RESEARCH ON ESTABLISHING THE CONCEPT FOR THE ORIENTATION OF AN AUTONOMOUS VEHICLE

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SUMMARY: This research aimed to design and develop concepts regarding the orientation system of an autonomous vehicle. Five concepts were created: the mixed orientation system concept, the utilization of radar sensors for robot movement concept, the utilization of Lidar sensors for robot orientation concept, the infrared-based orientation system concept, and the concept for the charging station, the webcam-based orientation system and QR code concept. Using the Analytic Hierarchy Process (AHP) analysis, the optimal concept was selected.

KEYWORDS: orientation, concept, AMR (Autonomous Mobile Robot), charging station

1. Introduction

In general, an AMR (Autonomous Mobile Robot) can be guided to the charging station using a navigation and localization system such as SLAM (Simultaneous Localization and Mapping) technology. This system employs a combination of sensors like lidar (Light Detection and Ranging), cameras, proximity sensors, or inductive sensors to detect and recognize the surrounding environment, identify obstacles, and calculate the robot's position relative to the charging point.

Parts of this paper were refined using ChatGPT [1].

2. Concepts

There are numerous different concepts that can be developed for an orientation system for an AMR and charging station. Some of these concepts may focus on using proximity sensors and guiding mechanisms such as pallets, while others may utilize advanced technologies like lidar or camera systems.

In general, there are many different directions in which such an orientation system for an AMR and charging station could be developed, depending on the specific needs of the application and the budget available for acquiring the components.

2.1. Mixed Orientation System Concept (Concept A)

The concept involves the use of pallets mounted on the charging station to guide the robot to the charging position. Proximity sensors are mounted both on the front and the sides of the pallets to provide high precision in detecting the robot and its relative position on the pallets. These sensors are wirelessly connected to a microcontroller-based board attached to the robot, from the manufacturer Adafruit, to process the information and send commands to the mechanical guiding system.

By using a pallet, a flat and rigid surface can be ensured for positioning the robot, regardless of any imperfections on the surface where the charging station is located. The proximity sensors mounted on the robot can detect the presence and position of the pallet, enabling the robot to move safely and accurately to the charging station.

The use of pallets offers several advantages. It helps protect the proximity sensors from damage or premature wear by reducing friction with the surface of the charging station. Additionally, the pallets can be easily replaced if they get damaged or worn out, without the need to replace the entire charging station. Moreover, the pallets can be equipped with a mechanical guiding system to ensure perfect alignment of the robot with the charging station. This system can be in the form of a ruler or a guide rail, providing precise positioning of the robot on the pallets.

To ensure a secure connection between the robot and the charging station, the pallets can be equipped with additional features such as locking or fastening systems to provide a firm connection between the two devices. The guidance of the robot from point x, represented by the positioning marker for the robot in the orientation system relative to the station, is performed as follows: once the robot is positioned, it advances over the marker, which is validated by a mini webcam positioned above the marker. Based on information from the proximity sensors that detect a magnetic field (magnetic tape), the robot adjusts itself so that the proximity sensor closest to the magnetic field advances further. At this point, the rest of the pallet-based guidance system comes into play, with guide rails.

Ultimately, all these components can be connected to a baseboard that provides a control and communication interface between the proximity sensors, the mechanical guiding system, and the AMR robot. This baseboard can be controlled through a microcontroller or a remote control system, providing an easy and intuitive functionality for the user.

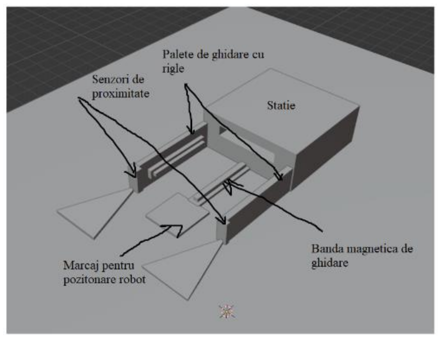

Fig. 1. Mixed Orientation Charging Station Concept

2.2. The concept of using UWB antennas for robot movement (Concept B).

Using UWB antennas for the robot's orientation was studied in [3].

