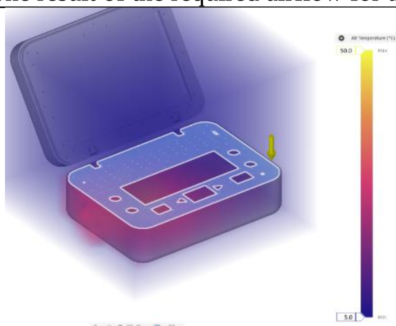
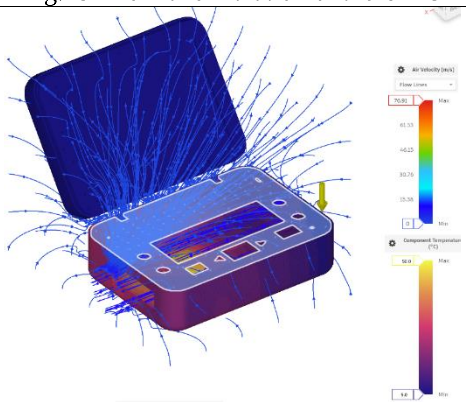
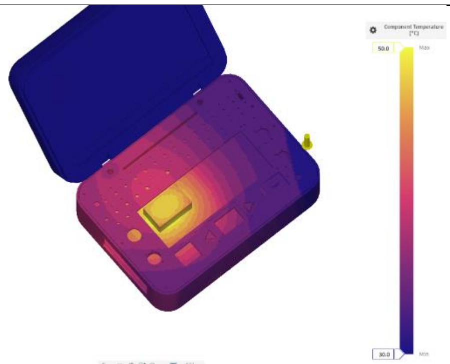


Fig.11 Definition of temperature constraints on each element of the UMC

3.2. Solving the problem and interpreting the data

The results of the thermal simulations are displayed in Table 2.

Table 2 Results of thermal simulations

Result of the simulation	Observations
 Fig.12 The result of the required airflow for the UMC	Based on the results, the airflow required for optimal ventilation of the electronic equipment within the UMC ranges between 1-15 meters per second. (Fig. 12)
 Fig.13 Thermal simulation of the UMC	The thermal simulation shows that the temperature-generating area is the processor zone, followed by the transistor zone, which serves to supply operating voltage to the equipment. (Fig. 13)
 Fig. 14 The concatenation between the airflow and the heat-generating zones	The result of the simulation illustrated in Fig. 14 represents the concatenation between the airflow and the heat-generating zones.
 Fig. 15 Areas with temperatures different from the ambient environment	Similar to previous simulations, the adjacent image depicts a gradual view of areas with different temperatures compared to the ambient environment. As anticipated in the hypothesis, the area with the highest temperature is indeed that of the processor. (Fig. 15)

4. Analysis of thermal loading on electronic equipment

4.1. Steps required for generating the thermal loading analysis

The remote control system testing was conducted in a normal operating environment, namely: Ambient temperature of 25.1 degrees Celsius and relative humidity of 58%. (Fig. 16)

Fig.16 Ambient temperature and relative humidity in the operating environment

The duration of UMC system usage under the above-described ambient temperature conditions was 2 hours. During the testing period, the UMC was subjected to constant processing load. Upon completion of the testing period, measurements were taken on the areas of interest to compare them with the values resulting from the simulations.

Fig.17 Thermal view of the UMC

Following the measurements, areas where the temperature exceeded the maximum threshold of 50 degrees Celsius were highlighted. (Fig. 17 and Fig. 18) The temperatures exceeding the permissible threshold were measured in the control module area of the charging system, specifically in the vicinity of a transistor that switches on/off the system's power supply in case of malfunction or overload. This thermal analysis revealed electronic defects that could lead to the UMC's suboptimal functionality. The resulting issue was subsequently resolved after replacing the defective component with a new one.

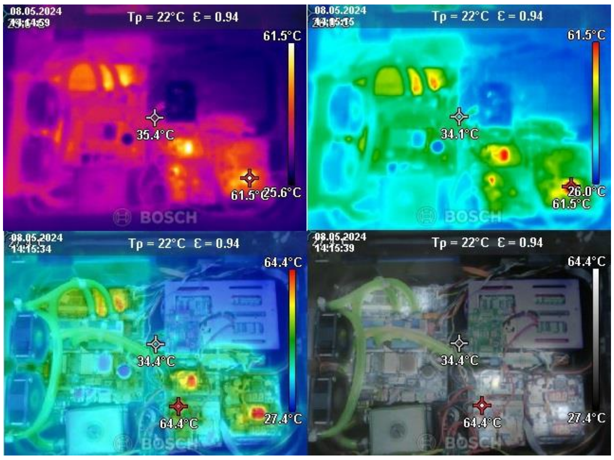


Fig.18 Thermal measurements to observe exceeding the maximum threshold of 50 degrees

5. Analysis of the electronic system within the UMC

Within the UMC, there are components that have been developed since the design stage by the current team in early versions. Therefore, it is crucial to study these systems to track their evolution over time and to highlight any errors that may occur during their operation. We deemed it important to focus on the quality of the power system and the errors that may occur in the software system.

5.1. Study of the UMC power system

The study of the battery charging system monitoring was conducted by capturing data from the hardware equipment aimed at achieving a normal charging cycle of the Li-Ion battery pack. The fragmented dataset is presented in Table 3, and the graph in Fig. 19 highlights the evolution of key parameters such as current, voltage, and temperature in relation to the charging time. A complete charging cycle was completed in 66 minutes, and the temperature varied by 15 degrees Celsius during this time interval.

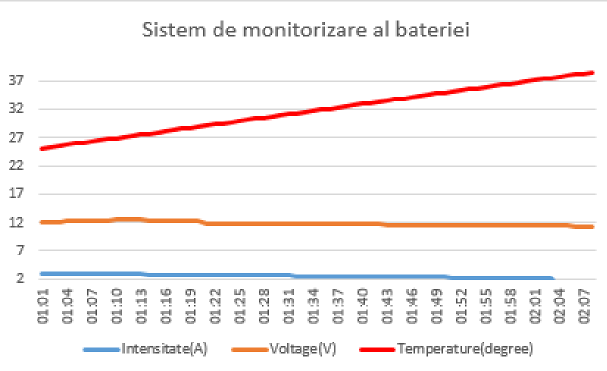


Fig. 19 Graph monitoring parameters throughout the charging cycle

Table 3. Selected values during the charging cycle

Time(hh:mm)	Current(A)	Voltage(V)	Temperature (degrees Celsius)
01:01	3.0142	12.0156	25.1
01:32	2.574	11.7635	31.3
01:41	2.4462	11.66	33.1
01:52	2.29	11.5335	35.3
02:00	2.1764	11.4415	36.9
02:08	0.5	11.3495	38.5

In the process of analyzing the charging cycle, it can be assumed that the system operates within optimal parameters with low dissipated power. In the subsequent stages, a more detailed study consisting of 600 charge-discharge cycles of the batteries is planned. The result of this study outlines a significant percentage in the reliability of the UMC.

5.2 Study on UMC Software Errors

Considering that some of the equipment found in the UMC component were developed by our team, it was deemed necessary to conduct a durability test that would highlight any potential errors that may arise during the data acquisition process captured from the front panel of the UMC. Fig. 20 shows the first version of the graphical interface developed, communicating via the computer located in the UMC with the hardware equipment that acquires signals from the switches on the front panel. Communication is achieved using a USB 2.0-TTL converter. The application is developed as a standalone package that can be individually installed by each user of the UMC system, with the graphical interface being created as an additional element that facilitates the detection of any errors in the applications.

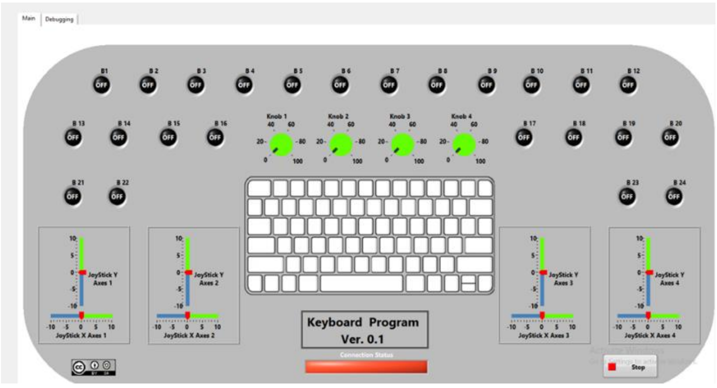


Fig. 20 Graphical interface of the driver used in the LabView software

The development of a file aimed at continuous monitoring of communication between equipment and setting the initial parameters for establishing the connection was essential. The application shown in Fig. 21 enables the operator to configure communication parameters while continuously monitoring the data packets captured from the equipment.

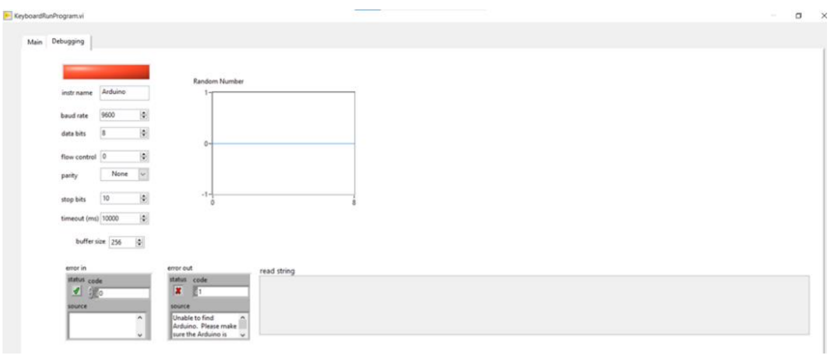


Fig. 21 Graphical interface for monitoring communication errors

The testing was conducted using a system that activates the contactors located on the control panel. In Fig. 22, the status of the user interface throughout the experiment can be observed. Data was acquired from both the program interacting with the user and the mechatronic system developed for the testing process. Following error analysis, the following errors were identified: 0.012% error in data packet transmission, 0.003% error in interpreting the data set by the graphical application. Thus, it can be concluded from the testing process that the software errors of this subassembly meet acceptable limits for functioning within UMC parameters.

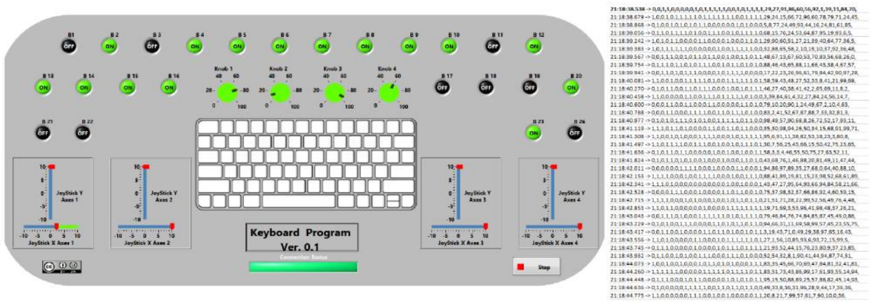


Fig. 22 Interface subjected to testing

6. Conclusions

The determination, analysis, and resolution of design and usage phenomena/difficulties of the developing product "Mobile Control Unit" were considered, utilizing dedicated software for specific situations, such as Autodesk Fusion, etc. Prototyping of key assemblies and subassemblies necessary for the development of the future product was carried out. Additionally, practical tests were conducted on the working prototype to better understand the phenomena that may be encountered during product use. The presentation of the research work aims to confirm the correctness of the presented stages.

7. Acknowledgments

Thanks go to Assoc. Prof. Dr. Eng. Mădălin-Gabriel CATANĂ and Prof. Dr. Eng. Tom SAVU, who provided both educational support and positive influence, leading to the successful completion of all activities undertaken by team members. Additionally, thanks are extended to the Scientific Student Sessions committee, whose professionalism and objectivity contributed to confirming the solutions studied by the project team.

