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DESIGN, SIMULATION AND PROGRAMMING OF AN ARDUINO ROBOTIC CELL

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Abstract. *According to the IFR (International Robotics Federation), the annual growth in sales of industrial robots in Brazil during the period 2018 to 2020 was 33% per year. According to statistics, it is clear that the future scenario is very promising and attracts the attention of robot manufacturers, however, there is a lack of qualified labor in Brazil. Thinking about the problem of teaching robotics in a practical way, the present work aims at the design, control and simulation of a robotic cell. To achieve the objective of the work, the additive manufacturing process was used for manufacturing the components. For actuation of the axes, stepper motors were used, for control and programming integration, the Arduino mega 2560 was used. Simulation of the robotic cell through the Robo DK software was done. From this, a robotic cell consisting of three modules was obtained: robot module containing a robotic arm with 6 (six) degrees of freedom and a gripper at the end effector; belt module containing a conveyor belt; and the electrical module containing Arduino and shield ramps 1.4 for integration. The results show the design and construction of the robotic cell and a palletizing operation with the selection of parts according to their color. Different manufacturing operations can be simulated with this cell, as the robot's inverse kinematics is implemented. With this, it is possible to study robotics in a practical way.*

Keywords: *robotic arm, Arduino, robotic cell*

1. INTRODUCTION

According to the International Federation of Robotics (IFR), the global manufacturing industry is facing major challenges, such as rapidly changing consumer trends, lack of resources, shortage of skilled workers, aging society and demand for local productions, automation based on flexible industrial robots offers the solution to all these challenges (International Robotic Federation, 2020).

IFR data indicate that the global robot market is 2.7 million units. With more than 15,300 robots in operation, Brazil leads the park of industrial robots in South America, which has another 3,500 equipment's. In Latin America, the country is second only to Mexico, which is close to the American market. Even so, robotization in the country is far from that adopted in developed countries. Brazil has 12 to 13 robots for every 10,000 workers, compared to 1,300 in the US, 938 in China, 1,200 in Japan and 2,700 in Korea (Sindicato das Metalúrgicas, 2021).

According to the most recent data released by the International Federation of Robotics, in 2016, 1,500 industrial robots were sold in the country, out of a universe of 294,000. Even with an insignificant volume in relation to the international market, the institution also points out that the annual growth for the Brazilian industrial robotics market was 33% per year, between the years 2018 to 2020, that is, the country is the market with the highest percentage growth potential in this period in the world (Pineda, 2018).

Still according to Pineda (2018), looking at the statistics, the future scenario is very promising and attracts the attention of robot manufacturers. An interesting point to be considered in the country is that, together with the growth of robotics and industrial artificial intelligence, job opportunities in the sector also increase. However, in Brazil, there is a shortage of qualified engineers, programmers, and technicians with specialization to work with robots and, for this reason, it is not uncommon for large consumers of robotics to bring labor from abroad.

In this context Industry 4.0 is a wide system of advanced technologies such as artificial intelligence, robotics, internet of things and cloud computing that are changing the forms of production and business models in Brazil and worldwide. Having a significant impact on productivity, increasing the efficiency of resource use and the development of large-scale products, in addition to promoting the integration of Brazil into global value chains (Silveira Filho, 2018; Portal da Indústria, 2018). Smart robots are the crucial part of digitizing the manufacturing industry due to the challenges already mentioned, such as major challenges and rapidly changing consumer trends, scarcity of resources, shortage of skilled workers, aging society, and demand for local productions (Almeida, 2019).

In this context, a series of papers have already developed robotic arms with the aim of training. Benitez, Symonds and Elguezabal (2020) present the design and construction of an accessible and open source robotic arm for teaching robotics courses online. Guimarães (2020), developed a manipulator with 4 degrees of freedom, using Arduino UNO as a control board, and associative programming through this and MATLAB. Ali et al., (2022), created a robot with 5 degrees of freedom, controlled via Bluetooth module and Arduino, for connection they used the MIT Inventor App, generating an interface to control it. Shetty et al. (2019) also used the Arduino UNO as a base, however it differs in relation to the connection system, they use an ESP-8266 board connected to the board. Souza, Miranda and Santos Junior (2022) aimed to make a pedagogical robotic arm that could help in the development of children with Autistic Spectrum Disorder. Hemmelder et al. (2018) developed a 3D printed articulated arm robot with IoT capabilities. Kato (2015) aimed to design and implement a manipulator robot with didactic purposes, in order to popularize the technology and reach an audience of high school, technical and higher education students.

