Pieces Separation Applied to a RV-2AJ Industrial Manipulator

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Abstract: **The objective of this work is to create a system for separating types of pieces for didactic purposes. An artificial vision system applied to a manipulator was used to perform this task of classifying and separating the pieces, through the use of digital image processing. The vision system uses a camera attached to the robot's end-effector, whose objective is to identify the area, perimeter and position of the centroid of the pieces to be separated. The separation of objects is performed between two classes: with round and non-round shapes. The tests were carried out with objects such as screws and nuts. After obtaining the positions of the objects to be separated by the vision system, some characteristics of these related to the reference system of the robot base are determined. Some difficulties were observed in the recognition of objects related to the colours and lighting conditions of the separation environment. To reduce these problems, black colour objects were used in order to reduce the reflectance. Another problem encountered in the separation process is related to the relative position of objects. In this case, two or more objects can be identified as a single object, depending on their relative positions. The system classifies with a rate of hits greater than 95%.**

Keywords: **Computer Vision, Manipulator, Pieces Classification, RV-2AJ.**

I. INTRODUCTION

According to [1], the use of machines with the potential to replace human labour in physical activities and decision-making tasks can be attributed to robotics.

Debates have been held on the social impacts generated by automation processes over the last few decades. Data have shown a reduction in jobs within the industrial segment. On the other hand, the experience of industrialized countries presents automation as fundamental for the survival of companies. It has been seen that companies that chose not to automate their processes lost competitiveness or even had to close down their activities.

In fact, the increasingly competitive market requires specialized labour, opening new jobs in maintenance, programming and machine operation activities.

The *International Federation of Robotics* (IFR) is a non-profit organization whose objective is to promote research, development and use of international cooperation in the field of robotics. Annual surveys are carried out by the IFR worldwide on the process of replacing human labour with robots.

The year 2020 saw a 0.5% growth in robotic unit installations with a total number of 383,545 units installed. On the other hand, the year 2019 showed a drop of 10%, reflected by trade difficulties between the USA and China, with the automotive and electro/electronic sectors being the ones that suffered the greatest impacts [2].

Yet according to [2], the year 2020 consolidated Asia as the world's largest robot market, with a percentage of 71% of new installations (corresponding to 266,452 units), followed by Europe with 67,700 units. Installations were 38,736 units in the Americas in the same year. International Federation of Robotics data also point out that 76% of global robot installations are concentrated in 5 countries: China, Japan, USA, South Korea and Germany, showing an industrial imbalance worldwide.

Educational robotics seeks to escape of comparatives discussions between advantages and disadvantages involved in the automation process. Instead, it has as an objective to support the professional training process for this market segment, increasingly demanding and lacking qualified labor.

Robotics has been inserted in the curricular grades of various institutions from basic to professional educational training in recent years around the world. Studies suggest that, due to its multidisciplinary characteristics, robotics improves the academic performance of students in other areas, such as mathematics and physics. Thereby, it should be emphasized the growing need for qualification of teaching professionals to also act as knowledge trainers in the area of robotics [3].

Data from the 2021 World Robot Report carried out by IFR, show that in Brazil, there are 10 robots for every group of 10,000 workers. The small index shows a potential for growth in the robotics area for the next few years.

The expectation of growth in the robotics market brings the need for specialization of professionals in the industrial automation segment, requiring professional education institutions prepared to deal with this demand, in addition to seeking didactic tools to make learning more attractive for students, such as situations close to those found in the industrial environment.

The work that generated this text aimed to develop an application to be used as a teaching resource for subjects related to the area of robotics in the technician and University graduate levels.

It was used a simple computer vision system for pieces' recognition and classification.

Works related to the industrial manipulators, can be found in several texts. In [4], can be found a path planning based on joint space to achieve real-time path planning speed without modeling or training the workspace in advance. A framework using computer vision techniques for manipulator calibration can be found in [5]. A method of prediction for capturing the robot dynamics and stability based on data-driven is given in [6]. A method to determine controller gains that ensure closed-loop stability without trial and error gain-tuning, can be found in [7].

This text is divided as follows: Section II briefly describes the industrial manipulator used as a teaching tool, presenting some of its most important characteristics. Some basic aspects of computer vision and the system developed can be found in section III, including a description of the method for recognizing and manipulating pieces, using the homogeneous geometric transformations. The results presentation can be found in section IV, where numerical values of the data obtained in the tests process were performed by the system.

