Initiation to robotic arm control and image processing with CMUCAM module

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Abstract: This aim of this paper is to share novel or different didactical experience, taking into account evolution of student's behaviour. We describe briefly some of these major changes. The consequences on the quality and efficiency of traditional pedagogy are then pointed out. From these observations, we show that didactical adaptations must be done, in particular to improve interest, involvement, and motivation. As an example, we present here a didactical project called "initiation to robotic arm control and image processing". Technical approach and design are detailed. Finally, we discuss the advantages of our approach and give results we obtained through this didactical process.

Key words: Image processing, robotic arm, mixed digital/analogue circuits design, learning by project.

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1. Introduction

Since several years, French national statistics shows global demotivation for the scientific curriculum and disaffection for all theoretical lessons. This has been recently amplified by the covid period [1]. Economical, commercial, cultural, sport education studies seem to be now more attractive for the university's students.

In our electronic department of engineer school ENSEIRB-MATMECA, we observe in particular, a kind of increasing gap between the student's needs and what we proposed to them.

This student's evolution generates a general loss in term of teaching efficiency [2]. In particular, we can point out, in our electronic department some specific problems:

- Till now, our generic and basic theoretical courses were a full classroom traditional teaching with ten sessions of one hour and a half each. However, we observed a loss of interest for these courses and a higher absenteeism rate than before despite a strong checking.
- Although the situation for practical teaching is a little better (no absenteeism), it is far from perfection: in particular, student's projects in second year of study were classical electronic design projects scheduled over semester, with several phases, bibliography, theoretical analysis and computation, practical design and measures. Year after year, we observed, among other facts, that projects were no more finished on time. A probable lack of prerequisite and difficulties to go from theory to practice, [2] are the reasons of this situation.

Similar changes in student's needs and practice are observed in other countries and particular care is taken by colleagues in many institutes [3], [4], [5].

Regarding this evolution, several modifications were done in our school. Theoretical lessons are now a mix between theoretical explanations and direct immediate exercises to apply courses. For the practical teaching part, we tested an alternating approach for the student's project. We give in this paper, a typical example of project we introduce last year and we give design details, explain how the students worked to obtain interesting results and a finished project.

2. Student's project example

2.1 Student's project organisation

Each year, a team of teachers gives practical multi thematic projects to illustrate the main topics of our school: analogue, digital, radiofrequency, power electronics, programming, and so on. These projects are done over one full semester, with one session of three hours per week. Students work by pair.

2.2 The robotic arm project

As an example of practical learning strategy, we describe here a student project we made one year ago. Originality of this student's project is to associate a robotic arm, a micro controller board and a camera to make some 'intelligent' actions and to reproduce a typical human movement. It was voluntarily an open project without too strong specifications. Thus, students feel free to decide their own scenario and to explore the capacity of this actuator. Thanks to a modular design approach, it allows focusing on a global system design and concrete understanding. The chosen scenario is described in next paragraph §2.3.

2.3 Chosen scenario

After discussions, bibliographic researches and evaluation of realistic abilities compatible with student's skills and duration of the project, they chose the following scenario:

The system must recognize a green glass hovering on a table nearby the arm. This one must explore and scan the space around, find the location of the glass and pointing to it. When it is correctly oriented, the plier must grip the glass and take it back to initial position.

The following paragraph §3, 4, 5 describes the chosen electronic modules required to make this project.

3. Processing board

In order to control the robotic arm we use a classical Arduino Uno module [8] based on a micro controller ATmega328 (figure 1).

Voltage supply is 5V. The clock frequency is 16MHz. It has 14 digital I/O pins and 6 analogue input pins, I2C bus, which is enough for our application. Some of them can deliver directly a PWM signal (suitable for driving servomotor).

Figure 1: Arduino uno module

4. Short description of braccio arm

The "braccio arm" [9] is made of plastic. It is dedicated to didactical applications (Figure 2a). It consists of a base, 3 mobile segments, a rotating plier with two 'fingers' and six servo motors representing the bonds of the arm. Servo motors are classical servo used by hobbyists. Angle of rotation is proportional to the pulse width of the PWM signal applied to the servo. Angle range is 0° to 180° when pulse width varies from 1ms to 2ms. An interface board for powering and connecting servo signals is available into the package. An Arduino open source library is also available for easy management of servomotors with a classical Arduino micro controller board.