Different from these works, in this paper we propose a design, control and simulation of a robotic cell to training applications. The prototype of a robotic arm with 6 (six) degrees of freedom and a gripper at the end effector was manufactured, integrating it with the prototype of a conveyor belt, and with an Arduino as control and programming hardware, thus it was possible to develop a robotic cell for robotics training applications.

2. DESIGNED ROBOT

The robot was manufactured using the 3D printing for most of the parts, which were prototyped at the CTIF (Laboratory of Technology and Innovation in Manufacturing) at UNIFEBE, or by the author with his own 3D printer, in both locations. A Creality printer, model Ender 3, was used, where the parts were printed on PLA material (Polyácido Lactico), with filling between 20 and 30%. Some parts that were not produced in 3D printers, being aluminum and stainless steel, required manufacturing through plasma cutting, and also a bench drill.

Table 1 presents the parameters of the robot of this project. This robot is based on the Skyentific (2029), but with modifications. As the objective was not design a new kind of robot, but build an infrastructure to develop a robotic cell for robotics training applications. Different from the original robot, in this work was designed a tool fixed to the end effector and the integration with the conveyor belt.

Table 1. Specifications of the SKF 2000 robot.

Robot version	**SKF 2000**
Payload at the wrist (kg)	0,15
Number of axis	6
Controller	Arduino Mega 2560 + Shield Ramps 1.4
Axis	
Axis movements	Min. and Max. Angles
Axis 1	-100° to +100°
Axis 2	-80° to +100°
Axis 3	-170° to +100°
Axis 4	-180° to +100°
Axis 5	-110° to +100°
Axis 6	-360° to +100°

The final budget with all parts, components and resources was R$ 3990.00, of which R$ 926.30 refer to the mechanical part, and R$ 3063.70 refer to the electrical part as shown in Table 2. The values refer to the year 2022.

Table 2. Equipment and material costs of the project.

Mechanical parts		**Electrical parts**	
Description	Total cost ($)	Description	Total cost ($)*
Pulleys and belts	39,12	Nema steeper motors	453,58
Bearings	38,39	Wires and conectors	49,81
Metal sheets	8,19	Power supply	17,41
Screws	45,52	Sensor and controllers	49,56
3D printer filaments	30,72	Drivers	43,72
Equipments rents	27,65	Servo SG90	6,14
Total	183,59	Total	620,22
		Total of the robot =	803,81

*Considerer exchange rate 1 BRL = 0,2048 USD

2.1 Assembling of the robotic cell

To adapt the robotic arm to the final project (separation of the cubes by color), it was necessary to add a gripper to the robot, a gripper sized to be used with an SG90 servo motor, with low weight and that is compact, since the robot has a capacity load of 0.15 kg. Figure 1 shows the sequence with some steps for assembling the robot, and the assembled robot.

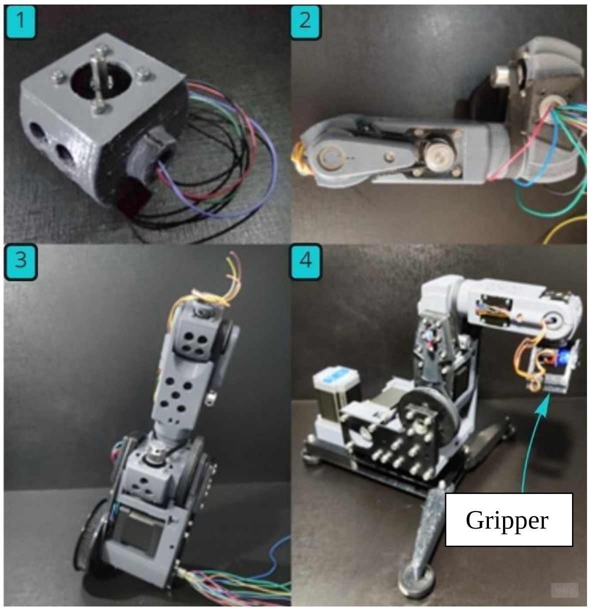


Figure 1. Robot with the gripper at the end effector.

