

Project-Based Learning Environment: Integration of an Educational Robot Arm with Computer Vision and ROS

Teixeira, C. F. A*, Da Silva, K. F*, Barros, A. M*, Bitarães, S. M*, Thiago Filho, A. M. S*, Dos Santos, P. H*, Cocota Júnior, J. A. N*

**Control and Automation Engineering Department, Federal University of Ouro Preto, Ouro Preto, Brazil (e-mails: cleyson.teixeira@aluno.ufop.edu.br, kassia.fernanda@aluno.ufop.edu.br, anna.barros@aluno.ufop.edu.br, santino.bitaraes@aluno.ufop.edu.br, alexandre.filho@aluno.ufop.edu.br, paulo.hs@aluno.ufop.edu.br, cocota@ufop.edu.br)*

Abstract: Robotics is a science, which aims at controlling mechanical systems through electrical systems and computer techniques. Robotics has a high rate of applicability but, in order to make it easier to comprehend when it comes to learning processes, methodologies that enhance the student's performance and learning curve, like the project-based learning method, are indispensable. The project-based learning technique diverges from the conventional approach, as it makes the many students the object itself of their learning development, by giving them the power of choice and major control over the entire process. This article aims at presenting the project developed by students from the "Robotics and Its Elements" class ministered at Universidade Federal de Ouro Preto - UFOP. The project dealt with concepts, approaches, explanations, and techniques that created a robot-cell (Melfa RV-2AJ and its peripherals) which used the ROS framework system alongside computer vision resources. The robot, after its completion, was able to perform repetitive tasks such as the detection and gathering of specific physical elements – it can manipulate them properly. To make those tasks possible, a Kinect camera was used to obtain data such as the depth and location of the elements which were in the robot's range of grasp. In addition, a detection mechanism derived from the combination of an open source graphic library called OpenCV with the usage of the HSV color system was an important accessory, so that color calibration and orientation addressed properly. Finally, the designated framework (ROS) suited to establish a connection between the robot and its whole operational environment, in order to make the data-sharing and input signal both able to work over the robot's mobility.

Keywords: Project-Based Learning (PBL), Robot Operating Systems (ROS), Computer Vision, Mitsubishi Melfa RV-2AJ Robot, Computer Vision Assisted Programming

1. INTRODUCTION

Robotics is a prominent subject with a great degree of applicability in many different areas. From automobile to biomedicine industries, its involvement can be traced even to domestic entertainment. Robotic arms emerged essentially within the industrial environment, due to the need to manipulate certain elements with higher precision, repeatability and security (Tijani, 2016). According to Radlak and Fojcik (2015), robot arms are the most important industrial robots. When they are integrated with cameras, they can extend their functionalities in order to realize repetitive tasks when it comes to smart and controllable actions.

Robotic themes and their applicability have been increasingly studied and discussed at Schools and Universities (Benitti, 2012). However, developing a Robotics' project is not an easy task, as it requires things such as the planning of a physical project and software development for controlling purposes (Lahtinen, Ala-Mutka, Järvinen, 2005).

During the development of a project, one of its phases consists of programming. Each project requires specific programming language, so that a kind of previous knowledge is required from the students, as well as some kind of familiarity with some programming tools which comes from practicing; that ends up being some sort of learning obstacle. Furthermore, at this stage, the need to understand and manage the entire process emerges (Lahtinen, Ala-Mutka, Järvinen, 2005) and (Gonzalez and Zalewski, 2014).

A very important programming tool related to project development is called GitHub. Being not necessarily a tool, it is a company which hosts the coding, where the majority of codes are essentially open source. During 2019, specifically on May, the company made widespread the fact that it reached 37 million users and more than 100 million repositories, that fact alone gracing it with a great deal of research potential and usability by the developers (Gousios et al. 2014). The platform helps the students with the programming, as they can easily find base code for their projects, so that they are able to find a resolution to complex problems. Another upside is the enhancement of teamwork

skills, not only between groups of students from the same institution, but also world widely (Dabbish et al. 2012).

