BOTTLE MANIPULATOR WITH VACUUM GRIPPER

CARUSO Noemi[1], DIACONU Britany, LABANCA Nicoletta Annetta
[1]Faculty: FIIR, Specialization: Erasmus, Year of study: 2, e-mail: n.caruso5@studenti.unisa.it

Scientific Leader: Assoc.Prof.. **Bogdan Felician ABAZA**, Prof. **Adolfo SENATORE**

ABSTRACT: Handling of palletizing bottles in the beverage sector led to the development of specialized systems currently in use. Changes in the packaging (material and shape) of the products in order to reduce the consumption of plastic could make these systems no longer adequate: a study has been carried out for the development of a new product that, according to fourth industrial revolution, allows greater flexibility for the objects to be manipulated. For this purpose, the needs of the market were analyzed, identifying the target segment and the USPs; then the needs were transformed into functions and technical solutions through functional analysis. Several concepts have been designed and analyzed: economic analysis and general considerations showed that the concept with the best performance and that best meets the needs of the target client consists of a granular clamp that allows the handling of bottles thanks to the phenomenon of jam, generated through the creation of vacuum.

KEYWORDS: granular gripper, vacuum gripper, bottle manipulator, palletizing, industry 4.0.

1. Introduction

The industrial area of interest for the following project is represented by the drink industry. A common problem for all beverage companies is the organization of bottles full in stable pallets, ready for transport. This aspect of the outgoing logistics is the specific domain of the proposed product: a system that allows to take the bottles from the filling structure and transport them consequently to the palletizing islands, through the action of the vacuum, adapting to the bottle with high flexibility. This is a Business-To-Business (B2B) product, so trade takes place between companies; in particular, the main target is medium and large companies. The product meets their explicit needs: faster operations, higher productivity, greater safety and ergonomics at the workplace, physical relief for the operator, more flexibility to cope with changes in packaging (shape, size and materials) that companies need to use in order to reduce the amount of plastic used.

2. Business strategy

In order to implement a marketing plan aimed at the successful product and capture the latent needs of consumers not satisfied by the products of the competition, was carried out the analysis of competitors; the most important results of which are shown in Table 1. Flexibility refers to the product's ability to pick and place on bottles with different diameters. Pick and place capability refers to the ability to grab multiple bottles simultaneously, while automation refers to the possibility of operation without significant human intervention.

Table 1: Main results competitive analysis

	Anver [1]	Simtech GGW [2]	Simtech GGS [3]	Solaut [4]	Lifts All [5]	UniGripper [6]	Pronal [7]	Vmeca [8]	Schlmaz [9]	Piab [10]
Flexibility				X		X		X		
Automation	X	X		X		X	X			X
Pick-and-place capacity		X		X	X	X	X		X	X

The analysis shows that the main competitors are those highlighted in green: their limit is that to take advantage of the high flexibility of the product it is necessary to incur additional costs. Objective of the planning study will therefore exceed this limit equipping the device of inherent flexibility. Instead of achieving high collection and placement capacity, the focus has been on making flexibility the strong point of the product due to a significant change in market conditions that is affecting the beverage industry. Plastic pollution is one of the most serious environmental threats of our time, this drives companies to reassess their processes, including packaging, to ensure greater environmental sustainability. The change in the materials used could cause variations in the shape or size of the treated products, as happened with the natural mineral water of the San Benedetto industry. The proposed product allows to adapt without problems to the possible variations that companies in the beverage sector may decide to implement (intrinsic flexibility – no additional cost). In addition, we must not forget the evolution that is transforming all companies, the fourth industrial revolution, aiming at intelligent production currently at the forefront. The developed device is a combination of intelligent physical components, with built-in processing and storage options, that connect over the network.

3. Functional analysis

Based on research carried out in the context of market analysis, functional analysis may be performed. The core of external functional analysis is represented by the realization of the Octopus Diagram (Fig. 1), which highlights the associations of the system with the elements of the environment.