8. Bibliography

[1] A Brief History of Drones, https://www.iwm.org.uk/history/a-brief-history-of drones#:~:text=In%201935%20the%20British%20produced,82B%20Queen%20Bee., accessed on April 4, 2024;

[2] UAV ground control station , https://en.wikipedia.org/wiki/UAV_ground_control_station, accessed on 5 April 2024;

[3] USBasp - USB programmer for Atmel AVR controller, www.fischl.de/usbasp/, accessed on 08 January 2024;

[4] Liang Song, Deen Zheng, Yazhen Wei: "Unmanned Aerial Vehicle Remote Control and Control Method Thereof", (US 11188072 B2), accessed on 10 May 2024;

[5] Labview - LabVIEW is a graphical programming environment, https://www.ni.com/en/shop/labview.html , accessed on 07 April 2024;

[6] Fusion 360 - Autodesk Fusion is the end-to-end design, https://www.autodesk.com/products/fusion-360/overview?term=1-YEAR&tab=subscription, accessed on 15 January 2024.

SCIENTIFIC RESEARCH ON THE DEVELOPMENT OF A PAIR OF ROBOTIC ARMS FOR COMUNICATION WITH HEARING DEFICITS

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ABSTRACT: The development of a pair of robotic arms for communication with hearing-impaired people requires a multidisciplinary approach, namely robotics, signal processing, human-computer interaction. The detailed design of robotic arms for hearing impaired people involves taking into account the specific needs of these people, as well as integrating features that facilitate their communication and interaction with the environment.

KEYWORDS: detailed design, robotic arms, hearing impaired individuals.

1. Introduction

The robotic arms are a mechanism composed of links, interconnected through suitable joints, to achieve the degrees of freedom and spatial movement required for executing commands. Due to its functional similarity to a human hand, it is also called anthropomorphic. The term “pair of robotic arms for hearing-impaired individuals” refers to a robotic system formed of two articulated arms that are specially designed and crafted for use by hearing-impaired individuals. In order to facilitate communicationthrough sign language, the pair of robotic arms mimics as closely as possible structure and proportions ofhuman arms. Proportioning for printing 3D of the component element includes approximately the actual length of the human arm as well and mobility of the fingers.

2. Strategic development and specifications of robotic arms designed for communication with hearing-impaired people

2.1 Strategic Marketing

To reach the target audience, the marketing strategy will focus on:

- Marketing channels: strategic partnerships with organizations dedicated to hearing-impaired individuals to increase awareness level.
- Participating in conferences and events related to technology and accessibility.
- Online advertising towards hearing-impaired individuals, their families and healthcare professionals.[2]

Price strategy: Market competition analysis will determine the establishment of a competitive price, taking into consideration both production costs and the value the product brings. Market competition analysis was executed in the scientific report2 from which the following conclusions resulted:[2]

- Unlike competitors who utilize similar software, our approach for this pair of robotic arms is unique. The graphical interface is built on a codebase written in JavaScript programming language using the Next.JS 14 framework for user interface, while REST APIs integrate the Johnny Five serial communication library. The monitored data and I/O (input/output) are stored in a PostgreSQL database (arelational database supporting transactions). The materials used are significantly better, with the arms being manufactured from Anycubic PLA, a material Significantly better in quality compared to the ABS used by competitors. The amount of material used is minimal (1.4 kg for 92 component parts), making thearms lighter and more efficient. The design is similar to that of competitors but with key improvements. We have added several elements that enhance the functionality and reliability of the arms. Additionally, we have managed to significantly reduce assembly time. Considering all the advantages listed, our competitive price of $4000 is justified.

2.2 Objective specifications of the robotic arm

To fulfill specific needs of users, the product will need to respect the following specifications:

• Functionality: Creating a set of sign language recognition algorithms that work accurately in various lighting and background conditions, as well as a set of tactile gestures on the robotic arms that correspond to common words and concepts in sign language.

• Performance: Establishing clear objectives for the precision and reaction speed of the robotic arms, developing an intuitive and easy-to-use interface for easy arm control, and optimizing the design for portability and ease of transportation.

• Reliability: Conducting extensive testing to guarantee the durability and consistent performance of the robotic arms. Developing a service and technical support plan for customers. Implementing safety features to prevent accidents.

• Inclusive design: Developing the robotic arms will take into account the comfort and ease of wearing for people of different body sizes.

• User testing: To obtain feedback throughout the development process, tests will be conducted with hearing-impaired users.

3. Project management and economic analysis for the development of a pair of robotic arms for hearing-impaired people.

3.1 Project management

Efficient project management for the development of robotic arms requires careful planning and rigorous execution. Key steps include [3]:

• Defining the Scope and Objectives: Clearly establishing the project scope and specific, measurable, achievable, relevant, and time-bound (SMART) objectives is essential to guide team efforts and evaluate progress.

• Project Planning: Breaking down the project into smaller tasks, estimating the necessary resources, and establishing a detailed schedule.

• Resource Management: Efficient allocation of human, financial, and material resources is crucial to optimize performance and minimize costs.

• Monitoring and Control: Constant monitoring of project progress, identifying potential issues, and taking corrective action in a timely manner.

• Risk Management: Identifying, evaluating, and planning strategies to mitigate potential risks are essential to minimize negative impacts on the project.

3.2 Economic Analysis [4].

A detailed economic analysis is essential to evaluate the feasibility of the project and make informed investment decisions, key elements include:

• Development Costs: Estimating the costs associated with research, design, manufacturing, and testing of the robotic arms.

• Operating Costs: Estimating the costs associated with operating and maintaining the robotic arms.

• Economic Benefits: Evaluating the potential economic benefits of the project, such as improving the quality of life for hearing-impaired individuals and increasing productivity.

• Cost-Benefit Analysis: Realizing a cost-benefit analysis to compare the project costs with the anticipated benefits and determine the profitability on investment.

4. Certification, commercialization and recycling of robotic arms for hearing-impaired people

4.1 Certification:

• Safety Standards: Robotic arms intended for hearing-impaired individuals must comply with relevant safety standards, such as SR ISO 10218-1:2011 (Robots and robotic devices - Safety of industrial robots - Part 1: Robots) [5] and ISO 13485:2016 (Medical devices - Quality management systems - Requirements for regulatory purposes) [6].

•Testing Procedures: Robotic arms must be rigorous testing to ensure they are safe and reliable.

4.2 Commercialization:

• Identifying the Target Market: It is important to identify the target market for robotic arms. This includes hearing-impaired individuals of all ages, as well as professionals who work with hearing- impaired individuals, such as speech therapists and audiologists.

• Marketing Strategies: Efficient marketing strategies need to be developed to reach the target market.

•Distribution Channels: Efficient distribution channels need to be established to make robotic arms available to customers. These may include medical distributors, online stores, and hospitals.

4.3 Recycling:

•Recyclable Materials: Robotic arms are made from a recyclable material, namely PLA (polylactic acid), which is a biodegradable material, meaning it can be decomposed by microorganisms under appropriate conditions without polluting the environment.

•Recycling Programs: Recycling programs need to be developed for robotic arms at the end of their lifespan. These programs should be easily accessible to customers and ensure responsible waste elimination.

•

5. Manufacturing and Testing of Robotic Arms

Manufacturing involves a series of steps, from designing and fabricating individual components tothe final assembly of the arms. Testing involves evaluating the performance of the arms in various scenarios and identifying potential issues.

5.1 Designing and Manufacturing Components

Designing the component elements of robotic arms for hearing-impaired individuals involves developing and conceptualizing these elements to ensure optimal, intuitive, and safe operation ofthe robotic arms. The component elements of the robotic arms were designed using the CATIA V5 program [7].

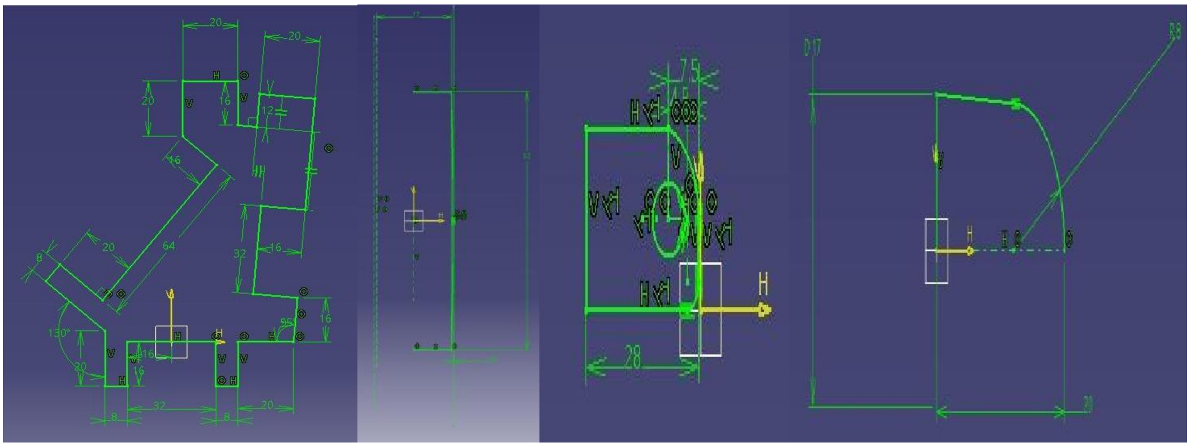


Fig 5.1 The sketches of some component parts that are part of the assembly of robotic arms

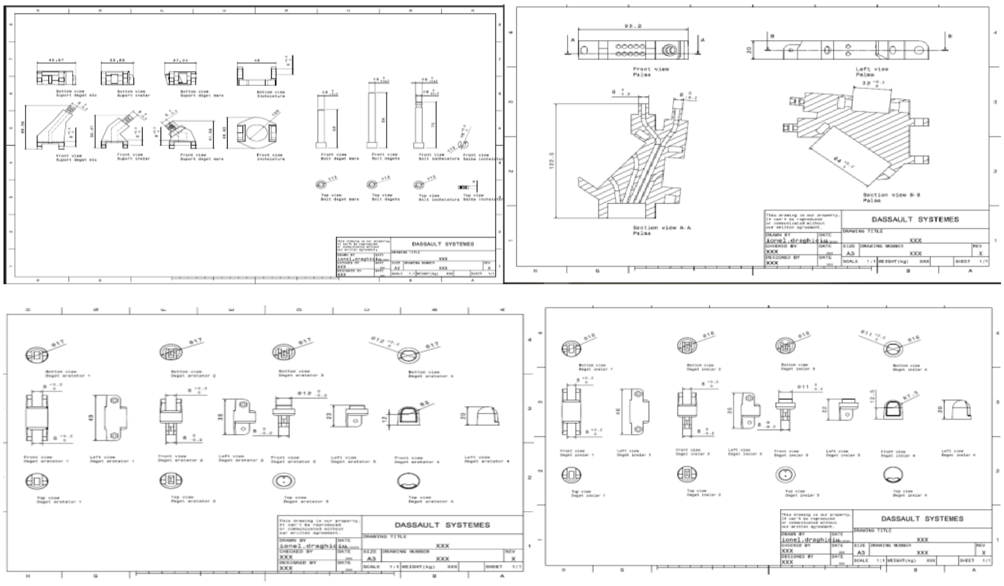


Fig. 5.2 execution of components within the assembly of robotic arms.

The components where manufactured using 3D printers, Ender3 and Ender3Pro,and the software used is called PrusaSlicer. The printers and the software were utilized to select the most optimal printing parameters.