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II. RV-2AJ INDUSTRIAL MANIPULATOR

The robot used in this work is shown in Fig. 1. It is a small manipulator model RV-2AJ, manufactured by Mitsubishi Electric. The RV-2AJ model has an articulated architecture with 5 degrees of freedom, whose joint activation is performed completely through electric actuators, with the exception for the end-effector, which is pneumatically activated. The joints are driven by position servomotors, whose position readings are performed by encoder sensors.

This manipulator model has the possibility of being programmed and moved through the pendant interface or via an external controller.

When controlled by an external device, Mitsubishi proprietary software can be used, or applications can be developed to communicate and send commands to the robot's control system.

The RV-2AJ model can be programmed using two different programming languages: **Mastermove Commands** or **Melfa Basic IV** [8], the latter of which was used in this work.

The Melfa Basic IV is a language that has commands easy to learn. It is an interpreted language, where the source code is read and executed by the interpreter, without the need for translation into machine code.

Detailed information about the RV-2AJ manipulator controller, such as control system parameters, programming language commands and variables can be found in [8].

The Fig. 2 shows the representation of the robotic cell used in the development of this work. All sensor movement and reading operations must be carried out through the controller, which receives commands from external devices and sends them to the robot for execution.

The programming used to carry out the parts movement tasks was carried out in an application developed using the set of digital image processing tools, in order to extract characteristics of the parts necessary for their classification.

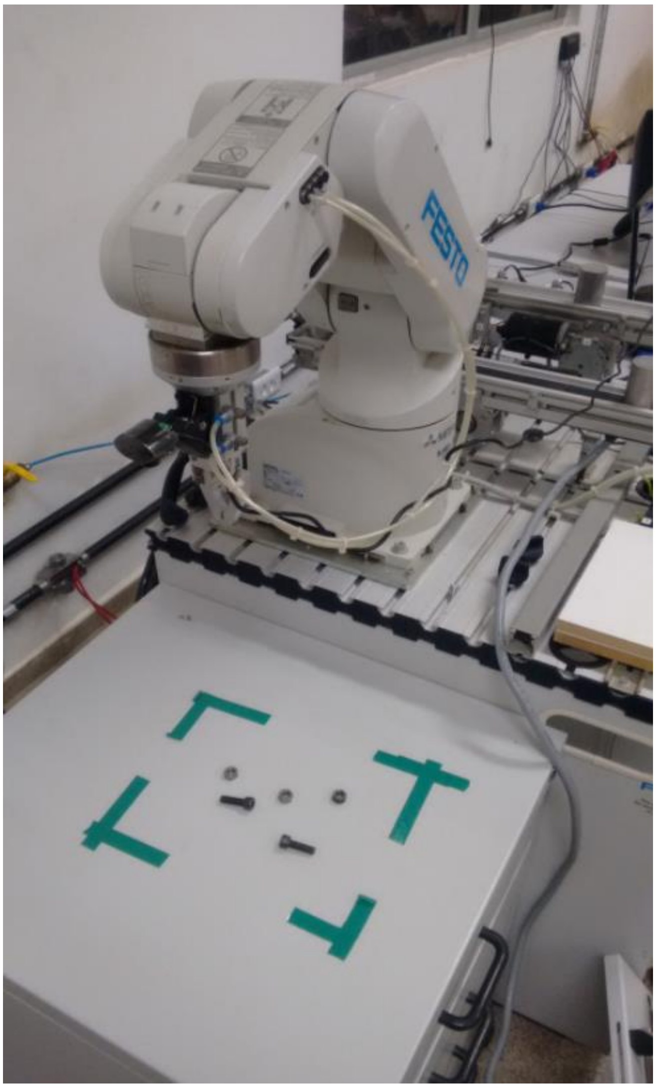

Fig. 1. RV-2AJ Industrial Manipulator.

It was used homogeneous transformations to realize the positions of pieces related to manipulator base.