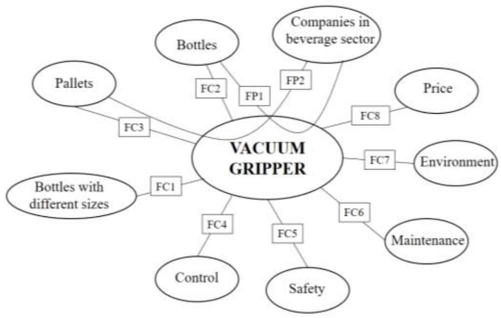


Figure 1: Octopus Diagram

Such association can be main functions (FP) or constraint functions (FC). For each identified service function (SF), acceptance criteria and requirement level have been specified. The results are summarised in the table 2.

Table 2: Table of the specifications

SF	SERVICE FUNCTION	ACCEPTANCE CRITERIA	REQUIREMENT LEVEL
FP1	Allow the user to grab, leave and move bottles	Weight	From 0 to 3 kg
FP2	Allow the user to palletize bottles	Distance from pallet	From 500 to 1000 mm
		Pallet size	1.200 x 800 mm (UNI-EN 13698-1)
		Number of bottles	From 109 to 272
FC1	Handle bottles with different sizes	Diameter of the bottle	From 20 to 100 mm
		Height of the bottle	From 100 to 400 mm

FC2	Must identify the moment when the bottle is ready to be taken	Relative pressure	Different from 0 (from 0,01 to 1 bar)
FC3	Identify where the bottles are to be left (palletizing islands)	Free position on pallet	Speed of sound * flight time given by the ultrasound sensor
FC4	Must be controllable	Connection mode	Relay - Arduino
		Type of software	LabVIEW
FC5	Must ensure the safety of operators	Visual signal when the approach of operators is possible	Green light
FC6	Must allow real-time information detection for predictive maintenance	State of resources	No signs of wear
		Rhythm of manipulation	Approximately constant value
FC7	Must resist its environment	Temperature	From 0°C to 40°C
		Humidity	Less than 60%
FC8	Must have an acceptable price	Price	Comparable with the prices of competition products

For internal functional analysis (internal components and their technical functions), the FAST Diagram was used (Functional Analysis System Technique). This diagram allows to connect the functions in a hierarchical way and details in multiple levels as each service function is concretized in one or more technical solutions. The diagram (Table 3) represents the starting point for the development of competing concepts.

Table 3: FAST Diagram

<table>
<tr><td colspan="7">Allow users to do pick-and-place operations
(1)</td></tr>
<tr><td colspan="3">Grab, leave and move bottles
(1.1)</td><td>Palletize bottles
(1.2)</td><td colspan="3">Real time capabilities
(1.3)</td></tr>
<tr><td>Handle bottles with different sizes
(1.1.1)</td><td>Identify the moment when the bottle is ready to be taken
(1.1.2)</td><td>Identify where the bottles are to be left
(1.1.3)</td><td>Place the bottle in the free space on the pallet
(1.2.1)</td><td>Controllable
1.3.1)</td><td>Real time information detection for predictive maintenance
(1.3.2)</td><td>Ensure the safety of operators
(1.3.3)</td></tr>
</table>

By hand (1.1.1.1)	Granular gripper (1.1.1.2)	Pneumatic clamps (1.1.1.3)	Suction cups (1.1.1.4)	Inflatable callipers (1.1.1.5)	Flexible foam (1.1.1.6)	Pressure sensor with strain gauge (1.1.2.1)	Ultrasonic sensors (1.1.2.2)	Micro switch (1.1.2.3)	Manual settings of coordinates (1.1.3.1)	Ultrasonic sensor (1.1.3.2)	By hand (1.2.1.1)	Robotic arm (actuator) (1.2.1.2)	Conveyor (1.2.1.3)	Locally and visually (1.3.1.1)	PC (Relay, Arduino, LabVIEW) (1.3.1.2)	Manufacturing Execution System (1.3.2.1)	Walkable strips for safe distance (1.3.3.1)	Emissions of light signals (1.3.3.2)

4. Competing concepts

Following functional analysis, the possible concepts that best fit the needs of potential customers in the Industrial Area of Interest have been determined, in congruence with the business strategy and the USPs. In accordance with the FAST Diagram (Table 3), the concept proposals include the technical solutions specified in table 4.