The conveyor belt (Figure 2), used in this work, initially developed by Souza (2021) had a conventional DC 5V motor, an ultrasonic sensor, and an Arduino Uno controller board. In our project it was made changes to suit the final objectives. In order to automate the conveyor belt (Figure 16b), two sets of infrared LEDs were completed, one at the entrance and one at the exit of the conveyor belt, for starting and stopping the motor when its signal was interrupted. The conventional 5V motor was replaced by a Nema 23 stepper motor. In the conventional motor, after powering off the energy supply to the motor, it continues to move with the inertia of the system, this movement does not occur with the stepper motor, which after interruption of the pulse signal, its stop is practically immediate. Finally, a color sensor model TCS230 was inserted, this has the purpose of identifying the color of the sample block and sending the signal to the controller board. Some parts had to be designed, namely, the support for the Nema 23, support for the color sensor, and guide for the hubs. All designed parts were made using the 3D CAD Solidworks software.

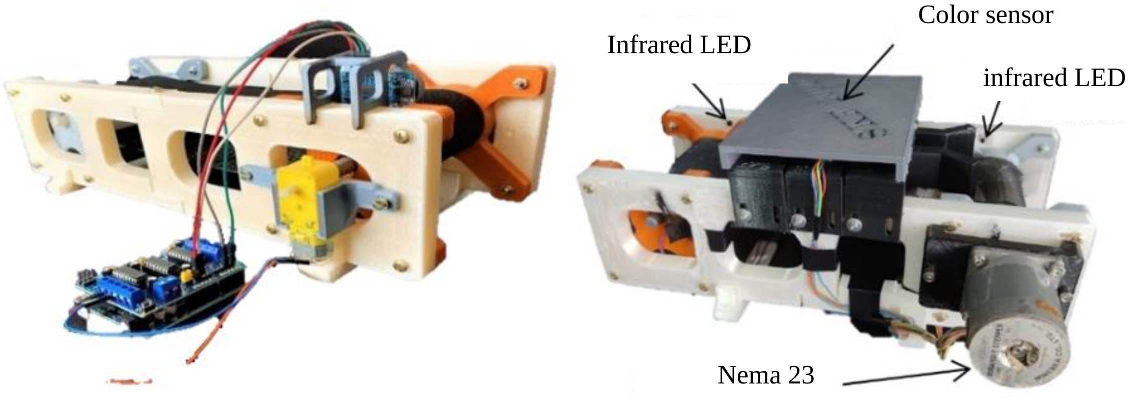


Figure 2. Conveyor belt: a) from Souza (2021), and b) designed in this work.

To the assembly of the electrical part with the integrated robot and conveyor belt, an electrical schematic was developed, where it is possible to identify all connections between components and the board, both for the robot and the conveyor belt. To control the robot and the conveyor belt, an Arduino Mega 2560 board was used, an open source board widely used for prototyping, it has 54 digital inputs and outputs, and 16 analogue, and is also compatible with the shield ramps 1.4, a model used to control CNC machines and 3D printers. The ramps 1.4 board supports controlling up to 5 stepper motors, in this project 3 inputs were needed to control the motors of joints 4, 5 and 6 through the DRV8825 drive, and also an input for the treadmill motor with the A4988 drive. The motors of joints 1, 2 and 3, being more robust and having a higher consumption, were coupled to TB6600 drivers separated from the arduino+shield set, with only the control outputs (ena, dir and pul) connected to the shield. All other sensors, and the grapple were connected to shield ramps 1.4. The schematic of the robotic cell is illustrated in Fig. 3. The appendices show the complete electrical schematic of the robot developed in this work.

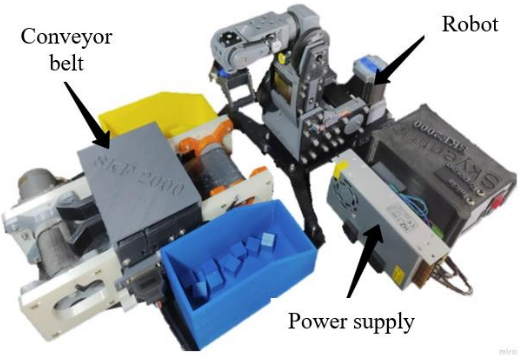


Figure 3. Robotic cell developed in this work

2.2 Kinematic of the robot

The robot's position kinematics solution is performed through direct and inverse kinematics. The convention that was used for the direct kinematics of this robot, the D-H convention (Denavit-Hartenberg), results in a homogeneous transformation matrix, where the parameters that constitute the D-H matrix: the rotation angle of the joints θ_i, the angle of rotation between joint axes α_i, the length of links a_i, and joint displacement d_i are shown in Tab. 3.