Radar sensors transform echo-type microwaves into electrical signals. They use wireless technology to detect motion, velocity, and object localization. They can detect objects at very long distances. One device that falls into this category is the ESP32 UWB module.

The ESP32 UWB module consists of a DW1000 transceiver chip, low-frequency UWB communication protocol, and ESP32 WROVER. It measures the frequency of the wave and the distance. To measure the distance, at least three modules are needed. Two modules will have fixed positions (anchors), and one module will move (the tag).

A major disadvantage of this module is measurement error caused by omnidirectional waves. The solution to this problem is rotating the module. This requires adding a support for the module, an Arduino, a stepper motor, a drive, and a breadboard for connection. Their placement is shown in Fig. 2.

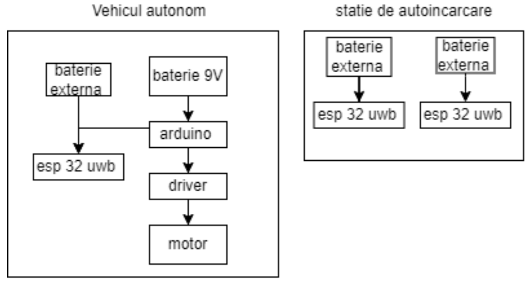

Fig. 2. Placement of components

For power supply, an external battery will be used for the tag, along with a USB cable for its connection. A 9V battery will be used to power the Arduino, driver, and stepper motor, and a battery connector will be required for this purpose. Dupont wires will be needed for the connections.

Source of inspiration[2]

2.3. Lidar Orientation System for an Autonomous Vehicle (Concept C)

- The orientation method that utilizes the Lidar system is one of the most common technologies for measuring distance and determining the position of an autonomous robot in relation to its surrounding objects. The operating principle of the sensor is illustrated in Fig 3.

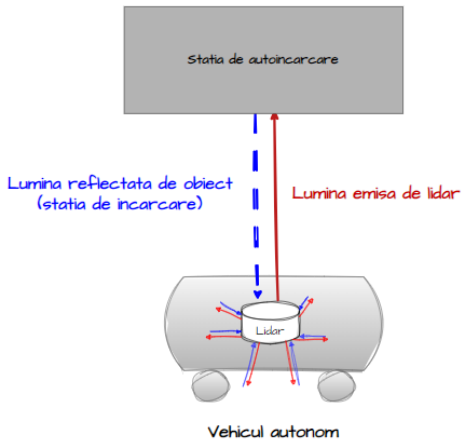

Fig. 3. Lidar Operating Principle

In the case of using the Lidar system for orienting an autonomous vehicle towards the charging station, several criteria need to be considered, including the sensor implementation on the vehicle, data processing, reading and displaying, and the method of powering the Lidar.

Implementing the Lidar sensor on the autonomous vehicle can be challenging due to the complexity of measurement. To implement the sensor on the vehicle, you will need a Lidar sensor, development board, cables, power supply, and mounting system.

Depending on the communication ports of the Lidar sensor, such as USB (UART), Ethernet, or RS232, research should be conducted on compatible acquisition systems.

Data acquisition from the sensor can be done using various development boards, such as the Arduino development board. This acquisition system offers lower processing power compared to ARM models (such as Raspberry Pi, Nvidia Jetson), but the major advantage is the significantly lower acquisition cost compared to other systems. The only compatibility method for communication between the sensor and the acquisition board is through the RS232 protocol, which involves transmitting data using two wires (Rx, Tx).

A secondary alternative for data acquisition is the Nvidia Jetson development board (communication interfaces: HDMI, Ethernet, USB).

Raspberry Pi is a feasible solution for data acquisition from the Lidar sensor (communication interfaces: HDMI, Ethernet, USB, Wi-Fi, Bluetooth).

The Lidar sensor can be powered in two ways: direct power supply using an external source or powering through the USB port of the acquisition board.

The cost of implementing the Lidar sensor on the autonomous vehicle is higher compared to other distance sensors, but the major advantage is its ability to continuously measure 360 degrees.