Generally speaking, the greatest hardship during the project is the management. By knowing how to manage people, to make a coherent and realistic schedule and to provide technical training for those involved, all the tasks can be executed more smoothly. As a result, different educational methods are emerging – such as the Project-Based Learning methodology – and platforms that encourage practical and theoretical teaching, such as the robotic educational laboratories.

According to Lima and Andriola (2013), their research identified three issues exposed by teachers when they are teaching the skills needed to perform on par in the subjects. Those issues are strongly attached to the students' own struggles. The most notorious one is associated with the students' necessity to relate the learned content to the Market's demands. That one, alongside the other two, ends up diminishing the intensity of proactiveness, leading the students into a spiral of discouragement and lack of effort when it comes to learning the subject's content.

The conventional Brazilian's teaching methodology might be considered outdated. That also applies for the evaluation methodology, which consists of few practical activities compared to the theoretical ones assigned. Those methodologies, considering the Market scenario of the engineering as a profession, remains almost unchanged, even though there comes the evolution of many technological tools.

In order to drift apart from those traditional approaches, the use of methodologies which encourage students to appreciate and seek knowledge should be adopted. As stated by Portela et al. (2016), the proper education on Engineering requires an approach to the real-world issues and, therefore, the adoption of practical activities which can allow the students to enhance their experience in the area so that it results in the building of their skills. Therefore, games and simulations can be efficient pedagogical tools for teaching, since they allow the students to better their decision-making abilities, by exploring alternative strategies and their consequences.

According to Benitti (2012), a methodology that showed positive results consists of giving the students several options when it comes to the project's theme in order to give them control over it. That way, they can relate much better and even become more motivated while developing it.

On the other hand, another alternative is called Project-Based Learning (PBL); that is a learning methodology which aims at focusing on training, practical activities and project development. During its usage, PBL demands the figure of a tutor and well-elaborated problems in order to properly challenge the students so that its success rate is guaranteed. Critical thinking and analysis, teamwork, problem-solving skills, resilience, and proactivity are abilities which are worked through and developed in this methodology (Savery, 2006).

Cabre et al. (2013) used the Project-Based Learning methodology as well, in a way which favors the students to take action in order to play the central role both on the project itself and their own learning development, by downgrading the teacher to a more secondary role that has to do with the challenging of the students. The teachers observed positive responses and results in the evaluations of the ten students which were involved in the activities. They also noticed an increase in terms of motivation. The designed challenge was the detection of a randomly-disposed object in a specific workspace, involving the controlling of a robot in order to take the referred object and move it.

However, the students faced problems regarding the integration of robotic platforms with their respective systems, since it is necessary to establish a quick and effective connection between those systems. Currently, the Robot Operating System (ROS) is the preferred choice to make those connections easier and faster. The ROS is an open-source middleware system for robots which provides an interface of communication that allows data sharing between different modules, by integrating and creating a modular and user-friendly system. With the emergence of ROS, the integration and programming of robots became simplified (Quigley et al. 2009). In other words, the ROS makes an interface among robots and computers connected to the network and nowadays has lots of packages available to use them.

2. OBJECTIVES AND GOALS

This article deals with the accomplishments obtained from the integrated activities on which the students of Engineering took part in order to develop a robotic cell, such as the emergence of transversal competences, where the Project-Based Learning methodology is applied in order to lead the students to use ROS as a means to assist and control the operation of Mitsubishi's Melfa RV-2AJ Robot.

3. EDUCATIONAL ROBOTICS LABORATORIES

This section will present examples of robotic cells which were used by the students to develop the project, since its early stages. The tools and techniques will also be described, as well as the exposition of some constructive criticism regarding the decision-making process which concerns the communication between the robot and the composition of its system.

There are many educational platforms using ROS as a means to offer practical interaction between students and robots. One of them, which is based on Arduino, it is possible to create a network with many mobile robots, sensors, an operational display and a camera for computer vision. ROS works as an interface-like bridge by ensuring a smooth integration between all these modules. In essence, the

platform makes the programming process easier when it comes to putting them into full work (Araújo et al. 2015).