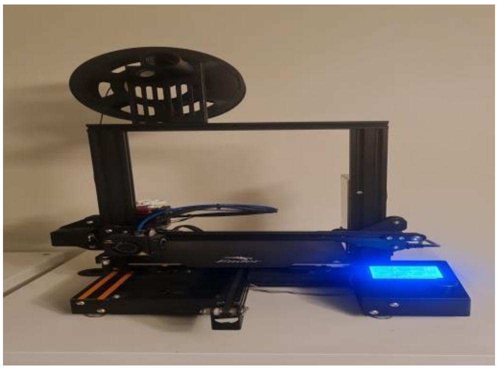


Fig. 5.3 The printer used Ender 3 Pro

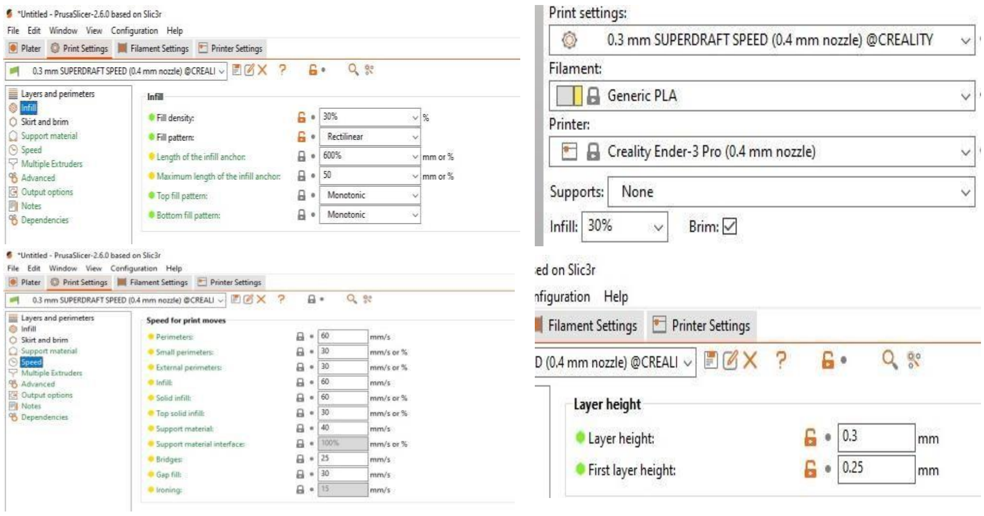


Fig. 5.4 Optimal manufacturing parameters for components

The nozzle diameter through which the filament passes is 0.3mm, with each layer of the printed element being 0.3 mm thick. The component parts in this assembly are printed with a density of 30%, which represents the percentage of material used to fill the interior of the parts. The printing speed of the assembly parts is 60mm/s. Printing of the elements was done at 210°C extruder temperature and 60°C bedtemperature of the printer. A printed and assembled robotic arm reaches the size of a human arm 45cm**.**

Fig. 5.5 The components of the arms on the printer bed in the program

In the manufacturing process of robotic arm components, was used printing technology thin layer to achieve precise details and polished surface.

This thing it's important to ensure a good interaction and safe with printed elements.

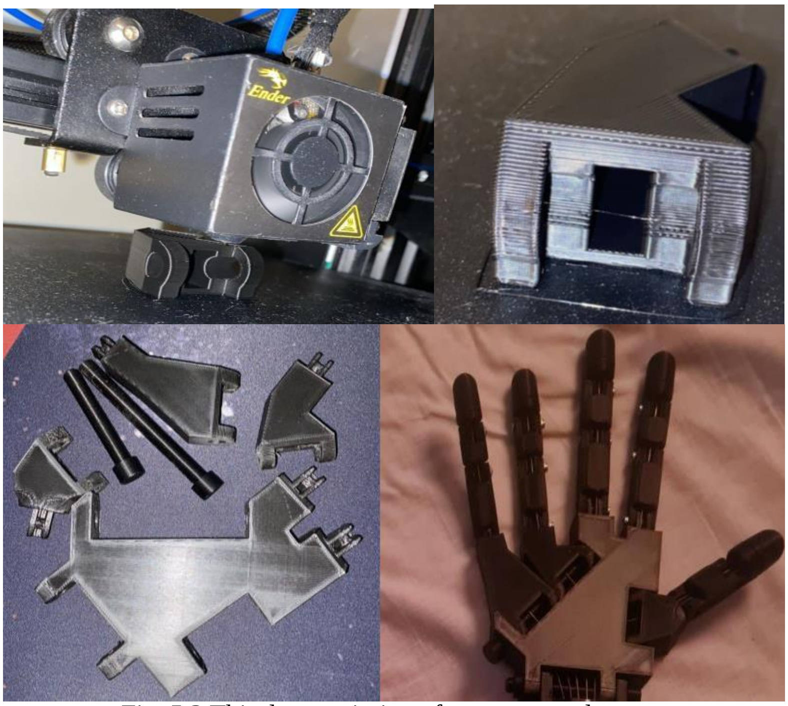


Fig. 5.3 Thin-layer printing of component elements

5.2 Assembling the arms

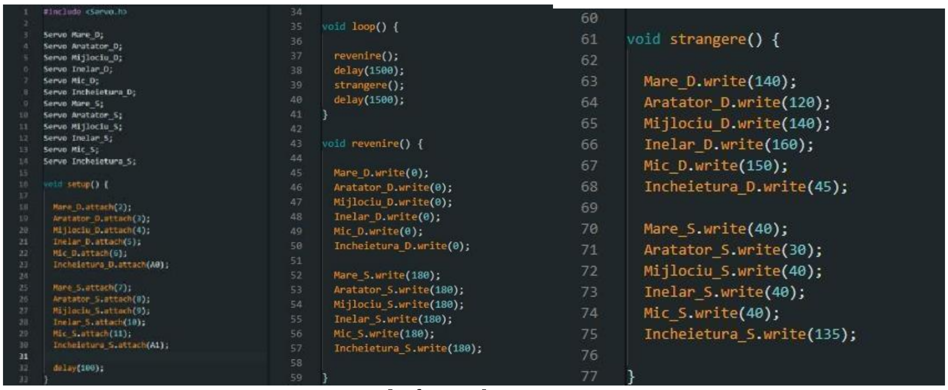
Once the individual components have been manufactured, they are assembled to form the robotic arms. This process involve mechanically connecting and configuring the control software. Assembly mustbe done with attention to ensure that the arms works correctly and are safe to use.

Fig. 5.4 Final assembly of robotic arms

5.3 Testing the Arms

Robotic arms must be tested rigorously to ensure they function according to specifications and are safe to use. Testing involves a series of different scenarios, including simple movements, object manipulation and interaction with surrounding environment. Any issue identified during testing must be fixed before the arms can be used by hearing-impaired people.

Testing code for closing and opening the robotic arms. The code was created in Arduino IDE 2.2.1 software to test the closing and opening of the robotic arms.



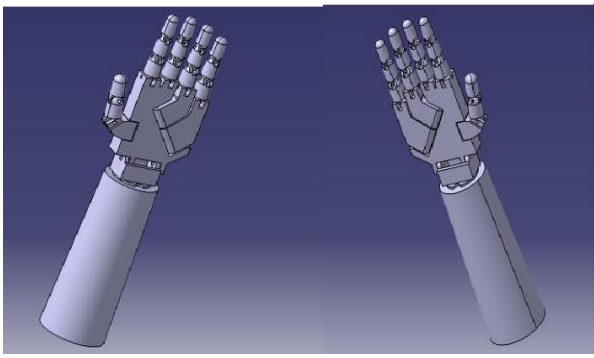
```
#include <Servo.h>

Servo Mare_D;
Servo Aratator_D;
Servo Mijlociu_D;
Servo Inelar_D;
Servo Mic_D;
Servo Incheietura_D;
Servo Mare_S;
Servo Aratator_S;
Servo Mijlociu_S;
Servo Inelar_S;
Servo Mic_S;
Servo Incheietura_S;

void setup() {

  Mare_D.attach(2);
  Aratator_D.attach(3);
  Mijlociu_D.attach(4);
  Inelar_D.attach(5);
  Mic_D.attach(6);
  Incheietura_D.attach(A0);

  Mare_S.attach(7);
  Aratator_S.attach(8);
  Mijlociu_S.attach(9);
  Inelar_S.attach(10);
  Mic_S.attach(11);
  Incheietura_S.attach(A1);

  delay(100);
}

void loop() {

  revenire();
  delay(1500);
  strangere();
  delay(1500);
}

void revenire() {

  Mare_D.write(0);
  Aratator_D.write(0);
  Mijlociu_D.write(0);
  Inelar_D.write(0);
  Mic_D.write(0);
  Incheietura_D.write(0);

  Mare_S.write(180);
  Aratator_S.write(180);
  Mijlociu_S.write(180);
  Inelar_S.write(180);
  Mic_S.write(180);
  Incheietura_S.write(180);

}

void strangere() {

  Mare_D.write(140);
  Aratator_D.write(120);
  Mijlociu_D.write(140);
  Inelar_D.write(160);
  Mic_D.write(150);
  Incheietura_D.write(45);

  Mare_S.write(40);
  Aratator_S.write(30);
  Mijlociu_S.write(40);
  Inelar_S.write(40);
  Mic_S.write(40);
  Incheietura_S.write(135);

}
```

Fig. 5.5 Testing Code for Robotic Arms

6. Conceptual Design

The main purpose is to create a system that facilitates communications and interaction efficiently for the hearing-impaired people with surrounding environment, overcoming auditory barriers.

To select the optimal concept for finalizing the robotic arms, the initial phase was designing the component elements differently, as a consequence following an analysis we have chosen the most suitable concept for finalizing the robotic arms.



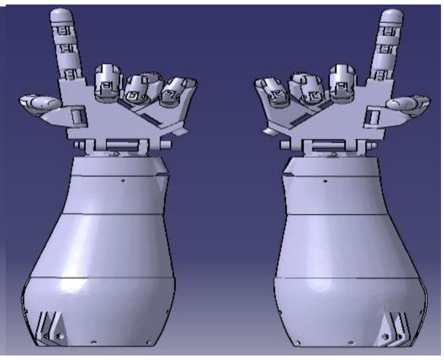


Fig. 6.1 The initial design of the robotic arms Fig. 6.2 The final design of the robotic arms

The initial printing of the component elements was done using ABS material. Following a material analysis conducted using the CATIA V5 application, specifically a Finite Element Analysis (FEA), it was found that ABS does not have as high a strength as PLA Anycubic, which is used in the manufacturing process of robotic arms.

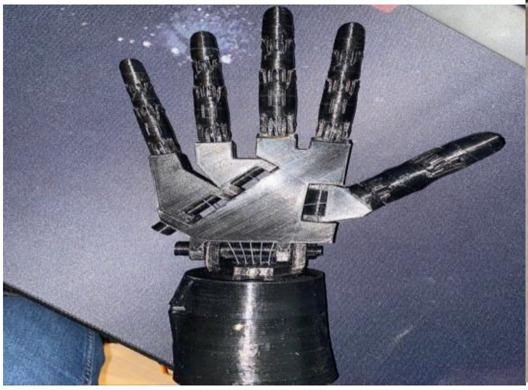



Fig. 6.3The robotic arm made with ABS material. Fig. 6.4 The robotic arm made with PLA material.

7. Detailed Design

The robotic arms need to meet a series of specific requirements to be effective in communicating with hearing-impaired people [9]. These requirements include:

- Precision and Dexterity: The arms must be capable of performing precise and delicate movements to accurately reproduce sign language gestures.
- Strength and Durability: The arms must be strong enough to express sign language effectively.
- Ergonomics and Comfort: The arms must be comfortable to use for extended periods.
- Safety: The arms must be safe for the user and those around them.

Components of Robotic Arms

Robotic arms designed for communication with hearing-impaired people typically consist of thefollowing components:

7.1 Elements Used for Assembling and Operating a Robotic Arm

- 46 printed parts- Textile thread of 0.8 mm, approximately 70 mm in length for a finger,6 MG 995 servomotors,40 screws,20 nuts,10 elastics for finger thread tensioning,10 tubes for threading to the fingers, Arduino, Servo motor shield, RD 50A power supply of 5V with 6A

Printed parts for a robotic arm:

- 1 palm,14 phalanges,5 fingertip parts,3 finger supports (large, ring, small),3 support pins (ring and small finger support, thumb support, wrist),1 locking washer for the wrist pin,1 wrist,2 gears for the wrist and wrist servomotor,1 wrist support,1 wrist servomotor support,2 guides for connecting wires,1 tensioner,1 servo motor support,5 servo motor pulleys,4 forearm housings,1 cover.