Table 3. D-H parameters of the robot

Link	θ_i [°]	α_i [°]	a_i [mm]	d_i [mm]
1	θ_1	-90	47	134,5
2	-90º+θ_2	0	110	0
3	θ_3	-90	26	0
4	θ_4	90	0	117,5
5	θ_5	-90	0	0
6	θ_6	0	0	28

The kinematic design of the robot and also the measurements of lengths and distances of the joints and links, in order to assemble the D-H matrix, were provided by the robot developer. To facilitate understanding, a representation of the kinematic project is necessary, and the measurements of distances and lengths on the image of the robot shown in Fig. 4.

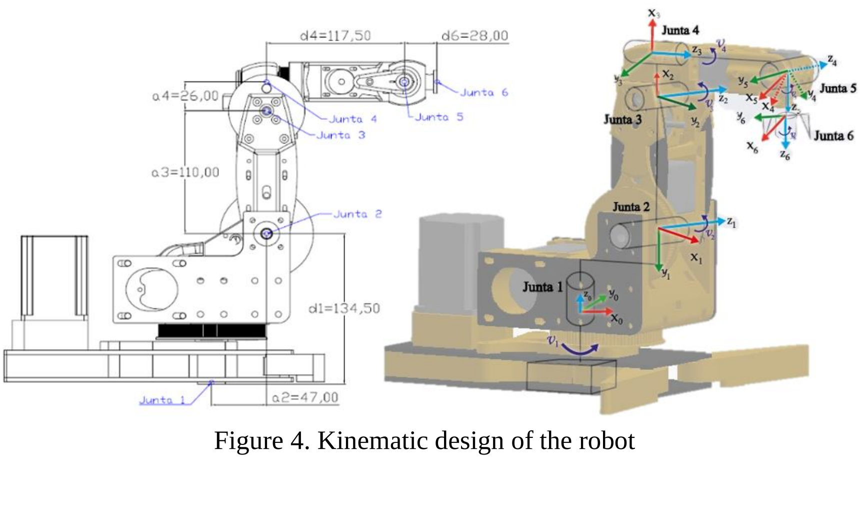


Figure 4. Kinematic design of the robot

To solve the inverse kinematics, as presented in the review, the problem was divided into two parts, where one constitutes the "arm" formed by joints 1, 2 e 3, and the other part called "wrist" consists of joints 4, 5 e 6. The solution of the inverse kinematics of this robot was carried out through the function "*void InverseK(float* X_{ik}, float* J_{ik})*" implemented in the Arduino IDE, where X_{ik} is the position vector of the end effector and J_{ik} the joint angles calculated by the function. The inverse kinematics solution in this work is used as provided by Skyentific (2019).

Algorithm 1 presents the solution of the first three joints of the robot (q_1, q_2, q_3) implemented in the Arduino. As presented in the review, these three values define the position of the robot's spherical wrist, defined by the p_w.