Table 4: Technical solution for competitive concepts

TECHNICAL FUNCTION	*CONCEPT 1*	*CONCEPT 2*	*CONCEPT 3*
FT 1.1.1	Granular gripper (1.1.1.2)	Flexible foam (1.1.1.6)	Granular gripper (1.1.1.2)
FT 1.1.2	Pressure sensor with strain gauge (1.1.2.1)	Micro switch (1.1.2.3)	Pressure sensor with strain gauge (1.1.2.1)
FT 1.1.3	Ultrasonic sensor (1.1.3.2)	Manual settings coordinates (1.1.3.1)	Manual settings coordinates (1.1.3.1)
FT 1.2.1	Robotic arm – actuator (1.2.1.2)	Robotic arm – actuator (1.2.1.2)	Robotic arm – actuator (1.2.1.2)
FT 1.3.1	PC – Relay, Arduino, LabVIEW (1.3.1.2)	PC – Relay, Arduino, LabVIEW (1.3.1.2)	PC – Relay, Arduino, LabVIEW (1.3.1.2)
FT 1.3.2	Manufacturing Execution System (1.3.2.1)	Manufacturing Execution System - MES (1.3.2.1)	Manufacturing Execution System (1.3.2.1)
FT 1.3.3	Emissions of light signals (1.3.3.2)	Emissions of light signals (1.3.3.2)	Emissions of light signals (1.3.3.2)

In addition, it was necessary to define the reference range, for bottle size and pallets, in order to allow an optimal design of the device. The reference values are given in table 5.

Table 5: Reference range for concept design

BOTTLE SIZE RANGE	Weight	0 – 3 [Kg]
	Diameter	20 – 100 [mm]
	Height	100 – 400 [mm]
PALLET SIZE RANGE	Size (UNI-EN 13698-1)	1.200 x 800 [mm]
	Distance of the pallet from the pick-up point	500 – 1.000 [mm]
	Number of bottles on pallet	109 – 272 [items]

The first concept involves the use of a granular gripper supported by an aluminium base, drilled at the top to allow the passage of the tube for air intake, necessary for the creation of the vacuum. The pressure sensor indicates the presence of the bottle while the ultrasonic sensors identify the height of the bottle at first and the free position on the pallet later. In order to ensure perfect adhesion between the base of the clamp, the membrane and the suction tube, two O-Ring gaskets in nitrile rubber have been inserted.

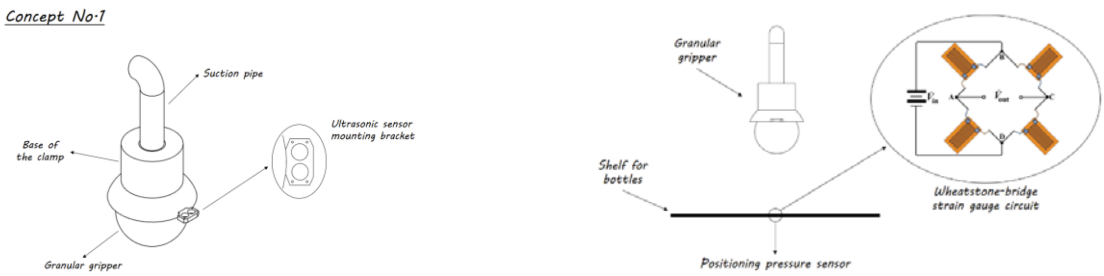
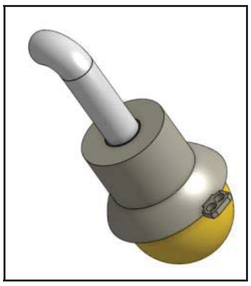