In another platform similar platform in terms of Arduino and ROS usage, there is a more powerful kind of board integrated with the Ubuntu OS. In this one, there is the building of a differential mobile robot with Arduino UNO used for the management of hardware peripherals. ROS then makes the integration between a computer vision system to the robot movement system. So, the teleoperation of the robot is made possible, as well as the mapping of the surroundings and the reaching of certain goals (Gómez et al. 2015).

ROS is also widely used when it comes to mobile manipulative robots (Bischoff, Huggenberger, Prassler, 2011). However, in Osentoski et al. (2012), it is also used for a robot whose manipulator is static. There is also the creation of a remote educational lab in which it is possible to interact with a robot that has two manipulator arms, having ROS responsible for its interfacing with the computer that is connected to the network of choice.

Educational Laboratories are also built without ROS, according Cabre et al. (2013). To do without it, a Service-Arm Type CS-113 robot with 6 degrees of freedom, controlled by ASCII and coupled with a webcam for computer vision was used alongside a specific function developed for communicating with Matlab. The Matlab performed the processing of images by storing the captured data in whole three-dimensional matrices in two ways: a predefined function `v-capg2` and by the Matlab toolbox. Even though it is an excellent tool for image processing, it has low response time, which impacts considerably the data exchanging with the robot by demanding a high amount of system and hardware resources, in a sense, it demands a very capable computer with great processing power in order for the tasks to be performed properly.

Given the ever-growing need for robotics learning, remote laboratories are increasingly used to teach techniques and to improve students' skills. According to Xu et al. (2020), an experimental teaching model was developed in combination with virtual reality, remote control, and an on-site laboratory to support robotic kinematics teaching, and its test resources could be web-shared for wider audiences. They could operate the robot off-site and achieve the same results as on-site operations. As a result of this, the students could choose one of the three modes to examine the effectiveness of their study, or they could first use simulations and later operate robots on-site or remotely and obtain real-world experimental results. Besides, remote labs can be built by an application, such as claimed by Amaral and Dos Santos Lopes (2019), which the app supports the teaching of programming, through which it is possible to manipulate a remote mobile robot through algorithms and visualize the execution of the codes in real-time.

There is also the possibility of building remote Educational Laboratories without the usage of ROS, as in Buitrago, Giraldo and Lamprea (2011), and Crainic and Preitl (2014).

In both cases cited, the interfacing between the robot and the server is carried out directly with RS-232 serial communication. The goal was to make the remote interaction with the manipulator robot from Mitsubishi Melfa RV-2AJ possible.

Another possibility is to use Melfa RV-2AJ together with Mitsubishi-supplied MelfaRxm middleware by developing a Windows program with a graphical interface so that the manipulator can be controlled (Esa et al. 2011). However, the problem of using middleware to communicate with robots is the limitation which comes in always having to use specific software middlewares. Therefore, by installing a ROS package to communicate with the RV-2AJ robot, the integration with any other system would be facilitated since their packages would replace the required middleware, like, for example, using the ROS Freenect for computer vision. On the other hand, without the ROS package, the need to use more than one middleware would arise, since besides the one from Mitsubishi, another one would be needed for the computer vision instrument. In most cases, such specific middleware would not even exist, so that one would have to be created.

Mitsubishi's Melfa RV-2AJ is a robot arm which has five degrees of freedom, being classified as an anthropomorphic articulated robot. It has a handling mechanism which can accomplish pitch and roll movements (Mitsubishi, 2009). It is widely used in the assembly, handling, loading, and unloading of parts up to 2kg, with a maximum range of 410mm and repeatability of 0.02mm. Its usage is very common in Robotics' educational projects. The schematic of this robot can be seen in Fig. 1.