OpenAI's ChatGPT as a source of inspiration[1].

2.4. Infrared Orientation System and Charging Station Concept (Concept D) [4]

In the suggested IR-based docking system for autonomous recharging of the mobile robot [5], the hardware consists of an Arduino UNO microcontroller, voltage sensor, IR sensor, Bluetooth HC 05, battery charger, ALCD screen (16x2), and 4 DC motors driven by L293 drivers. Fig. 4 illustrates the block diagram of the autonomous mobile robot.

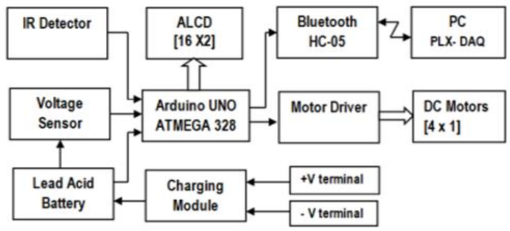

Fig. 4. The block diagram of the autonomous mobile robot

The robot, while performing its assigned task, autonomously navigates to the docking station for recharging if the battery voltage level reaches the threshold value. The IR receiver sensor mounted on the robot is activated to scan the IR emitter sensor located near the docking station. The IR transmitter serves as a unique reference point to guide the robot towards the recharging station.

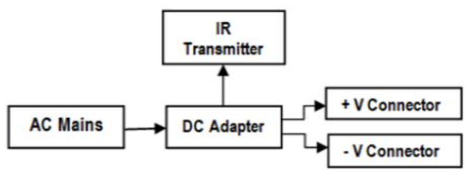

Fig. 5. The block diagram of the recharging docking station

Fig. 5 presents the block diagram of the docking station used for recharging the robot. The robot is equipped with a battery charging module to support the 12V cable charging, and a current detection unit that uses a comparator to measure voltage input differences to determine the charging current. The battery voltage values are converted to the specified format and then transferred through the Arduino Uno controller port with the help of the HC-05 unit to the computer. Once the battery voltage level reaches a value higher than 12V, the microcontroller system will be activated, commanding the robot to detach from the charging station and navigate back to resume its activity.

The 12V DC charging voltage is provided by the robot's battery charger during recharging. While the battery is being charged, the microcontroller reads the battery voltage at regular time intervals and transmits this data through the HC-05 Bluetooth module to the computer. The LCD display on the robot continuously indicates the battery voltage charging level.

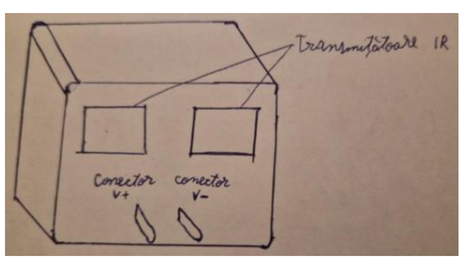

Fig. 6. The concept of an IR (Infrared) charging station

2.5. Web camera and QR code guidance system (Concept E)

A webcam connected to an Arduino board is installed on the autonomous mobile robot.[6] On the charging station there is a QR code that serves as a reference for the alignment and connection/disconnection sequences. The charging station is a fixed one, therefore the QR code will not change its position and there will be no errors when trying to estimate its position.

Advantages of using QR code: easy to detect and read by robots; cost-effective; easy to create and produce; includes error correction functionality; can store a considerable amount of information.[5]

Recognition rate decreases with increasing distance between QR code and camera. The size of the QR code is therefore determined by the capabilities of the camera and the distance to the robot.[5] Therefore the size of the QR code will be 30 cm. Zbar is used to read the code.

Two algorithms are used for approaching the charging station. One is related to QR code detection, while the other refers to the approach procedure.