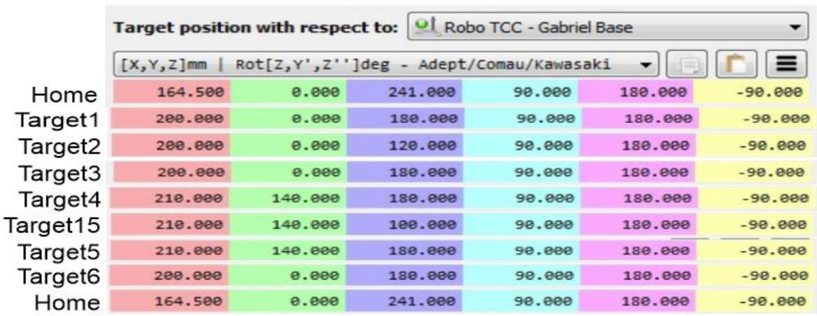
Algorithm 1: Function that calculates the inverse kinematics of the robot for the first three joints (Adapted from Skyentific, 2019).

```
void InverseK(float* Xik, float* Jik)
{
 // first joint
  Jik[0]=atan2(Xsw[1],Xsw[0])-atan2(d[2],sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-
d[2]*d[2]));
  // second joint
  Jik[1]=PI/2.0
  -acos((r[1]*r[1]+(Xsw[2]-d[0])*(Xsw[2]-
d[0])+(sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-d[2]*d[2])-
r[0])*(sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-d[2]*d[2])-r[0])-
(r[2]*r[2]+d[3]*d[3]))/(2.0*r[1]*sqrt((Xsw[2]-d[0])*(Xsw[2]-
d[0])+(sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-d[2]*d[2])-
r[0])*(sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-d[2]*d[2])-r[0]))))
  -atan((Xsw[2]-d[0])/(sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-d[2]*d[2])-r[0]));
  // third joint
  Jik[2]=PI
  -acos((r[1]*r[1]+r[2]*r[2]+d[3]*d[3]-(Xsw[2]-d[0])*(Xsw[2]-d[0])-
(sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-d[2]*d[2])-
r[0])*(sqrt(Xsw[0]*Xsw[0]+Xsw[1]*Xsw[1]-d[2]*d[2])-
r[0]))/(2*r[1]*sqrt(r[2]*r[2]+d[3]*d[3])))
  -atan(d[3]/r[2]);
```

All the scripts and files are in the following link < https://drive.google.com/drive/folders/1S6G5784fldy_u0ZnmqviBGqBOFy-i-7M?usp=sharing > and can be accessed online.

2.3 Offline programing

With the aim of promoting an online learning environment, a simulation of the robotic cell was carried out in the Robo DK software. To insert the 3D robot in the software, it was necessary to import the complete assembly in a step file, the model was configured within the software itself, the "split" option was used, where the entire step was divided into several parts, being " exploded", and then to relocate the joints, all parts corresponding to the base were selected, and then converted into an object through the option "convert to object", the same was necessary for the other joints, in this way the robot was configured in 7 parts. All the files are available to download and test. The targets to the inverse kinematic was programmed (Fig. 5) and then the simulation was carried out (Fig. 6).



Home	164.500	0.000	241.000	90.000	180.000	-90.000
Target1	200.000	0.000	180.000	90.000	180.000	-90.000
Target2	200.000	0.000	120.000	90.000	180.000	-90.000
Target3	200.000	0.000	180.000	90.000	180.000	-90.000
Target4	210.000	140.000	180.000	90.000	180.000	-90.000
Target15	210.000	140.000	100.000	90.000	180.000	-90.000
Target5	210.000	140.000	180.000	90.000	180.000	-90.000
Target6	200.000	0.000	180.000	90.000	180.000	-90.000
Home	164.500	0.000	241.000	90.000	180.000	-90.000

Figure 5. Coordinates and orientations configured in the Robot DK software.

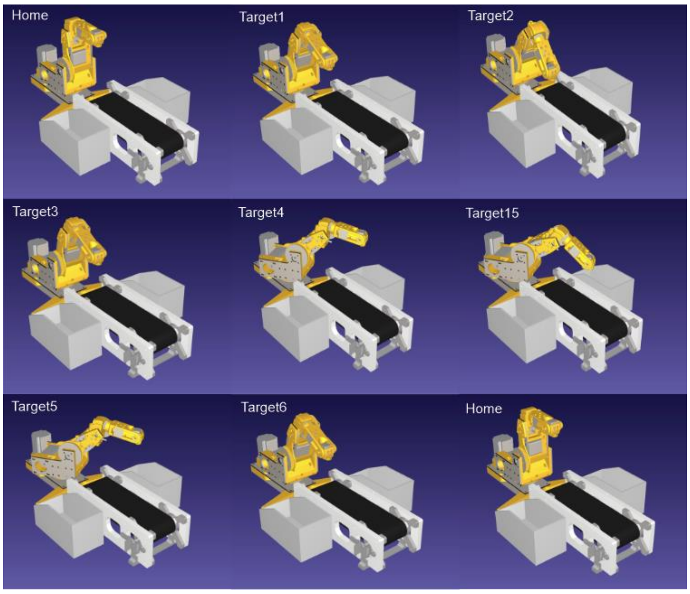


Figure 6. Sequence of movements of the Robot taken from the Robot DK software, for pick and place of the blue cube

The same sequence of movements was performed to pick and place the yellow cube, but targets 9, 16 and 10 have a negative "y" coordinate sign (-140). With this simulation it is already possible to train the robot programming offline. One limitation is the software license, whose free version is only valid for 30 days.