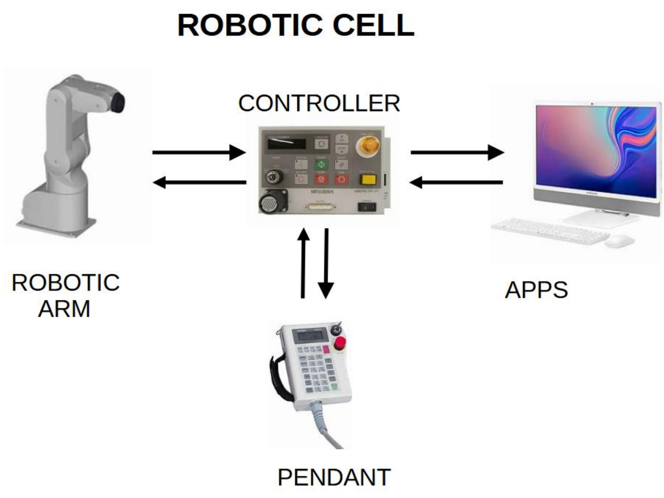

Fig. 2. Robotic Industrial Cell.

III. SYSTEM DEVELOPED

In the process of recognizing and classifying pieces, two types of these were used: screws and nuts.

The process of classifying the pieces starts with the collection of the image in the work environment where they are placed for separation. At this stage, some characteristics of the pieces are extracted, such as area and perimeter. Still in this step, the centroid coordinates of each piece on the camera frame are determined, whose objective is to perform the manipulation for each one of them, in the final process stage. Based on the characteristics obtained from each piece, their position related to the robot's base coordinate system are determined, through homogeneous geometric transformations.

A NEOX webcam model NXW036 with resolution of 10,000 K was used in the computer vision system. This camera was fixed directly on the robot's end-effector.

Due to its educational nature, priority was given to the use of free license software. Thereby, Octave was chosen, since this software meets these requirements, in addition to having image acquisition and processing packages, essential to speed up the development of applications in this area, as well as the ease of communication with the controller of the industrial manipulator RV-2AJ.

A set of tools developed for Octave was used to help create new applications to the RV-2AJ handler. More details about this toolbox can be found in [9], and information about the robot programming language syntax is find in [10].

The artificial vision process is one of the basic requirements so that the parts sorting system works properly.

Computer vision obtains characteristics of objects, such as their position in the camera frame. It is necessary to carry out a mapping of this position to the space of robot configurations. Some works have been proposed with the objective of accomplishing this task. A neural network was used in [11] with the objective of carrying out the control process of a robot, making the use of kinematics and calibration of the vision system unnecessary. Some difficulties related to the operation of the vision system and camera calibration with several algorithms used to solve these problems, in addition to the use of digital image processing to extract features from these images can be find in [12]. Object recognition using Artificial Neural Networks and Fractal Geometry is performed in [13].

In this work, the developed system initially obtain an image of the work environment where the pieces to be separated will be arranged. At this early stage, no objects are present in the scene. This initial image of the environment without pieces will be used as a reference.

After collecting the image of the scene without pieces, the objects are disposed randomly on the table and this new image obtained it will be compared with the initial scene without objects arranged. The images of objects to be detected by the camera undergo digital processing to adapt them to the needs of the recognition system. After collected, images in RGB format are converted to grey levels.

Changes in the lighting conditions of the environment, as well as the characteristics of the pieces, can degrade the performance of the recognition system, making it difficult to recognize these pieces. Another problem found in the system tests was the influence of the objects' arrangement on the work plane, since very close objects can be confused with a single piece, as shown is Fig. 3.

Fig. 3. Influence of distance on pieces recognition

The vision system continues capturing new images, determining the characteristics of the pieces (area, perimeter and centroid), verifying objects with shapes similar to the circular shape. The coordinates of these objects are calculated by the system, which triggers the controller to collect these pieces from the work table. The piece shape is obtained through an index calculated as proposed in [14]. This index is given by Eq. (1).

$$i = \frac{4\pi A}{p^2} \tag{1}$$

Where A is the object area and p is the measurement of its perimeter.

From Eq.(1) it's easy to note that for perfect circular shape objects, this index value must be 1. Pieces whose index have values close to 1, can be considered as having circular shape.

In practical tests nuts were used in different configurations, and this index was measured. It was done seventeen experiments with ten nuts in each of these tests.

The Fig. 4 shows the Frequency distribution of data obtained after 17 samples. In each data sample, it were used ten nuts disposed randomly in the workspace. The horizontal axis shows the indexes obtained by the vision system and the vertical axis shows the number of occurrences for each index obtained.