7.1 The components used for the construction and operation of robotic arms.

8. Conclusion

The research highlights an innovative and multidisciplinary effort in the field of applied robotics to address the specific needs of individuals with hearing impairments. This study demonstrates the importance of integrating robotics, signal processing, and human-computer interaction to create a robotic system that is adaptable, efficient, ergonomic, and meets all the conditions imposed by its users. The fabrication and testing of a pair of robotic arms for communication with hearing-impaired individuals is a complex process that involves several different stages. It is essential that all components are designed andmanufactured with precision and that the arms are rigorously tested to ensure they function correctly and are safe to use. When designing and manufacturing the arms, it is crucial to consider the specific needs of hearing-impaired individuals. The conceptual design of robotic arms for communication with hearing- impaired individuals is a complex process that requires special attention to the specific needs of the users.The detailed design of robotic arms for communication with hearing-impaired individuals is a challenging task that necessitates a multidisciplinary approach. The arms must be precise, strong, ergonomic, and safeto be effective in communicating with hearing-impaired individuals. Successfully developing robotic arms for hearing-impaired individuals requires a comprehensive approach that considers technical, regulatory, commercial, and environmental aspects. This includes adhering to safety standards, complying with regulatory requirements, and implementing effective marketing and distribution strategies.

9. Bibliography

[1]. Lambdageeks, "Robotic Arm Design Types Applications", Available at https://ro.lambdageeks.com/robotic-arm-design-types-applications/ - accessed on 26.03.2024 [2]. Investopedia, "Marketing Strategy", Available at https://www.investopedia.com/terms/m/marketing-strategy.asp - accessed on 07.04.2024

[3]. PMI, "Project Management Professional", Available at https://www.pmi.org/ - accessed on01.05.2024

[4]. Wikipedia, "Financial analysis", Available at https://en.wikipedia.org/wiki/Financial_analysis -accessed on 02.05.2024

[5]. ISO, "ISO 10218-1:2011", Available at https://www.iso.org/standard/51330.html - accessed on08.05.2024

[6]. ASRO, "SR EN ISO 13485:2016", Available at https://magazin.asro.ro/ro/standard/245721 -accessed on 08.05.2024

[7]. CATIA, "Catia", Available at https://www.catia.ro/ - accessed on 10.05.2024

[8]. ArduShop, "3D Printing", Available at https://ardushop.ro/ro/content/23-printare-3d - accessedon 12.05.2024

[9]. Arockia Selvakumar Arockia Doss, Birupakshya Mishra, Safal Mohammed, Pavan Kalyan Lingampally & Michael Short, "Robotic Arm for Biomedical Applications" – 2022 – Springer Reference

DEVELOPING A PROTOTYPE OF A FLEXIBLE COLD PRESS CELL

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ABSTRACT: The topic addressed in the dissertation is the development of a flexible pressing cell.

The assembly defining the flexible pressing cell consists of the following components: Robotic Arm, Hydraulic Press, Pneumatic Press, Conveyor, Matrix Rack, Robotic Arm Support.

The purpose of the flexible pressing cell is to be configurable to perform various processing or assembly procedures automatically and to allow remote command and control via the internet.

Thus, for the software component to be realized, the use of the LabView programming environment was necessary.

The project developed in the dissertation proposes the integration of multiple software components to create an automatic production flow.

KEYWORDS: Press, Robotic Arm, Conveyor, Cell.

1.Introduction

For the project development, in the initial phase, the components that will define the ensemble called the "Flexible Cold Pressing Cell" were studied.

The chosen components are as follows:

- Robotic arm
- Conveyor
- Pneumatic press
- Hydraulic press
- Matrix-type rack

The final aim of the project involves the creation and automation of a prototype of a flexible cold pressing cell designed to facilitate the execution of a complete production flow.

The production flow consists of a series of events aimed at reducing human resources within the process and simultaneously increasing the efficiency of production time and costs.

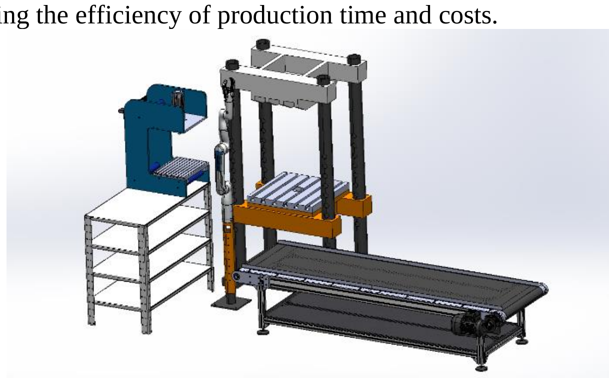

Fig. 1. 3D Model Flexible pressing cell.

The stages of the production flow are carried out as follows:

- The introduction of semi-finished products into the pressing cell by a human operator or by an auxiliary automated system.
- The conveyor takes the semi-finished products and delivers them to the position from where they will be picked up and identified by the robotic arm.

- Identification of the semi-finished products is carried out through image analysis using a camera attached to the surface of the robotic arm.
- Subsequently, the processing order of the semi-finished product is determined after identifying the type of semi-finished product.
- The robotic arm will move the semi-finished product taken from the conveyor in the pre-established processing order specific to the type of semi-finished product to one or each press in the correct order.
- After positioning the semi-finished products on the surface of one of the presses, the robotic arm will retract from the action area of the press and will start the processing.
- Upon completion of the processing procedure, the arm will return to the processed semi-finished product and move it to the next processing point or to a position on the surface of the matrix-type rack.
- The piece resulting from the production flow will be extracted from the system by a human operator or with the help of an auxiliary automated system.

Additionally, to optimize production time, the automation of the pressing cell will be enhanced so that, if the order of entry into the system allows, multiple pressing operations can be performed simultaneously.

2. Current State

To determine the current state regarding the flexible pressing cell, various flexible cells offered by other manufacturers were analyzed, such as:

- KUKA ready2_educate

KUKA ready2_educate is a variant of a processing cell with a didactic purpose offered by the manufacturer KUKA. It represents a modular industrial cell variant in which various accessories, as well as microcontrollers and data acquisition boards, can be integrated.[1]

Fig. 2. KUKA ready2_educate.

- KUKA cell4_FSW

KUKAcell4_FSW is a proposed flexible cell used in welding processes offered by the manufacturer KUKA. It promises increased efficiency resulting in fast production times and reduced production costs.

Additionally, KUKAcell4_FSW is accompanied by a software application that provides the ability to monitor and control the process remotely. [2]

Fig. 3. KUKAcell4_FSW.

3. Development of Hardware Equipment

After choosing the components that will define the flexible pressing cell, the stage of designing their arrangement within the cell and defining the space they will occupy was completed.

Using the SolidWorks application, the components of the cell were modeled and assembled so that the robotic arm can correctly reach each work point.

After designing the 3D model, the assembly or verification stage for each of the component equipment that make up the cell followed.

For each piece of equipment, visual inspections, mechanical functionality checks, and thorough inspections of the electrical systems were carried out.

As a result of the inspections, improvements or repairs were made to the equipment.

After confirming the correct functionality of the equipment in all respects, solutions were implemented for the control of the equipment and the acquisition of data related to their state.

The options used for this purpose are represented by Arduino MEGA development boards and National Instruments data acquisition boards.

The monitoring and control of the conveyor and the pneumatic press were carried out using Arduino MEGA development boards.

Fig. 4. Arduino MEGA.[3]

A modular system of National Instruments cDAQ-9172 data acquisition boards was implemented on the hydraulic press.

Fig. 5. NI cDAQ-9172.[4]

To integrate the Arduino MEGA development boards and the NI cDAQ-9172 data acquisition board, it was necessary to make electrical connections between the control instruments of the equipment and the signal inputs within the control modules.

4. Development of Software Applications.

To develop the software applications aimed at automating the cell, it was necessary to define a software architecture on which the applications were built.

Thus, using the Microsoft Visio application, the communication architecture between the equipment was modeled and defined.

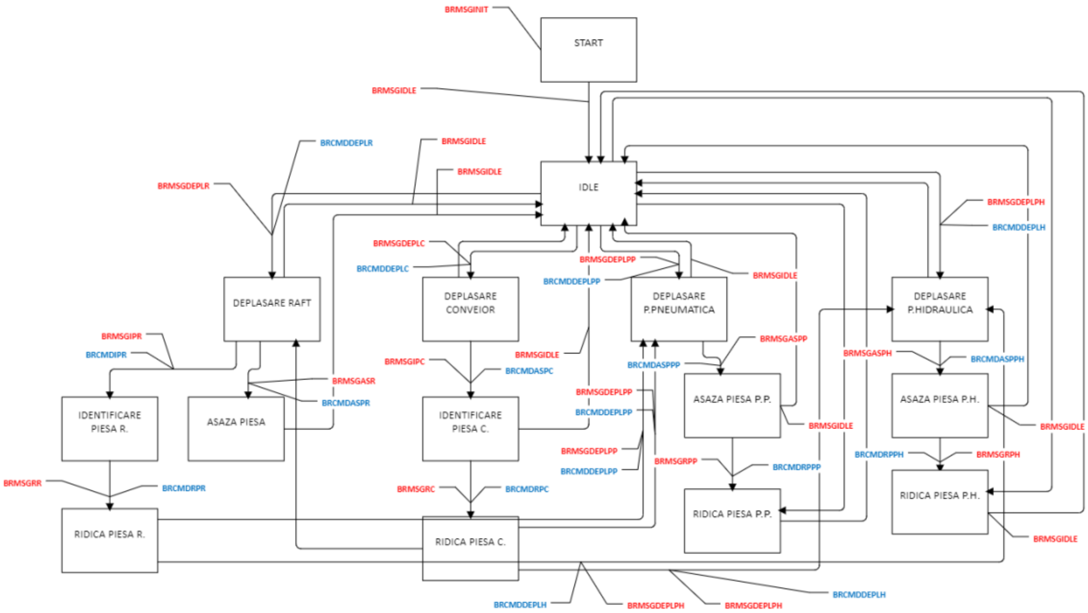

Fig. 6. Software Component Architecture

To develop the software applications, the LabVIEW programming environment was used. LabVIEW provides a simple and intuitive platform for implementing software solutions, while also offering a wide range of opportunities for integrating various types of components.

As the communication protocol between the subsystems of the pressing cell assembly, the MQTT (Message Queuing Telemetry Transport) protocol was chosen. This protocol relies on "PUBLISH" and "SUBSCRIBE" functions, which publish to or subscribe to topics.[5]

Through each topic, data (text type in the case of the project addressed) is transmitted, which serves to implement communication between the elements of the flexible pressing cell.

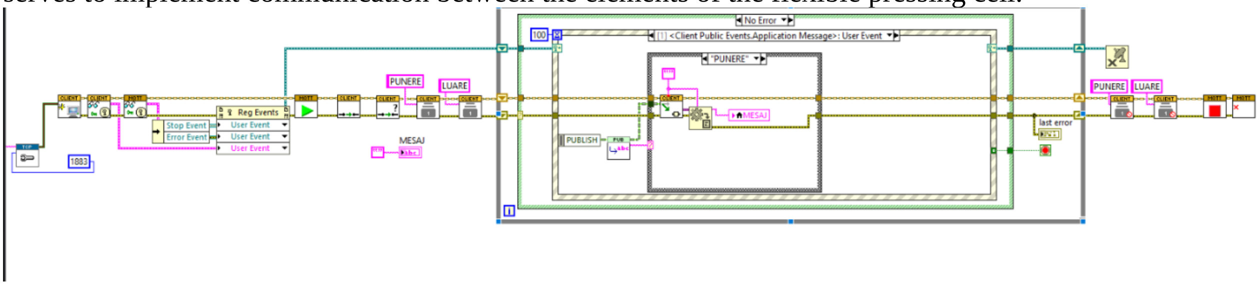

Fig. 7. „SUBSCRIBE" Function.