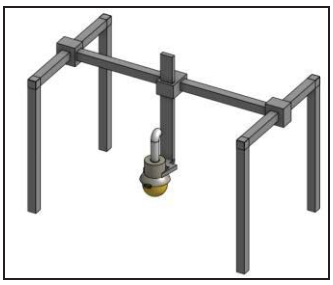
Figure 2: Concept 1

The concept 1 consist of components that are not expensive and that are easily available on the market, making it a competitive product economically. In addition, it satisfies the USPs, ensuring flexibility (wide range of diameter of bottles that can be handled) as an intrinsic feature and, in accordance of fourth industrial revolution, it is a combination of intelligent physical components, with embedded computing and storage possibilities, which are connected through network.

a)



b)



c) Components:

PVC membrane	Pressure sensor with strain gauge
Rubber granules	Ultrasonic sensor HC-SR04
Clamp base	Relay 220V
O-Ring gaskets	Arduino UNO
Suction pipe	LEDs
Gantry robot	

Figure 3: (a) 3D model of concept 1 (b) positioning of the product on the Gantry robot (c) List of main components

The second concept is characterized by a basic clamp, on which there are a vacuum gripping system for the generation of external vacuum and for the discharge function for a quick release of the product and separate connection from the Gantry Robot, through bolted flange. Below the base clamp is the flexible foam in EPDM, visible from the zoom in figure 4, and it is characterized by offset circular holes that allow suction and a strong hold of the object. Finally, connected to the flexible foam, there is a protective layer, suited for mark-free handling and applications with increased demands on the chemical resistance of the foam. Concept 2 is characterized by components whose production costs are high. In fact, from the study carried out the flexible foam has non-standard dimensions and therefore not present on the market. Moreover, since it is micro-perforated, it will have to be customized, for this reason it is estimated that the cost will be high. This also applies to the special bonding layer without silicone. Another disadvantage is related to the micro-switch: if it does not receive enough pressure to close the circuit and then to join the two contacts, the output signal does not undergo an instantaneous variation from top to bottom, then there is a bounce of the signal, which is to generate spurious signals, called symbols. Based on these considerations, the concept chosen for the development is the first.

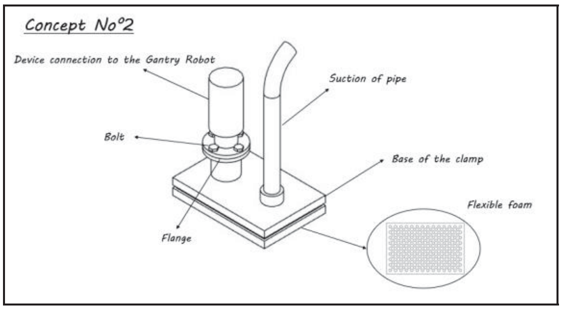


Figure 4: Concept 2

a)

b)

c)

Components:
Flexible perforated foam
Special silicon free adhesion layer
Clamp base
Suction pipe
Bolted flange
Gantry robot

Figure 5: (a) 3D model of concept 2 (b) positioning of the product on the Gantry robot (c) List of main components

5. Controls and Electrical System Architecture

With reference to the chosen concept, the product innovation consists of the granular gripper: a clamp consisting of 3 mm thick elastic PVC membrane and filled with sub-millimeter particles (EPDM rubber granules) [11]. The resulting advantage is the possibility of pick and place operations even in the case of incomplete coverage of the object thanks to the phenomenon called jamming transition. The granular material can flow freely, so the clamp approaches in soft state on the bottle deforming around it; following the air intake, the material hardens ensuring a firm seal of the object [12]. The weight of a grabbed object is scaled with volume but the holding forces adapt to the area. So knowing the size of the bottles it was possible to estimate the jamming pressure required by the gripper with the formula 1.