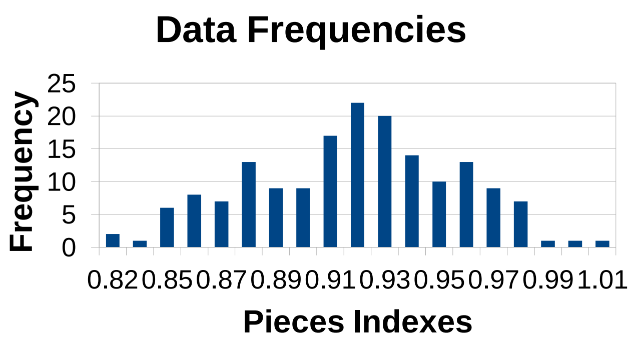

Fig. 4. Frequency Distribution

The Fig. 5 shows a Normal Distribution. For choose the index used as a threshold necessary to classify a piece as rounded, it was considered a probability of 95%. In this Normal Distribution, for gets this probability is necessary using an index of 0.82.

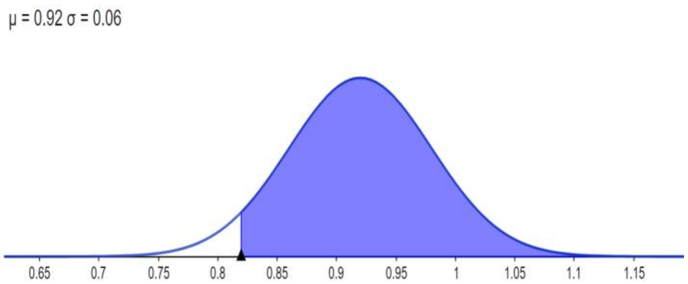

Fig. 5. Normal Distribution

The results obtained for probability in Fig. 5, was done using the *Geogebra online* calculator.

The Fig. 6 presents the pieces classifying and separation system.

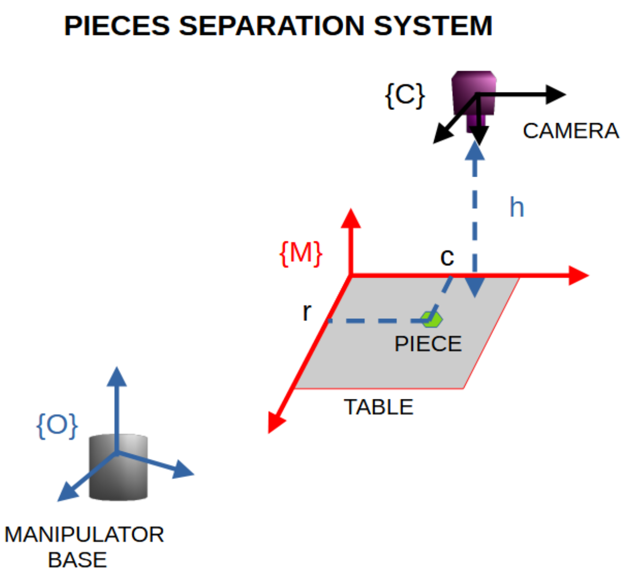

Fig. 6. Classifying and Separation System.

The pieces recognition procedure starts with the placement of these in the workspace and the positioning of the robot at coordinates x_c=10,y_c=-100,z_c=200 (units in millimetres).

The Positioning of this manipulator in these coordinates it was necessary so that the area captured by the camera has dimensions of 0.3 m x 0.4 m. Then the camera takes the image of the table with all objects present in the scene and calculates all parameters necessary for manipulation and separation to occur properly.

The system vision resolution used for capturing the camera image is 320 x 240 pixels. The pixel area parameters are given by: S_x = 0.4/320 and S_y = 0.3/240. Where S_x and Sy are the pixel width and length, respectively.

The coordinates values of the objects obtained by the camera, corresponds to the line and column indices (r,c) of the central pixel of the piece. These values must be converted into millimeters, since these are the units used in the robot's reference system.

The camera projection center, which contains the central point of the image (O_c=160,O_r=120) is shifted related to the obtained coordinates, so the conversion to calculate u and v must be carried out according to [15]:

$$u = -S_x(r - O_r) \text{ e } v = -S_y(c - O_c) \quad (2)$$

The manipulation problem consists in obtaining the object coordinates with respect to the robot base (x,y,z) from the coordinates of the image indices (r,c) obtained by the vision system. The solution to this problem is in the use of homogeneous transformations, according to [15].

Fig. 7 represents the geometric transformations involved in this process, as follows:

O - Robot base coordinate system;
C – Camera coordinate system;
M - Table coordinate system;
P - Coordinate system of the object's centroid measured by the camera.