The applications underlying the equipment operate sequentially and are executed in order according to the architecture established in the early phase of software component development.

Thus, each equipment communicates its current state on a specific topic and, if necessary, queries the state of other equipment in the system to determine the action it will take.

5. Testing.

In this stage, the complete assembly of the pressing cell will be functionally tested to ensure proper operation of the equipment, and adjustments will be made to optimize production time.

6. Summary.

Due to the precision of execution and the speed of communication between equipment, implementing a flexible cold pressing cell represents the optimal solution for cost and time efficiency within a production process aimed at achieving a considerable production flow.

7. Bibliography

[1] ***, „KUKA ready2_educate", available at https://www.kuka.com/en-de/products/robot-systems/ready2_use/kuka-ready2_educate , [Accessed on 07.05.2024].

[2] ***, „KUKA cell4_FSW", available at https://www.kuka.com/en-de/products/production-machines/kuka-cell4_fsw-friction-stir-welding-cell , [Accessed on 07.05.2024].

[3] ***, „Arduino MEGA", available at https://ro.farnell.com/arduino/a000067/arduino-mega2560-rev3-board/dp/2212779 , [Accessed on 09.05.2024].

[4] ***, „ NI cDAQ-9172", available at https://www.ni.com/ro-ro/support/model.cdaq-9172.html , [Accessed on 09.05.2024].

[5] ***, „ MQTT", available at https://www.emqx.com/en/blog/the-easiest-guide-to-getting-started-with-mqtt , [Accessed on 10.05.2024].

HYDROGEN ELECTRIC BIKE

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ABSTRACT: In this paper, we will perform a detailed analysis of the aspects of aerodynamics and parameter control in the fuel cell with respect to hydrogen bicycles. We will examine how the design and construction of these bikes influence aerodynamics during movement, and what improvements we can make. This analysis will provide a deeper understanding of the performance and safety factors associated with such a vehicle.

KEYWORDS: Hydrogen fuel cells, High pressure storage, Energy management, Efficiency optimization, Urban mobility, Aerodynamics

1. Introduction

Electric bicycles (e-bikes) have proven to be a promising solution for sustainable urban mobility, offering reduced emissions and greater accessibility compared to traditional vehicles. However, limitations in range and battery charging infrastructure for e-bikes may pose a significant challenge to widespread adoption. In this context, the present paper investigates the integration of hydrogen fuel technology in electric bicycles to overcome these obstacles and promote clean energy transportation. By developing and simulating a 3D CAD model for a hydrogen electric bicycle, this study aims to contribute to the expansion of research into alternative energy vehicles and sustainable mobility solutions.

2. Review of specialized literature

Previous research has demonstrated the potential of e-bikes to reduce greenhouse gas emissions, reduce traffic congestion and promote active transportation. Advances in battery technology, engine efficiency and design optimization have led to significant improvements in the performance and usability of these types of vehicles. In parallel, hydrogen fuel technology has emerged as a promising alternative energy source, offering high energy density, fast recharge times and zero emissions. However, the integration of hydrogen fuel cells in electric bicycles remains relatively unexplored in the literature. This review aims to address this gap by examining existing research on electric bicycles, hydrogen fuel technology and 3D CAD modeling in bicycle design.

3. Pressure level simulation

A hydrogen fuel cell is an electrochemical device that converts the chemical energy of hydrogen and oxygen into electricity, heat and water. This technology offers an efficient and clean way to produce electricity and heat with low pollutant emissions.

As part of our first numerical study, we performed a simulation using LabView software to analyze the variation of pressure and temperature inside the fuel cell. These two parameters are essential for efficient cell operation and optimal hydrogen transfer under form of energy. Since we did not have an existing physical model to obtain real data, we defined two variables to enter optimal initial values, and then observed how these parameters varied with changes in temperature and pressure during the simulation. This analysis allowed us to observe the fluctuations over time, to determine if we have constant cycles and over what length of time. In order to perform a more detailed analysis, we created a graphical representation at runtime inside the program and stored reports with the values obtained according to the simulation sequences performed.

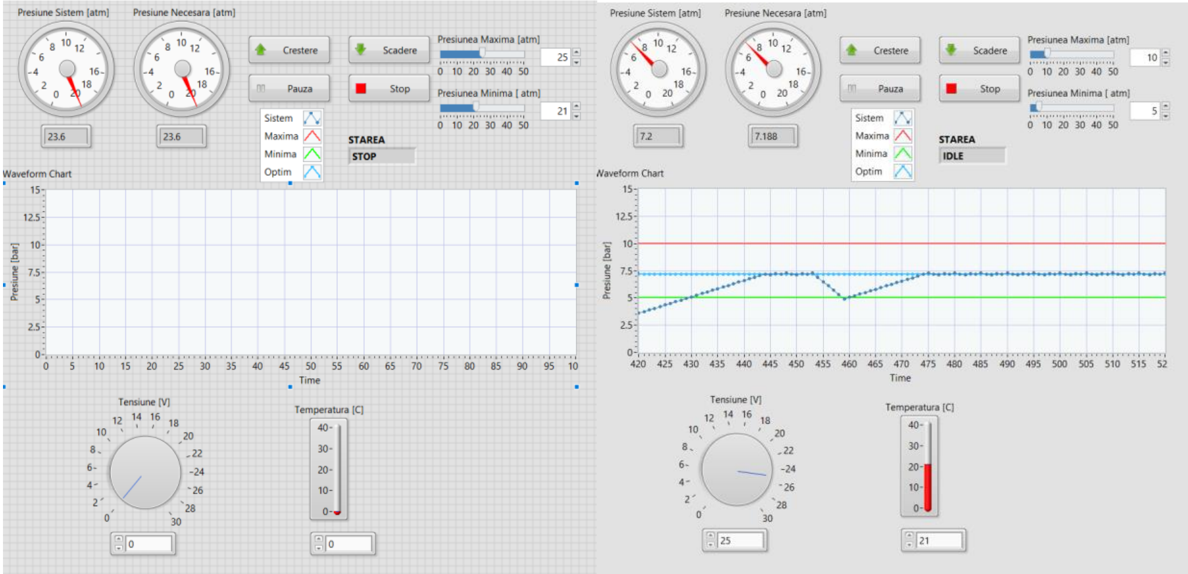

Fig.1 The interface of the program in pause and running state

The program automatically adjusts the optimum pressure level, adapting it to the voltage requirements of the fuel cell and the air temperature. We define a [Min, Max] range along with a target value for the desired pressure. Fluctuations in pressure are accepted as long as they remain within this range. When the upper or lower limit of the range is reached, the program initiates a correction by increasing or decreasing the pressure, depending on the limit reached (upper or lower). Once the optimal pressure is reached, the program waits for the preset interval to be exceeded to resume the correction process.

The formula underlying this algorithm is the following:

$$P_{H_2} = P_{O_2} \cdot e^{\frac{n \cdot F}{R \cdot T}V} \quad [8]$$

Where:

- n (the number of electrons transferred) = 2
- F (Faraday constant) = 96.485 coulombs/mol
- R (gas constant) = 8.314 J
- T (temperature in K) = variable
- V (voltage in V) = variable

4. Realization of the 3D Model

To begin, we started from a conventional bicycle design that was easily adapted for our innovative concept. We used the Catia V5 design program, a design tool used extensively in industry to develop and analyze complex models. In the initial stage of the project, we explored several proposed models for hydrogen fuel technology. We wanted to identify solutions that had already been tested and make improvements where we noticed potential problems or where current solutions were not optimal.

Here are some of the analyzed models:

Table 1. Competition analysis

Competing products	Product specifications
 The Linde Group – Linde H2 bike(1)	Country of origin: Germany Mass: 23.6 kg Speed: 25 km/h Dimensions: 1850x1100x800 mm Autonomy: 100 km Feeding time: 6 min Price: €3500
 Pragma Industries – Alpha Hydrogen Bicycle(2)	Country of origin: France Mass: 30 kg Speed: 25 km/h Dimensions: 1900x1050x650 mm Autonomy: 150 km Feeding time: 9 min Price: €4700
 Youon Technology Co Ltd – Y800(3)	Country of origin: China Mass: 25 kg Speed: 20 km/h Dimensions: 1340x1100x880 mm Autonomy: 60 km Feeding time: 4 min Price: -
 University of New South Wales - Hy-Cycle(4)	Country of origin: Australia Mass: 32 kg Speed: 35 km/h Dimensions: 1900x1030x750 mm Autonomy: 125 km Feeding time: 5 min Price: $2600

The process involved careful analysis of the technical and functional requirements for a hydrogen bicycle, including hydrogen storage capacity, fuel cell system integration, and design optimization to ensure aerodynamic performance and efficient operation. The current model made is very satisfactory for our requirement, certain points remain that will be optimized after several trials and tests that we will run, especially on a physical model.

4.1 Assembly components

The 3D CAD model made for the hydrogen electric bicycle incorporates several innovative features designed to improve performance and user experience. This bike is designed to offer a clean and energy-efficient alternative to conventional gasoline or electric models.

The main technical specifications include:

● **Lightweight aluminum frame:** To keep the overall weight of the bike to a minimum, we chose a high-quality aluminum frame that offers durability and corrosion resistance.

● **High-efficiency electric motor:** The bike is equipped with a high-performance electric motor that provides optimal power and torque for a pleasant and efficient pedaling experience.

● **Compact hydrogen fuel cell system:** To power the electric motor, we have integrated a compact group of hydrogen fuel cells. This system converts hydrogen and oxygen into water, while generating clean, emission-free electricity.

Renderings and 3D visualizations illustrate the bike's design from multiple perspectives, highlighting its aerodynamic and sleek profile. The shape and contours are optimized to minimize air resistance, allowing the rider to move quickly and efficiently. Ergonomic and aesthetic aspects are also taken into account to provide a pleasant and functional user experience.

The hydrogen electric bicycle is an innovative and sustainable solution for urban and recreational mobility, combining advanced fuel cell technology with the benefits of a modern electric bicycle.

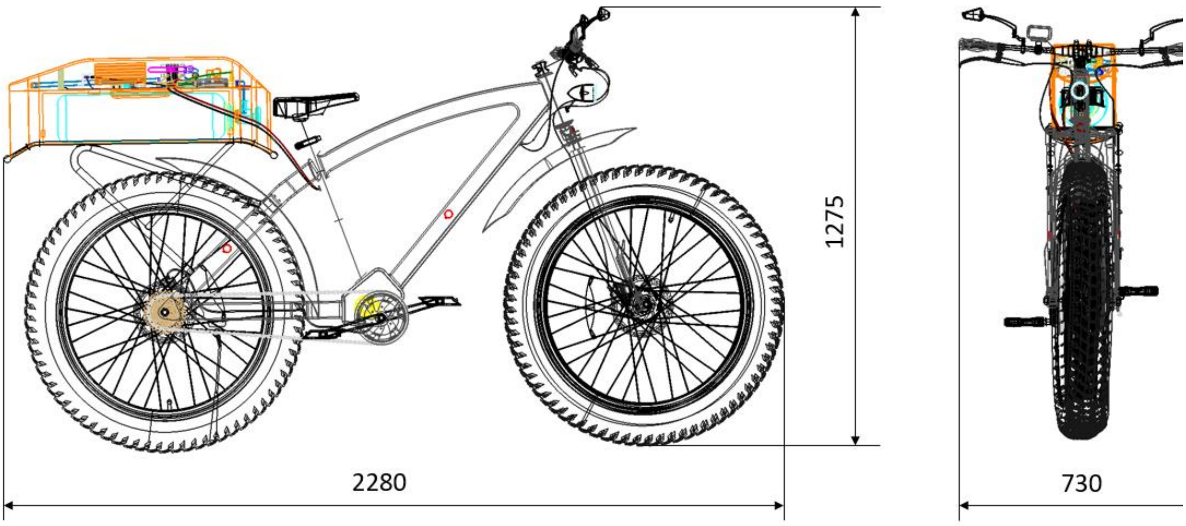

Fig.2 Bicycle assembly

In the presented CAD model we also have a proposal for replacing the hydrogen tank, the compartment attached to the bicycle frame has a hatch for opening the case where the tank is located, it can be easily replaced without imposing too many constraints.