$$P_{jam} \approx R_{max}\rho g \tag{1}$$

With regard to density, the materials considered are plastic (PET – Polyethylene terephthalate), aluminium and glass. From the calculation emerges a maximum value of 1.340 Pa, obtainable also with small pumps. The start mode of the device comes with the arrival of the bottle at the pick-up point: on the shelf there are 4 strain gauge sensors with semiconductor connected in a Wheatstone circuit, two in radial direction and two in tangential direction. The choice of these sensors is due to their accuracy even for low-pressure values [13] [13bis], as the bottles will exercise on the shelf a pressure that varies from 13,367 to 35,681 mbar. The range has been obtained by determining for each type of bottle the pressure exerted on the shelf and therefore on the pressure sensors. As a result of the pressure they undergo a mechanical deformation and a change in the value of resistor's conductivity, providing in output a change in resistance and a value of voltage different from the reference value. The final value that returns the Wheatstone circuit is unique and follows the formula 2.

$$V_{out} \approx V_{ref}\frac{1}{4}\frac{\Delta R}{R} \tag{2}$$

The Wheatstone circuit output becomes input to the actuator, the Gantry robot on which the clamp is positioned: it is a Cartesian robot with linear control axes [14] that works with a coordinate system x, y and z, and the Physical Computing, so all communications between sensors and actuators, are managed via Arduino. The activation of the robot involves simultaneously the activation of the ultrasonic sensor positioned on the appropriate mounting bracket, designed in accordance with the datasheet of the chosen sensor. Since the sensor has to determine the height of the bottle to be handled but also the free position on the pallet, the ultrasonic sensor HC-SR04 has been chosen for its range coverage. The emitter generates an ultrasonic pulse which propagates and is reflected until the receiver is reached: flight time is a function of distance. Knowing the distance value, Gantry robot will move the granular gripper along the z-axis, allowing the same to deform around the bottle. At this point the air intake begins, controlling the pump directly from the PC thanks to the presence of relay [15] and LabVIEW software. When a pressure value suitable for handling is reached, the valves shall be closed in order to maintain this value within the circuit: the bottle is ready to be handled and the movements of the Gantry robot along the x and the y axis allow the achievement of the palletizing island. The free position will be determined using the ultrasonic sensor once again: then the signal for the opening of the air valves, which allow the release of the bottle, is sent. The return of the Gantry robot to the initial position allows to start the manipulation of a new object. In order to ensure a safe and reliable working environment for the operator, a system has been adopted that, using light signals from LEDs (red/green based on motion/stationary mode), allows to signal when it is possible approach the device. In addition, the organizational evolution and the control of the process in real time is allowed thanks to the presence of the MES that, to operating level in the pyramid of the automation, collects information which rhythms of manipulation, speed, number of objects manipulated, coordination of movements. The MES, Manufacturing Execution System, assumes a fundamental role because it allows the organizational evolution of the production thanks to automatic collection of the data, ability to control and monitoring of the processes, so the production management will be able to verify in real time the evolution of the production, state of resources and to optimize processes. In order to configure connections between the components, a simulation was performed with Tinkercad (Fig. 6): a switch DPST DIP adjust the device on and off; the pressure exerted with the mouse on the pressure sensor simulates the arrival of the bottle and determines the lighting of the red LED, while with the release of the same lights the green LED; the ultrasonic sensor detects the distance along the z-axis, when it is less than 70 cm the bottle is present on the shelf so the servo motor, representative of the Gantry robot, moves in order to bring the clamp to the bottle and ensure its handling (Fig. 7). The current simulation has highlighted the correct interaction and communication between the sensors and the actuator chosen for the design of the device. Have also been identified starting mode, state machines and working modes.