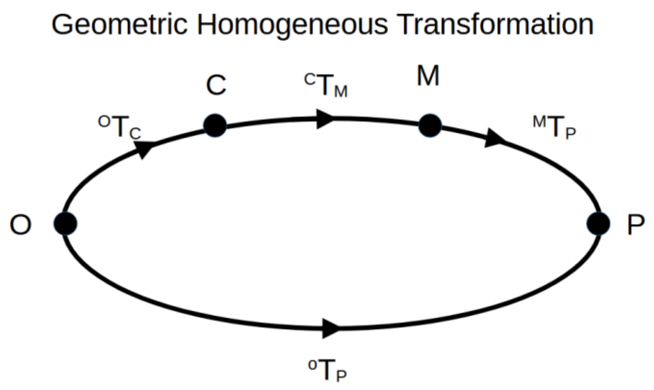

Fig. 7. Geometric Homogeneous Transformations

The Geometric transformation between the referential of robot base and of the camera is given by Eq. (3):

$$T_C^O = \begin{bmatrix} 1 & 0 & 0 & X_C \\ 0 & 1 & 0 & Y_C \\ 0 & 0 & -1 & Z_C \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

The Geometrical Transformation between the referential of camera and the table are given by Eq. (4).

$$T_M^C = \begin{bmatrix} 1 & 0 & 0 & O_r \\ 0 & 1 & 0 & O_c \\ 0 & 0 & -1 & h \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

The Geometrical Transformation relating the referential of table and Centroid is given by Eq. (5).

$$T_P^M = \begin{bmatrix} 1 & 0 & 0 & u \\ 0 & 1 & 0 & v \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

The Geometrical Transformation between the object and the robot referential, obtained after algebraic manipulations (Eq. 4, 5 and 6) is given by Eq. (6).

$$T_P^O = \begin{bmatrix} 1 & 0 & 0 & u + S_x O_r + X_c \\ 0 & 1 & 0 & v + S_y O_c + hY_c \\ 0 & 0 & 1 & -h + Z_C \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

Where: (u,v) are the coordinates of the object's centroid identified, calculated related to the camera coordinate system; S_x and S_y are the dimensions of a pixel, O_r and O_c are the projection center coordinates, h is the distance between the camera and the table plane and (x_c, y_c, z_c) are the camera coordinates.

The intrinsic and extrinsic parameters were measured experimentally, moving the robot and verifying the coordinates obtained.

IV. RESULTS

The evaluation of the system was carried out through tests to extract indicators of correct classification of the pieces, as well as adequate handling.

Test sets were performed, each one composed of five runs. The purpose of the tests is to measure the performance of the systems under different lighting conditions, as well as the proper handling using geometric transformations. Following are presented the results of three tests set:

1. Round Piece Count - This first test was performed to check the influence of lighting conditions. In this test, it was found that chrome pieces do not were properly recognized due to these conditions of lighting (reflectance). In this first step, 8 nuts and 8 screws were arranged and this procedure was performed 5 times. Table I presents The obtained results:

TABLE I. TEST SET 1
(Maximum illuminating)

Test Number	Errors Found
1	2
2	3
3	1
4	2
5	2

In this process, there was a small variation in obtaining the errors, due to the disposition of the parts in the environment of separation of the parts. The total error was 12.5%.

2. Piece counting with reduced lighting - In this second test, the lighting was reduced by half and black parts were used. The same number of nuts and bolts as in Test 1 were used.

In this phase, the errors obtained in counting parts were smaller than those found in phase 1. Errors due to the proximity of parts were found, resulting in an improper count. At this stage the total error was 3.75%.

The size of the pieces can also influence the results. In the image processing script, a threshold of 50 pixels for recognizing was used. This value was used through experimentation. Some threshold values were tested and a value adjusted to the recognition of the pieces was used. Table II show the results of Test Set 2.

TABLE II. TEST SET 2
(Medium illuminating)

Test Number	Errors Found
1	0
2	0
3	1
4	0
5	2

3. Pieces Manipulating – In this step, it was tested the manipulating system. It was verified if the round pieces were separated. The Table III show the results obtained.

TABLE III. TEST SET 3
(Manipulating System)

Test Number	Errors Found
1	0
2	0
3	1
4	1
5	0

In this last test, the correct values percent obtained was 97.5%. In this step, the errors are related to not directly to the manipulation system, but to the errors on the transformations calculus, due to vision system.