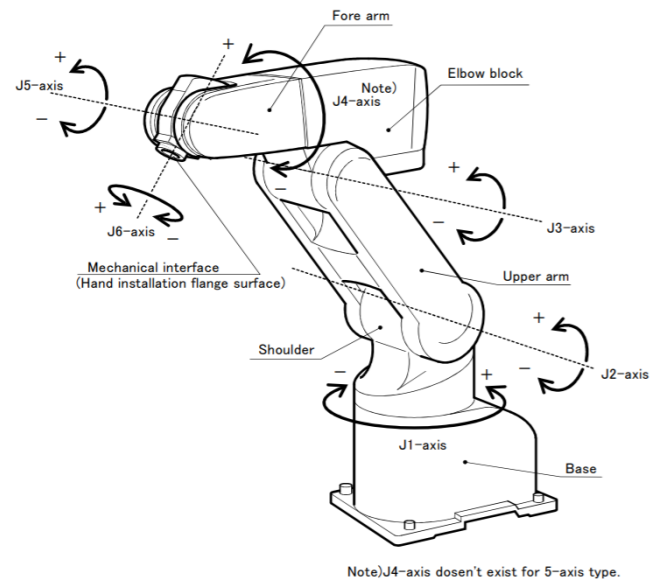


Fig. 1. Schematic with of all robot joints. Since it has only five degrees of freedom, the Joint 4 (J4) does not exist (Mitsubishi, 2009).

Therefore, as can be seen, there are some possibilities in building and developing a robot-cell. Even though the previous authors used a Melfa RV-2AJ (or another robot arm)

and a computer vision technique in their projects, they used some tools and equipment that almost are not recommended for a complex project and they needed to use some middleware to establish a connection between the robot and its peripherals. In addition, the most authors did not show students' skills improved during the project. In contrast, the authors of this project used a developed ROS package to establish a network between the robot and its peripherals and command the robot. Then, they made a survey to discover and register the students' skills evolution.

4. METHODOLOGY AND DEVELOPMENT

The project was developed at the Industrial Technologies Laboratory, inside the Department of Control and Automation Engineering, under Escola de Minas from the Universidade Federal de Ouro Preto (UFOP). The participating students were those from the 4th year and they were enrolled in Robotics Elements. Usually, there are 25-30 seats available for the subject, and there is always a final project (the project described in this article, for a real example), where the students organize themselves in groups of 5-7 people. In this case, 14 students from whole 2 different semesters were involved: 7 from the second semester of 2018, and finally, 7 from the first of 2019.

The Robotics Elements Professor presented several project options to the students, such as mobile robots, manipulators and computer simulation. The students had the opportunity to choose the one they felt most comfortable to work with and which aroused their interest and motivation to the fullest. Then, they chose the Melfa RV-2AJ to work with. Another important thing to mention is that the students were actually continuing the work-in-progress from a previous group, so that they would complement, enhance and finalize it; an evolutionary teamwork. That kind of work aims at constant development and experience exchanging between the students.

The project was segmented in two steps: (i) building up a ROS package for interfacing with the Robot RV-2AJ; and (ii) programming the robot to recognize a sequence of repetitive tasks. The activities performed in each semester can be viewed on Table 1.

Table 1. Developed Activities

Semester/Year	Activities
02/2018	ROS Communication Package Development
02/2018	Creating Functions for Robot Operation
01/2019	Recognition of Objects of Different Colors
01/2019	Recognition Algorithm for a Repetitive Task Sequence

4.1 ROS Package for interfacing with Melfa RV-2AJ

The robot has a controller with RS-232 serial communication interface. Through this interface, it is possible to load complete programs to operate the robot and send immediate response commands. It can also create these commands based on the same ones from MELFA BASIC IV programming language, as they must be adapted to the serial port's sending format.

Firstly, a Python program needs to be created in order for the communication between the computer and the robot controller. The controller interprets only specific language commands of choice, such as MELFA BASIC IV. The controller receives the commands in text format through serial communication. The Python library required for this interface to work is "pyserial", which allows the sending of the commands via the computer's serial port to the robot.