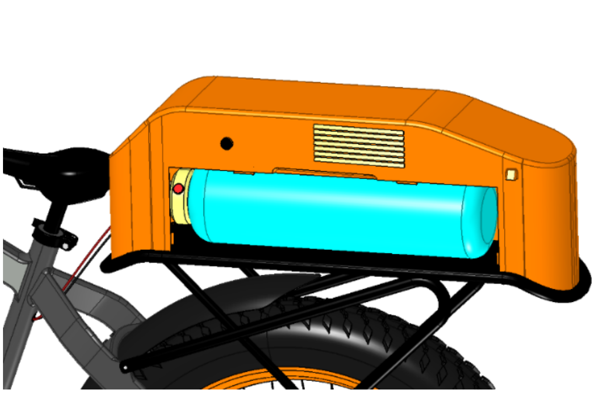

Fig.3 Quick changeable hydrogen tank

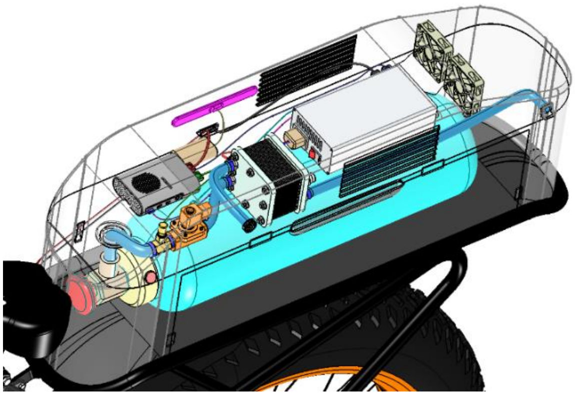

Fig.4 Fuel system components

The closing system has clips between the hatch and the body to prevent sudden opening in the event of an impact, the hydrogen tank is sealed inside to prevent it from falling or impacting during shocks. The positioning of the fuel tank compartment was chosen following the analysis of models already developed by other researchers in the field. In most of the models already made, its placement was done on the bicycle frame, we found this solution to be risky, especially for a hydrogen tank, but also a more inconvenient option for the user. I found the position on the frame to be the easiest in case of a possible incident and less uncomfortable.

4.2 Aerodynamic simulation

Considering that we are dealing with a means of transport, aerodynamics is a very important aspect in analyzing the feasibility of the product. All components of a bicycle can impact aerodynamics, from handlebars, frame, wheels to any accessory present.

In order to better understand this phenomenon, we made an analysis of our product, performing an aerodynamic simulation using the Autodesk CFD 2021 program, and analyzing the specialized literature regarding the aerodynamics of transport vehicles.

The basic formula of aerodynamics is the following:

$$D = \frac{1}{2}\rho V^2 A C_D \quad [7]$$

Where:

- D = aerodynamic drag;
- ρ = air density;
- V = relative speed;
- A = surface area;
- C_D = drag coefficient;

As can be understood from the given formula D, drag is a force impacted by several factors. The Greek letter ρ represents the air density, and V is the relative speed, as you can see it is squared, this means that a cyclist who goes twice as fast will feel the air resistance four times stronger. Furthermore, we are impacted by the frontal surface, more precisely the whole part of the body with which we move forward, in short, the smaller we are, the less opposition we will feel from the air. The last factor represented is the coefficient of aerodynamic resistance, this factor cannot necessarily be simplified or calculated because it is greatly impacted by fluctuations in speed, the stiffness of the surface on which we move, in technique this value is first the simulation of several sequences where they are taken into calculation of various factors, including positions of the cyclist during travel.

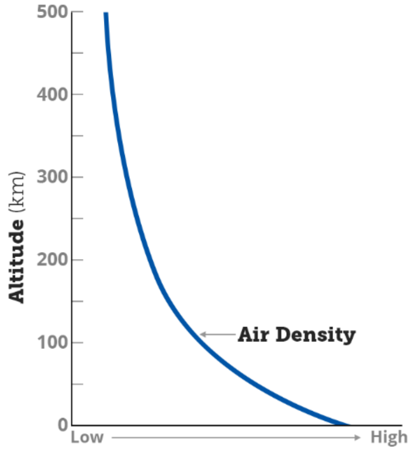

Fig.4 Graph of air density

Following this study to understand the aerodynamics, we performed as mentioned above an aerodynamic simulation for the hydrogen tank storage compartment along with the fuel cell infrastructure. Being currently a proposal, the results will be interpreted as such, not having a feasibility study on the casing by a specialist in resistance structures. At the moment we are focusing on the aerodynamics part to know the constraints from which we will start in the wider development of this product and to be able to decide future implementations at the level of 3D modeling of the part.

In the following images you can see the passage of air past the hydrogen compartment and the force with which it opposes the air:

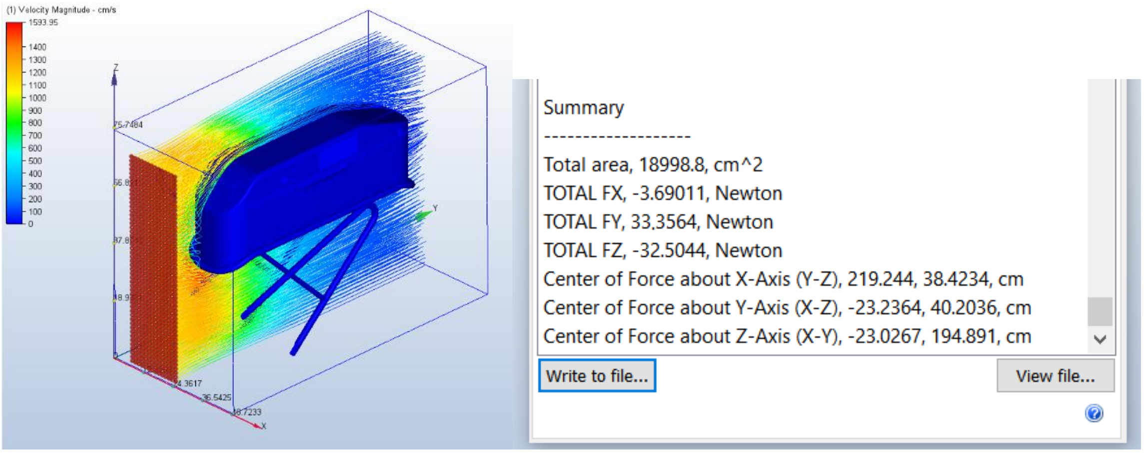

Fig 5. Simulation results

As results, we obtained approximately an aerodynamic resistance with a value of 33 N at a speed of 45 km/h. Compared to the current state of the case we can say that we are in the average parameters, we can draw the conclusion that the product is feasible and can be adjusted according to the requirements that will follow.

5. Case study

The results of the CAD modeling and simulation process demonstrate the feasibility and potential benefits of integrating hydrogen fueling technology into electric bicycles. Compared to current electric bikes, hydrogen-powered ones offer an extended range, faster refill times and a much lower environmental impact. Furthermore, the bike's modular design allows for easy customization and adaptation to different user needs and preferences. However, challenges such as hydrogen storage and distribution infrastructure as well as consumer acceptance and regulatory barriers must be addressed to realize the full potential of this technology.

6. Conclusions

This paper provided a detailed exploration of the complex systems and their interactions in hydrogen electric bicycles. Perfect coordination between hydrogen fuel cells, high-pressure storage and advanced energy management is essential for efficient energy use. The practical insights gained from this study contribute to ongoing efforts to optimize the performance and sustainability of hydrogen electric bicycles, enhancing their potential as viable solutions for green urban mobility.

7. Future research directions

Future research will look at improving the efficiency of hydrogen fuel cells, exploring advanced materials for high-pressure storage, and optimizing energy management algorithms for even greater optimization. The ongoing global interdisciplinary research in this field will undoubtedly contribute to the evolution and advancement of hydrogen electric bicycles as sustainable and practical solutions.

8. Bibliography

[1]. A.R. Hillman, 2019, Electrochimica Acta - The official journal of the International Society of Electrochemistry (ISE) ;
[2]. AUSTIN Hughes, BILL Drur, 2013, Electric Motors And Drives - Fundamentals, Types and Applications, Fourth Edition;
[3]. DUMITRESCU Andrei, OPRAN Constantin, 2002; Materiale polimerice, Caracterizare,Proprietăți, Prelucrare; Oficiul de informare documentara pentru industrie, cercetare management, București, România;
[4]. FRANCO Barbir, ANGELO Basile and NEJAT T. Veziroğlu, 2016, Compendium of Hydrogen Energy Volume 3: Hydrogen Energy Conversion;
[5]. GAVIN Walker, 2008, Solid-State Hydrogen Storage - Materials and Chemistry - Woodhead Publishing Series in Electronic and Optical Materials;
[6]. GUNO-BIN Jung - Department of Mechanical Engineering of Yuan Ze University, Taoyuan City,2019, Innovative Membrane Electrode Assembly (MEA) Fabrication For Proton Exchange Membrane Water Electrolysis;
[7]. HERSHEL Solomon, 2018, Fundamentals of Aerodynamics, Larsen & Keller Education
[8]. HUSSAIN Mohd Azlan, 2021, Modelling and Process Control of Fuel Cell Systems, Mdpi Ag
[9]. ION Sorin Mihai, NITOI Dan, CHIVU Oana, OPRAN Constantin Gheorghe, 2021, Finite element modelling of a plan polymeric composite product under impact and thermal conditions;
[10]. JÜRGEN Garche, C. Dyer, P. Moseley, Z. Ogumi, D. Rand, B. Scrosati, 2009, Encyclopedia of Electrochemical Power Sources;
[11]. OPRAN Constantin, NICOLAE Vasile, RACICOVSCHI Vasile, 2004, Biostructuri polimerice degradabile în mediu natural, VASILE GOLDIS University Press, ARAD, România;
[12]. OPRAN Constantin Gheorghe, 2017, Tehnologia Produselor din Materiale Avansate – Editura Bren, București, România;
[13]. SRIVATSA Raghunath, 2021, Hardware Design Considerations for an Electric Bicycle - Texas Instruments, Houston;
[14]. STEVEN L. Suib, 2013, Future Developments In Catalysis, Batteries, Hydrogen Storage And Fuel Cells, Department of Chemistry and Chemical Engineering and Institute of Materials Science, The University of Connecticut;
[15]. SUDDHASATWA Basu, 2007, Recent Trends In Fuel Cell Science And Technology, Springer;

(1) http://www.linde-gas.com.my/en/innovations/hydrogen_energy_h2/h2_bike/index.html - accessed in 18.05.2024
(2) https://pragma-mobility.com/en/ - accessed in 18.05.2024
(3) https://www.youonbikeshare.com/HydrogenBicycle/Y800 - accessed in 18.05.2024
(4) https://merlin-h2.com/ - accessed in 18.05.2024

RESEARCH ON THE DEVELOPMENT OF AN ELECTRONIC MONITORING AND LOCALIZATION DEVICE FOR PEOPLE WITH SPECIAL NEEDS

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ABSTRACT: In the context of the rapid advancement of assistive technologies, special attention is given to the development and implementation of electronic devices that meet individual needs, regardless of the user's motor and cognitive abilities. The article presents a comprehensive analysis of the potential of a monitoring and localization device for people with special needs, designed in the form of a wristband. By synthesizing the results of previous research and presenting the functional prototype, the current research highlights the significant contribution that this technology can make to improving the quality of life and individual security. Additionally, by exploring economic and commercial aspects, the article underscores the market potential for these devices, highlighting business opportunities and marketing strategies necessary for successful product implementation in the market.