The Fig. 8 shows the index calculus for classification of pieces.

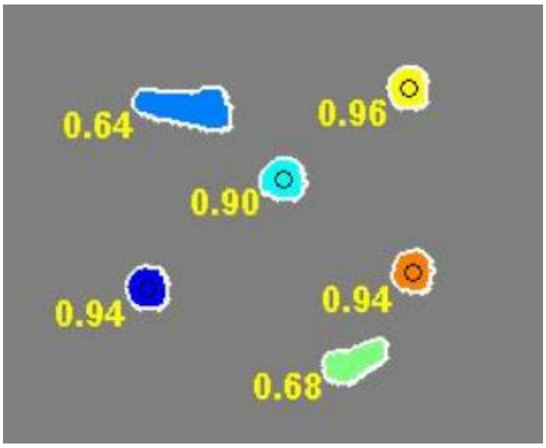

Fig. 8. Index calculus for classification of pieces.

It can be seen that all nuts are classified by an index greater or equals to 0.90, indicating round shapes, while bolts have index less than the threshold 0.82, being considered non circular pieces.

V. CONCLUSIONS

It's important in classroom that students have contact with practical tools, because this helps them to understanding the theoretical contents better.

This work has as principal objective being used as didactic tool for using in classroom related to image digital processing and robotic. Developing of tools for educational objectives justify due to its great importance in teaching.

The implemented system of classification works properly.

In this article, it was used concepts of geometric transformations, computational vision, robot programming languages and others.

The used method has limitations, since it can be used only for classifying objects in two different classes. In future works is proposed using Neural Networks for expanding the classification of pieces.

It's been hoping this tool being applied in classroom must to help motivate students, for interesting in this area.

REFERENCES

[1] L. Sciavicco and B. Siciliano, "*Modelling and Control of Robot Manipulators*". Springer, 2000.
[2] International Federation of Robotics, "Executive Summary World Robotics 2021 Industrial Robots".2021.
[3] J. Neto and S. Bertagnolli, "Robótica Educacional e Formação de Professores: Uma Revisão Sistemática da Literatura," *Revista Novas Tecnologias na Educação*, no. 19, pp. 423–432, 2021.
[4] Y.H. Yu and Y.T. Zhang, "Collision avoidance and path planning for industrial manipulator using slice-based heuristic fast marching tree," *Robotics and Computer-Integrated Manufacturing*, vol. 75, pp. 102289, 2022.
[5] H.M. Balanji, A.E. Turgut and L.T. Tunc, "A novel vision-based calibration framework for industrial robotic manipulators," *Robotics and Computer-Integrated Manufacturing*, vol. 73, pp. 102248, 2022.
[6] T. Cvitanic and S.N. Melkote, "A new method for closed-loop stability prediction in industrial robots," *Robotics and Computer-Integrated Manufacturing*, vol. 73, pp. 102218, 2022.
[7] C. Yu, Z. Li, D. Yang and H. Liu, "A fast robotics arm gravity compensation updating approach for industrial application using sparse selection and reconstruction," vol. 149, pp. 103971, 2022.
[8] "Melfa Industrial Robots Instruction Manual," *Mitsubishi Electric*, 2002.
[9] M. V. L. M. Andrade, F. C. Freitas, and F. V. Andrade, "Desenvolvimento de uma toolbox para aplicações em um manipulador RV-2AJ". *Congresso Brasileiro de Instrumentação, Sistemas e Automação*, 2019.
[10] A. Muñoz. and M. Coral, "Diseño y Construcción de un API para la Plataforma .NET que Permita Controlar el Brazo Robótico Mistubishi RV-2AJ Através del Puerto Serial", *Universidade Politécnica Salesiana*, 2012.
[11] M. Almeida, "*Controlo de um Manipulador Robótico Usando Visão*", *Universidade Técnica de Lisboa*, 2004.
[12] P. Corke, "*Vision and Control Fundamental Algorithms in Matlab*", Springer, 2017.
[13] C. Bisneto, "*Reconhecimento de Objetos Utilizando Redes Neurais Artificiais e Geometria Fractal*", Dissertação de Mestrado, SENAI CIMATEC, Salvador-BA, 2011.
[14] *Matlab Documentation*, Mathworks, 2017.
[15] M. Spong, S. Hutchinson and M. Vidyasagar, "*Robot Dynamics and Control*", 2nd Ed. John Wiley & Sons, Inc, 2004.