ROS Kinect Kame distro was used to create ROS packages in the Linux Ubuntu operational system (version 16.04). The package was developed in Python 2.7 programming language alongside the use of the computer vision library OpenCV, the OpenCV 3.4.5. In addition, the Freenect package was used for the communication between the computer Microsoft's Kinect.

The ROS-mitsubishi¹ package developed has got functions capable of performing the following commands on the robot: manipulator's cartesian movements, joints' angular movements, opening up and closing the claw. The reading of Cartesian coordinates and robot joint angles are also in the list of implemented functions. Fig. 2 is the flowchart of nodes and topics of the created ROS package.

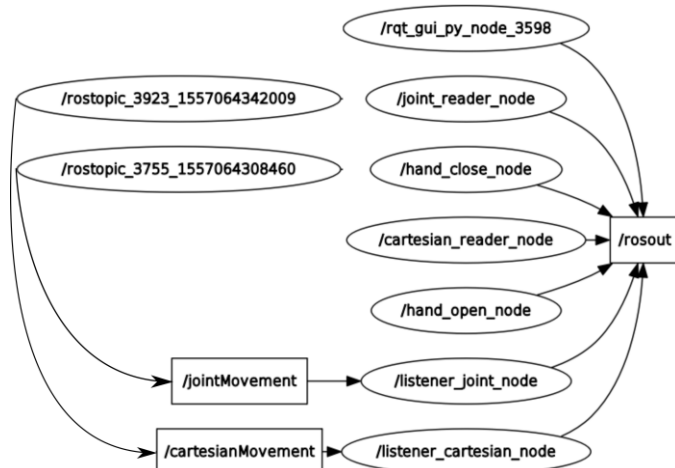


Fig. 2. Node and topic flowchart of the ROS package created for robot control.

¹ https://github.com/alexandremstf/ros_mitsubishi

4.2 B. Building up a repetitive task-sequencing recognition algorithm

There are several available ROS packages developed in order to integrate components; one of them is called Freenect, which is the one responsible for the communication between the computer and Microsoft Kinect. Kinect is a set of sensors and cameras which provides image signals. These signals carry data such as depth and the location of elements in space with high accuracy. The chosen version is the one which is used in Microsoft's XBOX 360. The images from Kinect must be processed in order to be transformed into concrete data.

This processing can be done by a computer vision library, which enables the manipulation of images in order to select the desired data. To achieve this, there comes the usage of OpenCV (Open Source Computer Vision Library) with Python language. This library contains many features which allow the tracking of positions in a determined space of a given color.

The Kinect was put in a suitable position for the reading to be executed. By fixating it, it was possible to follow the movement performed by the manipulator and perform the workspace scan in order to find the workpieces. By executing just one command through the ROS Freenect package it was possible to get the images. This visual sensing is worked through messages between ROS and OpenCV. Fig. 3 shows the system assemblage.

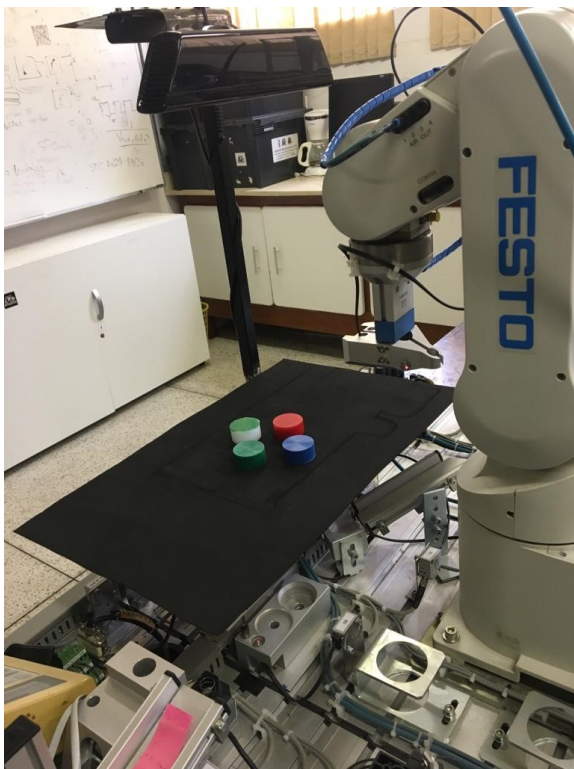


Fig. 3. Assembly of the robotic-cell system.