The basic idea of the first algorithm is for the robot to spin around in search of the QR code. It takes a picture, decodes it, and checks if there is a QR code with the desired information. If it does not find the QR code, it spins and tries again. Once the QR code is found, the robot will align with the QR code, meaning it will slowly turn until the symbol is centered.[5]

From the relative size of the QR code's lateral margins, the robot determines whether it is on the right, left, or centered. The distance at which the QR code is located is also perceived from the size of the QR code through camera calibration measurements and coordinate transformations.[7]

The second algorithm is the procedure for approaching the autonomous mobile robot to the charging station. The actions performed by the robot differ depending on the distance it is at. If the robot is far away it approaches directly. Once the robot is close, it performs an indirect approach. It turns slightly to centre the QR code. Finally, when the robot is very close to the station, it checks if the position of the QR code is appropriate. If the angle is right, the robot advances directly towards the loading station. Otherwise, an indirect approach is performed, i.e. the robot turns around and moves forward to get a better angle of attack.[5]

Fig.7. Robot's views from: left, center and right [5]

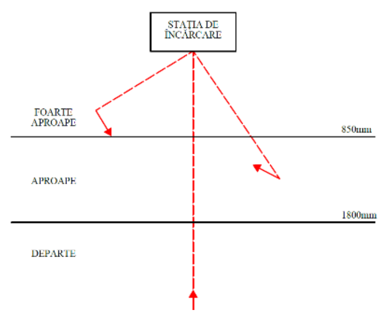

Fig. 8. Sample approaching behavior depending on the region

The concept of a charging station equipped with QR codes is illustrated in Fig. 7.

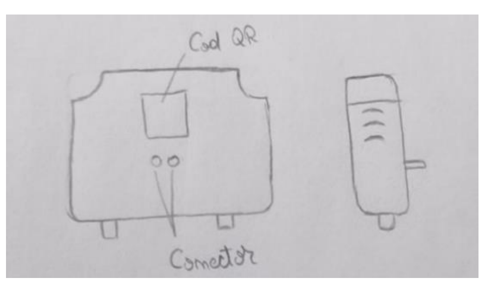

Fig. 9. Charging station concept

3. Concept selection

The concept selection utilized the Analytic Hierarchy Process (AHP) methodology .

The application of the AHP method starts by establishing the weights of each criterion under consideration. This is done using Saaty's 9-point scale, as presented in Table 3.1. This scale has been validated through statistical tests to provide reproducible results with high precision.

Table 3.1 Saaty's Fundamental Scale for Pairwise Comparison

Intensity of Importance	Definition	Description
1	Equal importance	Two activities contribute equally to achieving the objectives
3	Moderate importance	From thinking and experience, we can slightly favor one activity over another
5	Strong importance	From thinking and experience, we can strongly favor one activity over another
7	Very strong or demonstrated importance	One activity is strongly favored over another, based on demonstrated evidence in practice
9	Extreme importance	The evidence of favoring one activity over another is at the highest possible degree of certainty
2, 4, 6, 8	These scores are used as intermediate values	

The determination of weights is done using a square matrix (Table 3.2), where criteria are compared pairwise using Saaty's scale (Table 3.1).

Table 3.2 Square Matrix for Criteria Pairwise Comparison

	Operation simplicity	Ease of use	Reliability	Industrial design and ergonomics	Energy consumption	Precision	Cost
Operation simplicity	1	5	1	1/3	7	9	1/3
Ease of use	1/5	1	5	1/3	4	6	1/4
Reliability	1	1/5	1	1/5	3	1	1/4
Industrial design and ergonomics	3	3	5	1	9	9	5
Energy consumption	1/7	1/4	1/3	1/9	1	1	1/6
Precision	1/9	1/6	1	1/9	1	1	1/6
Cost	3	4	4	1/5	6	6	1
Total	**8.45**	**13.62**	**17.33**	**2.29**	**31**	**33**	**7.17**

Next, a table (Table 3.3) of normalized values is created by dividing the values in each cell of Table 3.2 by the column total. The average value for each row gives the weight for each criterion.