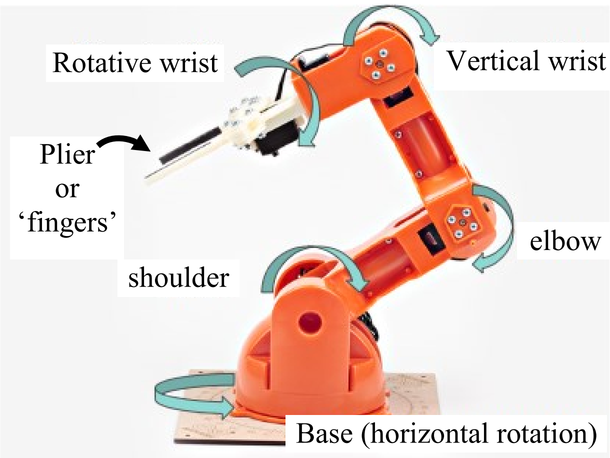


Figure 2a: Braccio arm view

Once the full arm assembled, the mechanical position must be calibrated to check correct alignments of arms in neutral position. Indeed, due to possible mechanical offset, (notched wheels of servos), a small difference can be observed. Offsets can be cancelled by software correction or by mechanical fine adjustments.

This first calibration defines the "zero" or the origin of each servo motor (Figure 2b).

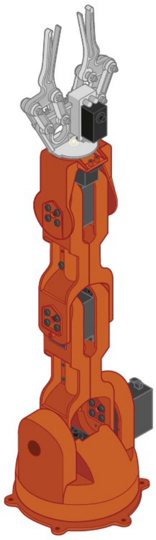


Figure 2b: Servo motor mechanical calibration

5. The sensors

In order to make the braccio arm ‘intelligent’, a camera is mounted on the top of last segment just over the plier. So, “fingers” extremities are visible in camera field of view (low part of the image). An Infrared sensor is also added to detect an object when it is between the plier fingers.

5.1 CMUCAM5 Camera

The most interesting sensor in the project is undoubtedly the CMUcam [10], [11], [12], with its CCD sensor OV9715 [13], and in-board image processing circuit for target tracking or avoidance.

The first CMU CAM module (figure 3) was designed by the Carnegie Mellon University a few years ago. We use here CMUcam5.

Main specifications are:

- Processor: NXP LPC4330, 204 MHz, dual core
- Image sensor: Omnivision OV9715, 1/4”, 1280x800 [13]
- Lens field-of-view: 75 degrees horizontal, 47 degrees vertical
- Power input: USB input (5V) or unregulated input (6V to 10V)
- Data outputs: UART serial, SPI, I2C, USB,
- Embedded image processing software

Since many digital pins are already used for servo motors control, we chose a data transmission with I2C bus (SDA and SCL connected to A4, A5 analog pins of Arduino module). An Arduino open source library is available for easy management of data transfer.

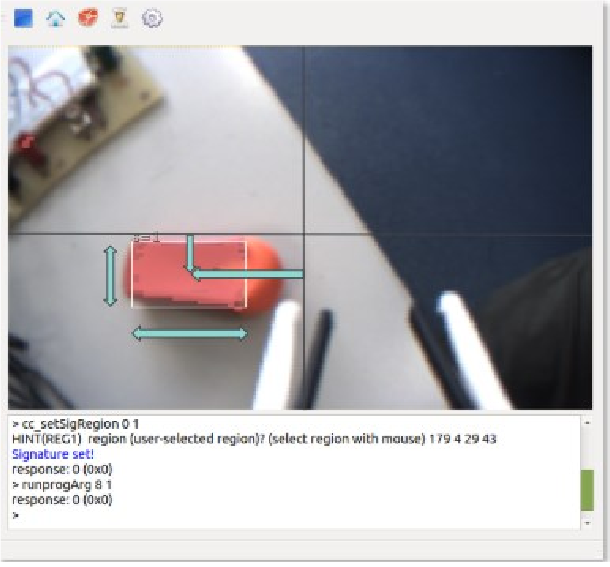
Figure 3: CMUCAM5 module

5.1.2 Object colour detection

Calibration and programming of the camera requires the Pixymon open source software [14], [15].

This allows first displaying what is seen by the camera on the PC screen (figure 4.) Then, it allows teaching to the camera (connected via USB port to the PC), up to seven colors to be detected and to assign a signature for each.