Therefore, it was necessary to build an algorithm using Python 2.7 which allows computer vision to be used in order to recognize objects and locate them by converting the Kinect coordinates, which are translated into the manipulator's while referencing the disks arranged over the table through ROS Freenect and OpenCV, then stacking them, following the sequence identified by the computer vision assisted programming.

The object recognition process uses OpenCV's Hue, Saturation, and Value (HSV) color system to calibrate each object of distinct colors. This system verifies the type (the colors present in the spectrum), the purity and the brightness of the color, respectively. To sum up, the goal is to highlight the workpiece of the chosen color by keeping it in white while the entire background remains black, as suggested in Fig. 4.

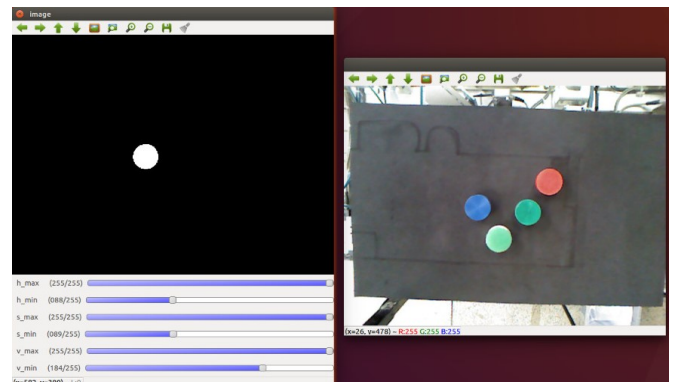


Fig. 4. Calibration Process. Four different color parts - blue part calibration.

After the calibrating the piece's color, it finds the Cartesian position of its center. Then, this position is treated then sent to the robot in order for it to go towards the piece and pick it up.

The algorithm² scans the site for the object and sends information to the arm for picking it up. This process is repetitive; the algorithm checks the object until it certain that the robot's claw has caught it. Then, it moves the workpiece to a suitable location. Finally, the robotic arm is ready to pick up another workpiece, completing the cycle and keeping it in loop, until the last piece is stacked.

Moreover, the robot is able to mimic the human movement by organizing the workpieces in a satisfactory and adequate place. A person deposits the objects manually, and then randomly scatter them. Afterwards, the algorithm stores the information about the pieces while respecting the way it was previously ordered and send commands for the robot organize then.

² <https://github.com/CleysonTeixeira/Repetitive-Tasks-with-Melfa-RV-2aJ>

5. DISCUSSIONS AND RESULTS

There were also other project options available for the students to choose from, which involved concepts of static and dynamic balance, mobile robotics, computer simulation or physical construction. In this moment, will be presented the survey on the robot programming project assisted by computer.

We, the project's author, verified about the project's applicability and effectiveness through a survey developed of students involved in the project in the second semester of 2018 and the first semester of 2019. A survey to validate the results was conducted with the 14 students who took part in the project, as seen in Table 2 below:

Table 2. Survey Answers

Answers	A%	B%	C%	D%	E%
The project motivated me to conclude my course.	85,71	14,29	0	0	0
The project is related to the theoretical content of the subject.	78,57	21,43	0	0	0
The project has motivated me to learn more about the subject.	64,29	28,57	7,14	0	0
I would recommend other students to attend this project with this methodology adopted.	57,15	35,71	7,14	0	0
The period to execute the tasks was adequated.	28,57	28,57	35,71	0	7,14
The project contributed to my professional career.	92,86	7,14	0	0	0
Skills and knowlegde earned during the project will contribute to my final project course.	21,43	21,43	21,43	21,43	14,28

A – Strongly agree; B – Agree; C – Neutral; D – Disagree; and E – Strongly disagree.