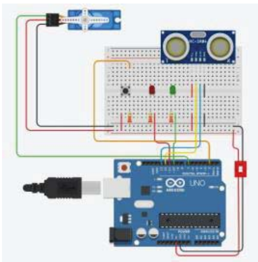


Figure 6: Tinkercad simulation

Figure 7: Approach of the clamp to the bottle for subsequent handling

6. Conclusions

After having thoroughly analyzed the two concepts, the winning concept was chosen in order to develop it and realize it. Regard to the implementation process, in according with the initial macroplanning, we made a risk management analysis from which the most important risk was related to the COVID-19, which hinders daily activities and therefore also university activities, preventing us from meeting and working face to face. The obstacle was partly circumvented, developing our concept virtually using 3D software, implementing and simulating sensors with LabVIEW and connection configurations with Tinkercad. As regard possible future developments, after finalizing the simulation of all controllers state machine modes, the focus will be mainly on the development of the prototype, based on simulations and tests developed virtually; then, from the studies carried out the device works for the considered ranges but it could be improved in order to be able to lift bottles with larger weights and belonging to wider ranges, in line with European standards, with a view to a world plastic free and environmental sustainability.

7. Bibliography

[1]. Anver corporation. https://anver.com/BottleHeadGripper
[2]. Simtech. https://www.simtech.biz/products/ggw-grippers-for-gripping-bottles/
[3]. Simtech. https://www.simtech.biz/products/gripper-for-all-types-of-bottle-necks-ggs/
[4]. Solaut. https://www.solaut.it/en/palletizer-robot-gripper-bag-palletizing-slip-sheet-dispenser/robot-palletizers-grippers-for-bottles-flacons-jars.htm
[5]. Lifts all. https://www.liftsall.com/lifting-tools/customised-grippers/vacuum-grippers/bottle-gripper-89-10638/
[6]. Industry search. https://www.industrysearch.com.au/intelligent-air-vacuum-gripper-for-plastics-unigripper/p/18668
[7]. Pronal lifting bag. http://pronal-liftingbag.com/pick-up-your-bottles-with-our-custom-designed-grippers/
[8]. Vmeca. https://www.vmeca.com/product-category/v-grip-system-en/
[9]. Schmalz. https://www.schmalz.com/en/vacuum-lifters-and-crane-systems/vacuum-tube-lifters-jumbo/vacuum-tube-lifter-jumboflex
[10]. Piab. https://www.piab.com/applications/solutions/packaging/handling-of-flexible-packages/
[11]. Miettinen, J., Frilund, P., Vuorinen, I., Kuosmanen, P., Kiviluoma, P. (2019), "Granular jamming based robotic gripper for heavy objects", Department of Mechanical Engineering, Aalto University, Espoo, 2019;
[12]. Brown, E., Rodenberg, N., Amend, J., Mozeika, A., Steltz, E., Zakin, M., Lipson, H., Jaeger, H. (2010), "Universal robotic gripper based on the jamming of granular material", Proceedings of the National Academy of Sciences of the United States of America, vol. 107, no. 44, 18809-18814;
[13]. Stssensors (2017). https://campaign.stssensors.com/blog/it/misurazione-elettronica-della-pressione
[13 bis] HBM. https://www.hbm.com/it/6992/using-weighing-technology-for-automated-filling-processes/
[14]. Giamod.it (2001). http://www.giamod.it/documentazione%20robot/generalita/gen_robot.htm
[15]. Electgo (2019). https://www.electgo.com/what-is-a-relay/
[16]. Course material Industry 4.0 (2020) - Assoc. Prof.. Bogdan Felician ABAZA. https://fiir.curs.pub.ro/2019/course/view.php?id=1560

8. Notations

The following symbols are used in the document:
P_{jam} = jamming pressure [Pa];
R_{max} = maximum radius of bottles to be handled [m];
ρ = density of bottle material [kg/m^3];
g = gravitational constant [m/s^2];
V_{out} = Voltage output from Wheatstone circuit [V];
V_{ref} = Wheatstone circuit reference voltage [V];
R = equivalent resistance of Wheatstone circuit [Ω];
ΔR = variation of the equivalent resistance of the Wheatstone circuit [Ω]