To do that, we first select in the menu « set signature x » then, we select a rectangular/square frame on the screen which define the desired color to be detected. Once the color learned (red object on example of figure 4), the camera will try to detect all the pixels or group of pixels of which the color is equal to the one selected previously. A tolerance margin can be defined.



```
> cc_setSigRegion 0 1
HINT(REG1)  region (user-selected region)? (select region with mouse) 179 4 29 43
Signature set!
response: 0 (0x0)
> runprogArg 8 1
response: 0 (0x0)
>
```

Figure 4: Camera in learning mode

Lastly, some general parameters such as white balance, contrast and so on, can be adjusted with pixymon.

5.1.3 Object detection with CMUCAM

The principle of detection [16], [17] is based on the colour difference between the background and the object to be detected. The CMUCAM module is able to detect several pixel blocks with the same colour. Then it returns information on the position X,Y, size and 'average colour' of each block. The X, Y coordinates of a point are obtained according to the given axis orientation (figure 5) and with the following useful scaled range X: 0 to 400, Y 0 to 200.

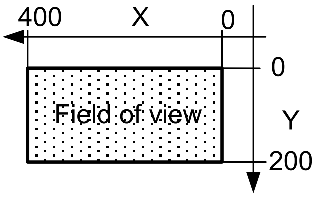


Figure 5: Scale and axis orientation of the image

5.2 Infrared sensor

A simple matched emitter/receiver infrared sensor (figure 6) is mounted on the plier. As the emitter and receiver are very close (a few centimeters), it is not necessary to modulate the IR light.

When the IR beam is cut, the presence of an object between the fingers is detected. Then, it is possible to press the fingers and to catch the object.

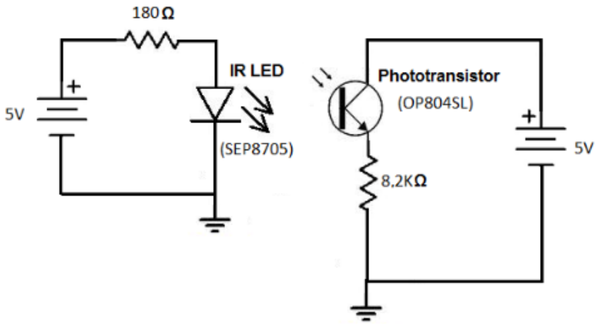


Figure 6: IR simple sensor

6. Global system architecture

Finally, the following global hardware architecture (figure 7) is adopted.

We can see the power supply, the processor board which will manage the movement of the arm. Servo interface board is just an hardware interface to connect the 6 servomotors of the arm. CMUCAM is installed and fixed just over the arm plier (to see the scene), while infrared sensor is mounted on plier's fingers. (emitter on one finger and receiver on the other).

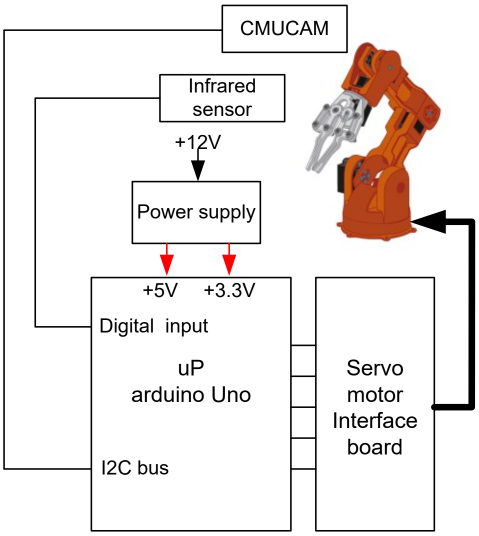


Figure 7: Global architecture

7. Moving braccio arm towards detected object algorithm

The heart and most interesting part in the project is probably the understanding and definition of a strategy to catch the green glass: which bond to move? Which sequence to program? That is finally, how to reproduce what a human is able to do easily without thinking?

Neither mathematical modelling nor trajectory equations were used. The strategy has been set up using biomimetic approach [18]:

One student first tried himself to catch the glass on the table with his own arm, while another observed and recorded the movement of each segment of the arm. After several attempts, it was possible to write an algorithm reproducing as well as possible the true movement.

Le principle is explained hereafter:

After "power on", a phase of initialization of the entire arm's segments position. When the system is ready, the camera returns regularly the number of detected bloc in its field of view. If no object detected, the base servo turns, makes a horizontal scan of space around and tries to find a colored object. When an object enters in the field of view of the camera, the base and wrist servo motors are moved to place the object at the center of the image.