The interviewed students were questioned about the methodology implemented in the project. 35.71% of students said that they have never had contact with this previous method and 64.29% have had contact in the following subjects: Embedded Systems, Real-Time Systems

Programming, and Control Theory III. When asked about active participation in the project, 92.86% of students reported that have participated actively, while 7.14% have not.

Regarding the greatest hardship faced in the project, 35.71% affirmed that they have had difficulty working as a team, 57.15% in computer programming and 7.14% in work documentation. It is justifiable that 57.15% of respondents had difficulties in building the algorithms used during the project because programming skills were not acquired previously in other subjects, and some tools were discovered by students only during the course of Robotics Elements (ROS, for example).

The students reported the difficulty in continuing a work that was started by another group in a previous semester. There is also an interdependent relationship where current project members needed to learn from previous ones, but the communication has not always been efficient. There was some lack of availability for meetings, and some students were hard to deal with in terms of social skills. It configures an experience which resembles business's, where it is often necessary to develop a work-in-progress whose building involved many collaborators. Appropriate documentation has been suggested to help understand what has already been done to reduce interdependency.

The survey made noticeable the fact that the motivation of the students enrolled in Control and Automation Engineering, as well as in Robotics Elements, increased. Students became more interested in the course and also robotics. In addition, all 14 students interviewed were passed the subject.

The interviewees reported that although, the projects were all from the same subject, they have specific problems when it comes to other areas knowledge. In this case, the challenges were about computer vision, robotic cell structural problems, Python programming, ROS package creation and lighting concepts.

The problem of programming language is so evident because the programming disciplines are carried out in previous years. Perhaps if the discipline of elements of robotics were carried out next to the other programming's subjects it would solve the problem. This challenge extends in developing other areas: computer vision, building up a ROS package and Python programming.

6. FINAL CONSIDERATIONS

The creation of ROS packages to operate the robot, as well as the recognition of pieces and the performing of the repetitive tasks assisted by computer vision were all successfully completed³. Through the package developed for the

³ <https://www.youtube.com/playlist?list=PLpOGfticbVAJZ8-6kKo5AsmkeKMNxMi0F>

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communication and the operation of the robot, it was possible to operate it to its fullest capabilities. Each individual piece was calibrated correctly, therefore preventing a single piece from a determined color from being misinterpreted for another during the stacking phase. From that on, the robot was able to distinguish the pieces and effectively stack them while following the previous configuration defined by the students.

The project succeeded from the technical phase to the use of a Project-Based Learning methodology, as the students achieved the desired immersion. According to the survey, they also felt more motivated in Control and Automation Engineering course and the Robotics Elements subject, while they ended up recognizing the importance of PBL for a successful professional career.

Overall, the subject has a wide range of possibilities, so that the student has the responsibility to choose and identify which theme fits them the most. It is important to state that the knowledge acquired by all the students, in spite of the theme of their choice, has a common ground when it comes to skills such as management, teamworking, analyzing, critical thinking, problem-solving, resilience, proactivity, documenting and curiosity over the world which involves Robotics. Those skills, whether perceived during the survey or throughout the project, will be instrumental for the students' professional life to come, regardless the area of Engineering they choose in the future.

We had difficulty in the parts calibration because of the natural and artificial laboratory's light influence. Then, in trying to solve this problem, we installed a led illumination. Unfortunately, we found that external brightness still affects the calibration process. Therefore, it would be ideal to build a closed structure or to insert the robotic cell in a controlled lighting environment to the perfect robot operation. We also suggest thinking to implement computer intelligence for brightness control by adding a neural network - it can change calibration parameters of HSV parts as the brightness changes, for example. Besides, as a possible and future line of research to improve the work, we suggest creating a robot platform that allows programming and operation it remotely containing practice scripts to be performed on it, such as web application or app.

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