2.4 Testing of the robotic cell

This work resulted in a robotic cell with application in palletizing by color selection composed of 3 modules. One robot module composed of a robot with 6 (six) degrees of freedom with anthropomorphic characteristics and a gripper on the end effector. One conveyor module composed of a conveyor with a stepper motor and sensors for automation, and finally the electrical module consisting of two power supplies, an Arduino mega and a shield ramps 1.4 board used to control the conveyor and the robot.

With all the parameters collected in the simulation and integrated into the Arduino programming, the tests in the robotic cell began. The cell proved to meet the ideal proposed for this project, being possible to simulate palletizing within an industry, separating the sample cubes after identifying their color, and taking them to the appropriate locations. Figure 7 shows the movements for palletizing the blue cube performed by the robotic cell, from the insertion of the cube on the conveyor belt, until the robot deposits the cube in the location and returns to the home position.

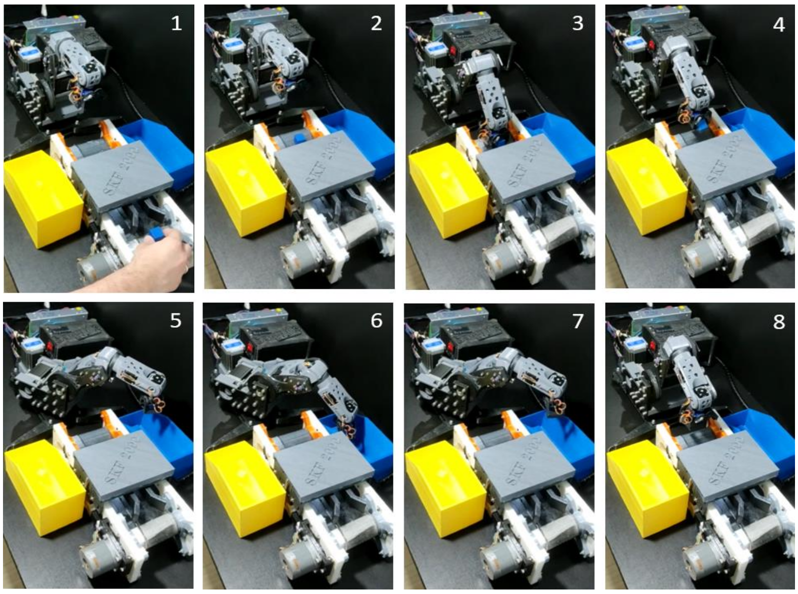


Figure 7. Illustration of the robotic cell working

A video of the robot is available at the link https://www.youtube.com/watch?v=bYXCDfHBzc0.

3. CONCLUSIONS

This work aimed to develop a robotic cell for robotics training. The prototype of a robotic arm was integrated into a conveyor belt, simulating the process of a robotic cell used for palletizing, not only virtually through the Robo DK software, but also through the Robot, Conveyor and Electric modules built in this work. Tests were carried out with the robotic cell, it proved to be functional, and after a battery of tests it obtained maximum use, 112 cubes passed through the robotic cell, from this sample 6 are yellow, and 8 blue, placing them those randomly on the conveyor belt were all selected and correctly allocated in the locations according to the color of each sample.

As a contribution to the flied, this project it is possible to highlight design of a robotic cell with a set of infrared leds to identify the start and stop of the conveyor belt and color sensor to read the color of the sample on the conveyor belt.

As topics for future work, it is suggested the development of a device to feed the conveyor belt, increasing the simulation conditions of the robotic cell, making it closer to what happens in industry 4.0. Another suggestion for work is the implementation of a cube counting system integrated with a cloud data storage and processing system.

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5. RESPONSIBILITY NOTICE

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6. APPENDICES