Table 3.3. Normalized Weight Values for Each Criterion

	Operation simplicity	Ease of use	Reliability	Industrial design and ergonomics	Energy consumption	Precision	Cost	Ponderea criteriului
Operation simplicity	0.118	0.367	0.058	0.146	0.226	0.273	0.047	0.176
Ease of use	0.024	0.073	0.288	0.146	0.129	0.182	0.035	0.125
Reliability	0.118	0.015	0.058	0.087	0.097	0.030	0.035	0.063
Industrial design and ergonomics	0.355	0.220	0.288	0.437	0.290	0.273	0.698	0.366
Energy consumption	0.017	0.018	0.019	0.049	0.032	0.030	0.023	0.027
Precision	0.013	0.012	0.058	0.049	0.032	0.030	0.023	0.031
Cost	0.355	0.294	0.231	0.087	0.194	0.182	0.140	0.212
Total	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.000**

Then a hierarchy matrix is created for each criterion separately for the four concepts (tables 3.4, ..., 3.10). The scale presented in table 3.1 can be used for this purpose.

Table 3.4 Hierarchy of Concepts for the Criterion "Operation simplicity"

Concepts		A	B	C	D	E
Operation simplicity	Hierarchy	2	3	2	5	3
	Fraction of Total	0.133	0.2	0.133	0.333	0.2

Tabel 3.5. Hierarchy of Concepts for the Criterion “Ease of use”

Concepts		A	B	C	D	E
Ease of use	Hierarchy	4	2	2	4	3
	Fraction of Total	0.266	0.133	0.133	0.266	0.2

Tabel 3.6. Hierarchy of Concepts for the Criterion “Reliability”

Concepts		A	B	C	D	E
Reliability	Hierarchy	2	2	3	4	3
	Fraction of Total	0.142	0.142	0.214	0.285	0.214

Tabel 3.7. Hierarchy of Concepts for the Criterion “Industrial design and ergonomics”

Concepts		A	B	C	D	E
Industrial design and ergonomics	Hierarchy	3	2	2	4	3
	Fraction of Total	0.214	0.142	0.142	0.285	0.214

Tabel 3.8. Hierarchy of Concepts for the Criterion “Energy consumption”

Concepts		A	B	C	D	E
Energy consumption	Hierarchy	3	3	2	3	3
	Fraction of Total	0.214	0.214	0.142	0.214	0.214

Tabel 3.9. Hierarchy of Concepts for the Criterion “Precision”

Concepts		A	B	C	D	E
Precision	Hierarchy	2	3	3	4	3
	Fraction of Total	0,133	0,2	0.2	0.266	0.2

Tabel 3.10. Hierarchy of Concepts for the Criterion “Cost”

Concepts		A	B	C	D	E
Cost	Hierarchy	1	3	4	4	3
	Fraction of Total	0.066	0,2	0,266	0,266	0.2

The decision matrix presented in Table 3.11 is created, where the weights determined in Table 3.3 are entered in the second column, and the hierarchical values obtained in Tables 3.4 to 3.10 corresponding to the considered criteria are entered in columns 3, 4, 5, 6, and 7. The decision scores entered in the last row are obtained by summing the products between the criterion weights and the hierarchical values from columns 3, 4, 5, 6, and 7.

Tabel 3.11. The decision matrix

Decision criterion	Weight	Concept A	Concept B	Concept C	Concept D	Concept E
Operation simplicity	0.176	0.133	0.200	0.133	0.333	0.200
Ease of use	0.125	0.266	0.133	0.133	0.266	0.200
Reliability	0.063	0.142	0.142	0.214	0.285	0.214
Industrial design and ergonomics	0.366	0.214	0.142	0.142	0.285	0.214
Energy consumption	0.027	0.214	0.214	0.142	0.214	0.214
Precision	0.031	0.133	0.200	0.200	0.266	0.200
Cost	0.212	0.066	0.200	0.266	0.266	0.200
Total	1.000	0.168	0.167	0.172	0.285	0.206

The option with the highest score, concept D, is chosen.

4. Conclusions

The AMR is guided towards the charging station using SLAM technology, which uses sensors (lidar, cameras, proximity sensors, and inductive sensors) to detect the environment, obstacles, and the robot's position.

There is a variety of concepts for an orientation and charging system for AMR.

Following the AHP methodology, the concept that will be further developed is concept D, which refers to the charging station with the infrared orientation system.

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