KEYWORDS: monitoring, localization, people with special needs, assistive technologies, data security

1. Introduction

In a continuously changing world, technology is becoming increasingly integrated into our lives, bringing with it opportunities and solutions for various challenges we face. In this dynamic landscape, one of the priorities is the development and implementation of technologies designed to support people with special needs, thereby contributing to improving their quality of life and, ultimately, increasing users' independence.

With this vision in mind, we have turned our attention to a particularly promising innovation: a monitoring and localization device for people with special needs, designed in the form of a wristband. This smart bracelet represents a significant step towards ensuring safety and personalized assistance for those facing various disabilities, such as individuals with neurodegenerative disorders of the nervous system, who experience cognitive and orientation issues (such as Alzheimer's disease, Parkinson's disease, Creutzfeldt-Jakob disease, Lewy body dementia), as well as young children who are more prone to the phenomenon of disappearance.

Our aim was to thoroughly explore the potential of this device, which can have a significant positive impact on individuals' lives and the community as a whole, especially since there is currently no similar product exclusively targeted at people with special needs in the Romanian market. Building upon the general context of the project and the importance of the product, in previous articles, we extensively analyzed the current stage of development of assistive technologies in this field, presented the technical and functional characteristics of the device, and highlighted the benefits it can bring to users, regardless of their motor and cognitive abilities.

In this paper, we will focus on relevant economic and commercial aspects, highlighting business opportunities and marketing strategies necessary for the successful implementation of the product in the market. By exploring studies in cutting-edge technology, developing the functional prototype, and relevant market elements, this article aims to provide a comprehensive perspective on the potential and benefits of this innovative device.

Finally, we will draw conclusions regarding future directions in the development and use of this type of technology, emphasizing the importance of continued research and innovation to provide efficient and personalized solutions for our target audience.

2. The synthesis of the results obtained in the previous research and the aspects highlighted up to this point

Given the context and the project's purpose presented in the introduction, we will now briefly outline the results of the previous research. This information will provide the basis for a deeper understanding of the evolution of assistive technology for people with special needs and will highlight the significant contributions that this device can make to improving the quality of life and security of users.

In the first two articles, we focused on exploring and developing a significant technological innovation: the monitoring and localization device for people with special needs who are at high risk of disappearance. In the first article **[1]**, we analyzed the current state of assistive technologies for this demographic group, emphasizing the importance and necessity of creating a dedicated monitoring and localization product. Through statistical analysis of the number of people with special needs in Romania **[2]** and previous research conducted for similar devices presented on the *ScienceDirect.com* platform **[3, 4, 5]**, we highlighted the benefits and key requirements for product development. Furthermore, we detailed the conceptual and detailed design of the device and the associated application, highlighting essential functionalities and technical approaches used to meet the specific needs of users. Additionally, we emphasized the importance of data security and protection against environmental factors to ensure the reliability and durability of the device. In the second article, we continued the research and detailed the understanding of the functions and phenomena underlying the realization of the product, using *Aulive.com* as the main source of information. Through detailed analysis of the needs and feedback of potential users obtained through questionnaires, we refined the project to optimally meet the requirements.

In conclusion, the first two articles laid the groundwork for the development and implementation of the product, highlighting the importance and necessity of this device for improving the quality of life for people with special needs and their families. By exploring previous research and the current state of technology, we substantiated the relevance and positive impact of this innovation in the field of assistive technology.

3. The development of the functional prototype

In this section, we focus on the practical aspects of the project, transitioning from the conceptual phase to implementation. Below, we will detail – using suggestive images – the process through which we transformed the initial idea into a functional prototype of our product. From conception to realization, we will explore each stage of the prototype development process, highlighting the key decisions made and the technologies used to ensure the proper functioning of the device and its dedicated application. At the same time, we will also focus on the essential features and functionalities of the prototype, highlighting the innovations and technical solutions adopted. Finally, we will examine the testing and validation process of the prototype, presenting the results obtained and the feedback received during this critical stage. Our goal is to provide a clear and detailed picture of how we progressed from concept to functional prototype, illustrating the efforts made to create an efficient and useful device for future users.

3.1 Features and functionalities of the prototype. Detailed description of the components of the monitoring and localization device and its associated application

A. The physical components used for the monitoring and localization device for people with special needs and their roles:

- **Arduino Nano V3 –** The microcontroller or Single Board Computer (SBC) serves as the brain of the monitoring system. It controls various hardware components, processes data, and executes the software logic. The choice between a microcontroller and an SBC depends on the computational requirements of the system and the form factor.
- **Server (API + DB) –** The server component is the backbone of our system. It manages data storage, communication with the device, and database operations. It is used for storing and retrieving vital data collected by the monitoring device.
- **Enclosure –** the enclosure is the physical shell that houses the electronic components of the monitoring device. It is designed to be durable and comfortable for the wearer, ensuring the safety of the components.
- **GSM/GPRS SIM800L 2.0 module –** this module enables communication between the device and the backend server of the application. It also allows real-time data transmission and remote control functionalities.
- **GPS NEO-6M module with antenna** - Provides location tracking capabilities for the monitoring device. It assists caregivers and users in keeping track of the wearer's position.
- **3.7V Li-Ion batteries –** These batteries are the power source for the monitoring device. They supply the energy required to maintain the device's operation for extended periods.

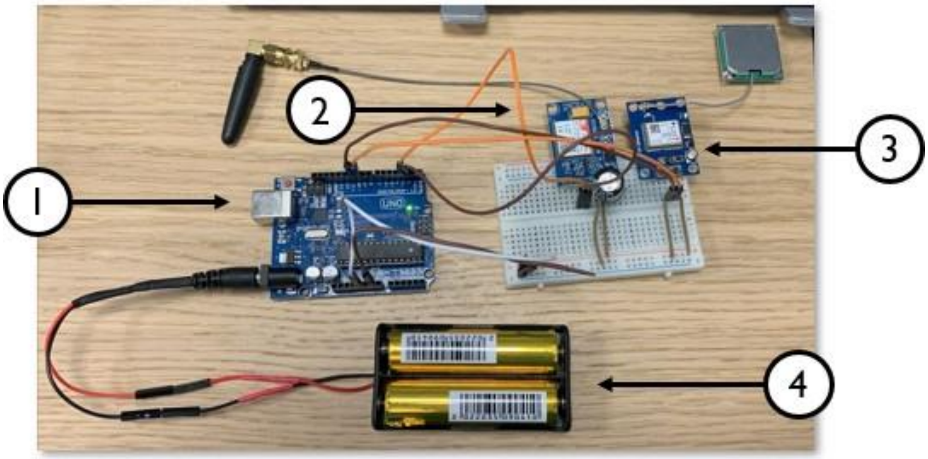

Fig. 1 Physical components for the monitoring and localization device

B. The technological package for the WEB application includes the following components:

a. Frontend technologies:

- **VITE:** Our choice for building the web application, *VITE* enables rapid development and generation of optimized builds for production, ensuring efficient application loading.
- **VUE -** The main framework for developing the user interface of our web application, *Vue.js*, provides us with the ability to easily create dynamic and interactive components.
- **VUE ROUTER -** Used for client-side routing in our web application, *Vue Router* facilitates seamless navigation between different views and pages.
- **PINIA** - Our state management library for Vue.js - *Pinia* helps us manage and share state across various components at the application level.
- **AXIOS -** used to make HTTP requests from our web application to the backend server, allowing retrieval and updating of data.
- **TAILWIND CSS:** provides a utility-first CSS framework that optimizes styling and ensures consistent design throughout the web application.

b. Backend technologies:

- **ASP.NET Core API**: the framework of choice for building the backend API of the application, ASP.NET Core provides a robust and scalable platform for web API development.
- **SignalR**: a real-time web communication library for ASP.NET, SignalR facilitates two-way communication between client and server in real time, allowing code on the server to send content instantly to connected clients.
- **Microsoft Azure**: the cloud computing platform offered by Microsoft, used to deploy the application frontend and API.
- **Entity Framework**: an object-relational mapping (ORM) framework used in .NET applications that allows developers to work with databases using .NET objects, eliminating the need to write raw SQL queries.
- **PostgreSQL**: the relational database management system (RDBMS) of choice for storing and managing the data used in our application.
- **Amazon Web Services (AWS)**: the cloud computing service offered by Amazon Web Services (AWS) used for the database.

3.2. Work steps. The functional prototype development process.

The development of the project included several key steps. In the first stage, component selection involved a rigorous analysis of the market and technologies used in similar monitoring and tracking projects. Based on this research, the following components were chosen: the Arduino Uno R3 board, the SIM800L GSM module, and the Neo-6M GPS module.

1. GPS module soldering

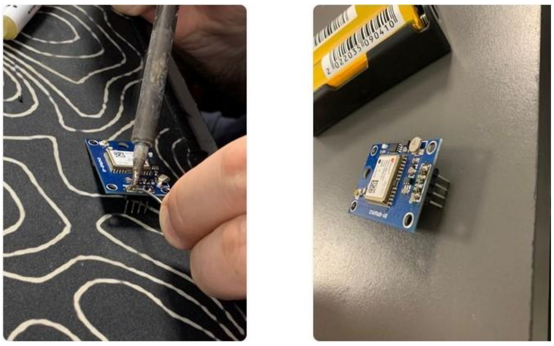

Fig. 2-3 Working steps for soldering the GPS module

2. GSM module soldering

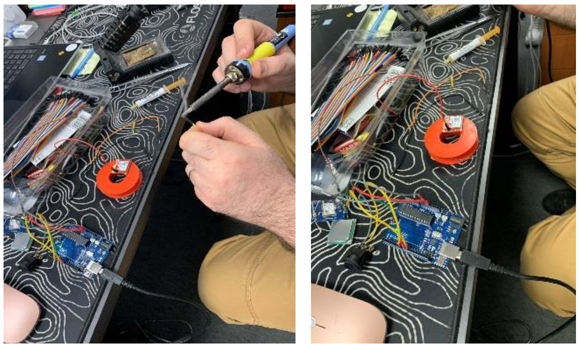

Fig. 4-5 Working steps for soldering the GSM module

3. Soldering Arduino board

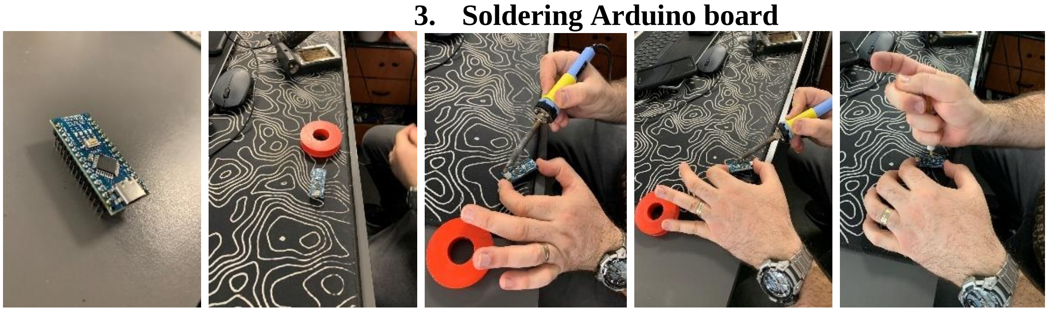

Fig. 6-10 Arduino board soldering steps

The next step was to test and evaluate the compatibility of the components, which we present in detail in the next section of the material.

3.3. Prototype testing and validation. Test results and feedback obtained during validation.

In this section, we present the testing and validation process of the prototype developed for the monitoring and location device for people with special needs. This device incorporates key technologies such as GPS, GSM and power supply systems, which are fundamental for the optimal and efficient functioning of the device in its specific context of use.

1. GPS module testing

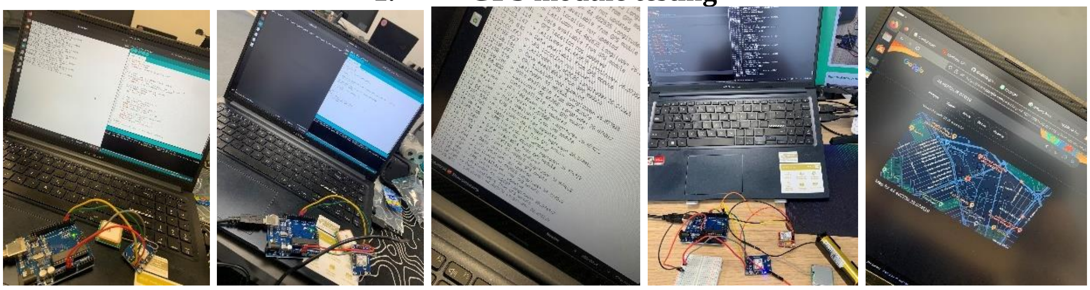

Fig. 11-15 GPS module test steps

2. GSM module testing

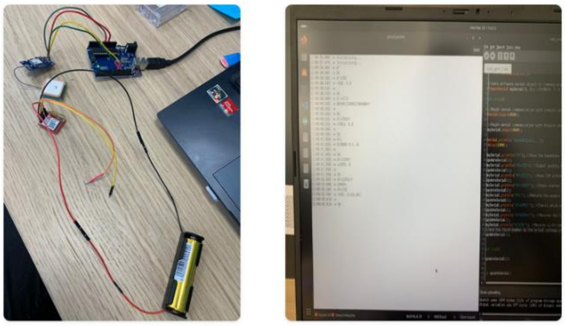

Fig. 16-17 Old GSM module testing steps

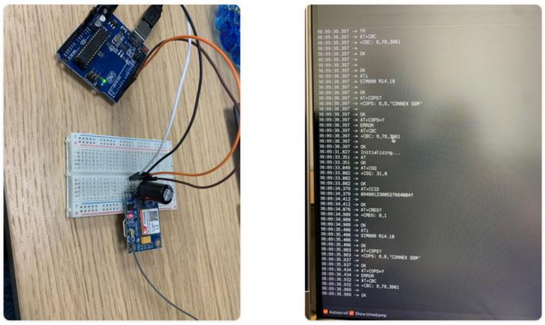

Fig. 18-19 New GSM module test steps

3. Battery testing

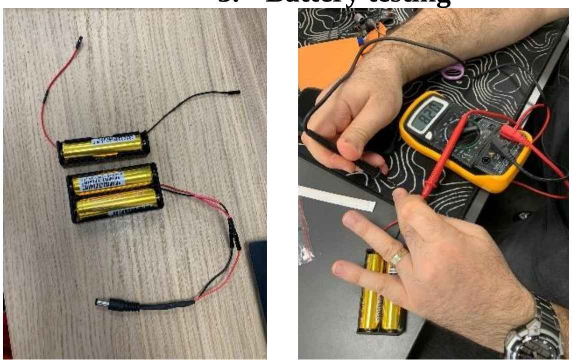

Fig. 20-21 Battery testing steps

The purpose of testing and validation is to evaluate the performance and functionality of the device in real-world situations to ensure that it meets the requirements and expectations of end users. As part of this process, we have carefully investigated how GPS and GSM are integrated and work in tandem to provide accurate location and communication information. We also paid particular attention to testing the batteries, as they are a key element in ensuring the autonomy and reliability of the device in everyday use. The feedback obtained during the validation process is essential for identify any problems or improvements needed and for adjusting the device's functionality according to end-users' needs and requirements.

During testing, we found that the GSM module has difficulty connecting to the network, and the GPS module sometimes takes a longer time to connect to the satellites, influenced by weather and environmental conditions. To remedy the problems identified, we decided to replace the faulty components. So the SIM800L GSM module was replaced with an improved version, SIM800L 2.0, equipped with a high-performance antenna, and the Arduino Uno R3 board was replaced with a smaller version, the Arduino Nano V3. However, re-testing the replaced components revealed new problems. The Arduino Nano V3 board was not supplying enough voltage to ensure proper operation of the GPS module. Thus, we had to revert to the Arduino Uno R3 board, which provided the necessary compatibility for both components. This decision was also motivated by the fact that the new GSM module requires a voltage of 5V to work properly.

Despite the difficulties encountered in the process of testing and evaluating the components, we approached each problem with determination and found appropriate solutions to ensure optimal functioning of the device. By replacing the incorrect components and adapting the configuration, we were able to overcome the obstacles encountered and identify the necessary remedial paths. This proactive approach and the solutions found have strengthened our confidence in the viability of the project and prepared us for the next stages of development.

4. Economic and commercial aspects

Analysis of the market and demand for the monitoring and tracking device for people with special needs reveals a changing landscape characterised by a significant increase in concern for the care and safety of this vulnerable segment of the population. Although the Romanian market is still in its infancy in terms of advanced monitoring and tracking solutions for people with special needs, there is significant potential for growth. By introducing this new device to the local market, we aim to respond to the emerging needs of the community by offering a product that not only adds significant value but also redefines the standards of care and safety for people with special needs.

4.1. Market and demand analysis for monitoring and tracking devices for people with special needs. Trends, competition and opportunities in the field

In our quest to develop an innovative and end-user-driven product, it was essential to identify and understand customer requirements in depth. Conducting interviews was a key step in this process. The interview guide used was designed to explore the needs, expectations and preferences of potential users, addressing a wide range of issues from technical product functionality to user interaction and ergonomic aspects.

Conducting an effective interview requires a systematic approach and a thorough understanding of the specific area in which the product is intended to be used. Interviews are not just a simple data collection, but a strategic tool for shaping a solution that perfectly aligns with market requirements and delivers an optimal end-user experience. In this context, the analysis of the results obtained from the interviews has given us a clearer understanding of customer needs and preferences, guiding us further in our efforts to develop and improve the product in order to respond effectively to market requirements.

In the market research process, we also focused on identifying and evaluating competing products in the field of monitoring and locating people with special needs. We analysed various products on the market that offer similar or comparable solutions to our product. This analysis included studying the main functions and features of competing products, as well as evaluating their ergonomic design and user interface. We collected the relevant data and performed a detailed analysis of the information found, in order to get a clear and comparable picture of each product.

The purpose of this analysis was to gain an in-depth understanding of the current landscape of similar products and to identify opportunities for product improvement and innovation. This information has helped us to assess our market positioning, and in the future will help us to develop effective strategies to differentiate and promote our device.

4.2. Business model and marketing strategy. Ways to promote the product and attract potential customers.

We are based on a simple and transparent business model with a focus on accessibility and quality service. Our marketing strategy focuses on educating and raising public awareness of the benefits and usefulness of the developed device to ensure that the product is precisely tailored to the needs and expectations of the local market. The development and promotion strategy will focus on careful analysis of the requirements and preferences of potential beneficiaries, using effective communication and promotion channels to reach customers. We have chosen to name the product **FIND-ER®**, and the solgan is: **Protect. Assist. Take care.**

By providing a fully integrated, efficient and affordable solution, we aim to become a key player in the market segment dedicated to the assistance and care of people with special needs in Romania.

4.3. Cost and sustainability aspects. How the need for affordability of the device and its environmental impact is addressed.

In recent years, Romania's economy has been under significant pressure, with slowing growth and currency fluctuations. The living standards of the population have been affected by inflation and a decrease in purchasing power, and the impact has also been felt on the accessibility of products and services **[6]**. Despite the economic difficulties, there is an increased need in the market for innovative, state-of-the-art care and support solutions, especially for vulnerable groups. Their safety and that of their families is a priority, and an effective and affordable solution can have a significant impact in this regard.

As outlined in the first article, the costs involved in the search and recovery of persons with special needs, together with the financial and social impact on families and society, underline the need for effective and affordable solutions for monitoring and locating those at high risk of going missing. In the case of persons with special needs, disappearances generate not only increased emotional concern but also an additional economic burden. These alarming figures underline the importance of continued efforts to develop effective tracking and tracing technologies to prevent unfortunate situations and increase the chances of finding those at high risk with little effort and minimal cost.

For the development of the cost model, we performed two separate analyses to estimate the minimum and maximum costs for each product element, subassembly and finally for the total product cost. The result was a maximum price of 2051.25 RON (about 400 EUR) and a minimum price of 1306.25 RON (about 280 EUR). To assess the positioning of the product in relation to competitors on the market, we developed *maps of competing products*, using performance and cost as benchmarks. Within these comparative maps, *both ideal value ranges* and *acceptable limits* were outlined, with the aim of positioning the developed product advantageously compared to the competition.

We want to make the device financially accessible for all user groups without compromising quality or functionality. Additionally, we are committed to using sustainable materials and technologies in our production and operations to reduce environmental impact and promote a healthier and more sustainable climate for all.

5. Conclusions and future research directions

In the current context of increasing numbers of people with special needs and heightened concerns regarding their security, the development and implementation of a monitoring and tracking device, in the form of a wristband, becomes imperative. The proposed product represents not only an innovative technical solution, but also a response to an urgent social need, offering a necessary and effective alternative in the absence of similar solutions on the market, as well as considering the significant difficulties that the national 112 emergency system encounters in managing missing persons situations **[7]**. As previously mentioned, difficulties may include additional delays in locating and intervening quickly in the case of people with special needs, such as people with dementia or young children, where time may be of the essence for their safety.

In order to better meet the needs of people with Alzheimer's or other forms of dementia, it is recommended to integrate artificial intelligence and behavioural prediction algorithms into the monitoring and tracking device for future research and product improvements. This approach could provide an advanced and adaptable solution capable of quickly identifying and responding to the individual behaviours and needs of vulnerable users, thus enhancing effectiveness and market acceptability.

In conclusion, bringing specialised and efficient technology to the forefront is a solution that complements and enhances existing infrastructures, ensuring a faster and more accurate approach to managing critical situations related to persons at risk of disappearance.

Bibliography

[1] IONESCU, Nicolae (coord.), TĂNASE, Alexandru, DRÎMBĂ, Andrei-Nicolae, BUCUR, Gabriela, *Research on the design and development of an electronic monitoring and localization device for people with special needs, Student Scientific Communications Session* 2023, National University of Science and Technology Politehnica Bucharest, Faculty of Industrial Engineering and Robotics, 2023

[2] National strategy on the rights of people with disabilities 2021-2027, http://sgglegis.gov.ro/legislativ/docs/2021/04/wfqgkt8_6ncsv3ymp0rj.pdf (accessed April 2024)

[3] Ning Zou, Yu Chi, Daqing He, Bo Xie, Zhendong Wang, *Together they shall not fade away: Opportunities and challenges of self-tracking for dementia care*, https://www.sciencedirect.com/science/article/abs/pii/S0306457322001340 (accessed April 2024)

[4] Chady ElMoucary , Abdallah Kassem , Dominick Rizk , Rodrigue Rizk , Sawan Sawan , Walid Zakhem, *A low-cost full-scale auto eye-tracking system for mobility-impaired patients*, https://www.sciencedirect.com/science/article/abs/pii/S1434841123004971 (accessed April 2024)

[5]P. Lopes, M. Pino, G. Carletti, S. Hamidi, S. Legué, H. Kerhervé, S. Benveniste, G. Andéol, P. Bonso, S. Reinge wirtz, A.-S. Rigaud, *Co-Conception Process of an Innovative Assistive Device to Track and Find Misplaced Everyday Objects for Older Adults with Cognitive Impairment: The TROUVE Project*, https://www.sciencedirect.com/science/article/abs/pii/S1959031816000269 (accessed April 2024)

[6] Tudorel, ANDREI (coord.), *Romania's economic and social situation 2020 and 2021*, *Statistical data*, National Institute of Statistics, 2023, https://insse.ro/cms/sites/default/files/field/publicatii/starea_economica_si_sociala_a_romaniei_2023.pdf (accessed April 2024)

[7] *,** *Black statistics: 400 missing children | How many people have disappeared in Romania in the last 30 years***,** https://mainnews.ro/statistica-neagra-400-de-copii-negasiti-cati-oameni-au-disparut-in-romania-in-ultimii-30-de-ani/?cn-reloaded=1 (accessed March/April 2024).