Then, movement is stopped for a short while and the camera stares the object without moving like a human eye could do.

Then, depending on the situation and relative position of wrist compared to forearm (normal, bent, aligned) (cf. schematic view figure 8a), three possible strategies to move towards the object are adopted.

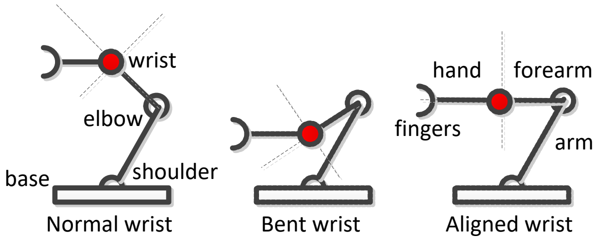


Figure 8a: Wrist position and angles definition

1) If wrist is in normal position:

Then, shoulder must move towards the object (Figure 8b). During the movement, the feedback control process will move the wrist servo to maintain the object centered on the image. Thus, the wrist will necessarily become aligned with the forearm.

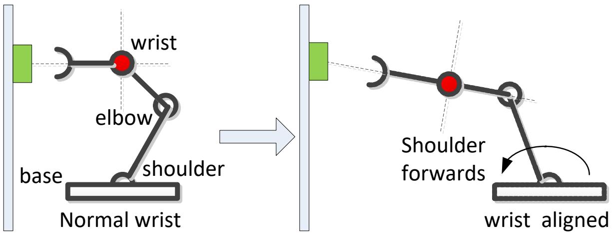


Figure 8b: movement in first situation

2) If wrist is bent:

Movement of the shoulder is reversed (figure 8c) compared to the first situation. And the wrist will also become aligned.

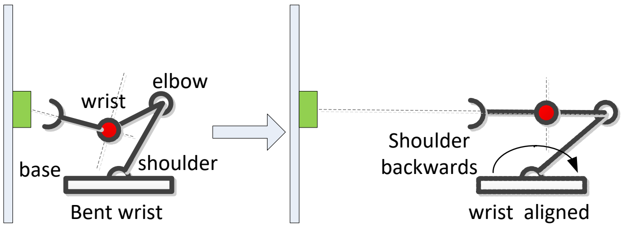


Figure 8c : Movement in second situation

3) Once wrist is aligned with forearm:

Object is now centered exactly between the two wide opened 'fingers' (figure 8c). We do not move anymore the wrist. Elbow is unfolded and the arm is stretched out, by moving the shoulder towards the object figure 8d.

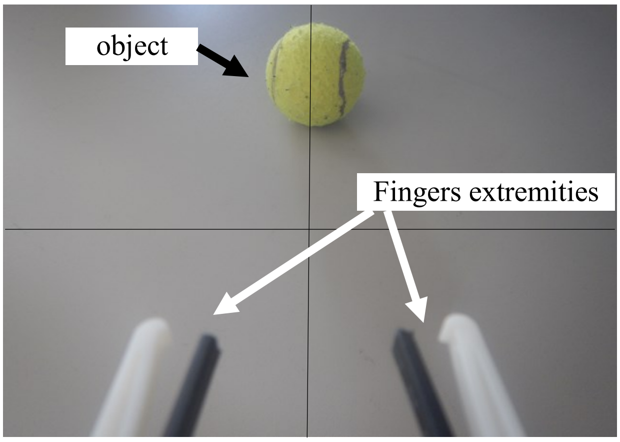


Figure 8c: Object being centred between fingers

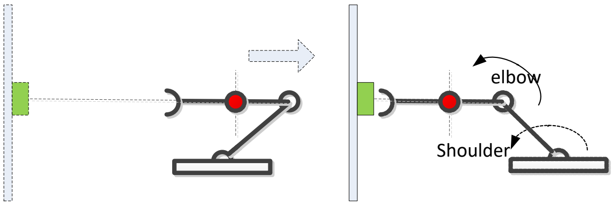


Figure 8d : Approaching object

If the arm reaches its maximum extension, it means that the object is too far to be caught. Then, the arm returns to a default position.

But, if the infrared beam is cut, it means that an object is passing between fingers. Then, movement is stopped, fingers are closed and after 1.5 second, the arms returns to initial position carrying the glass.

The global strategy is summarized in the flowchart figure 9.

Programming such motion strategy represents for the students, the writing of a few hundred lines of C code. Program looks quite compact, because the use of predefined high level functions for the control of the camera and the servomotors.

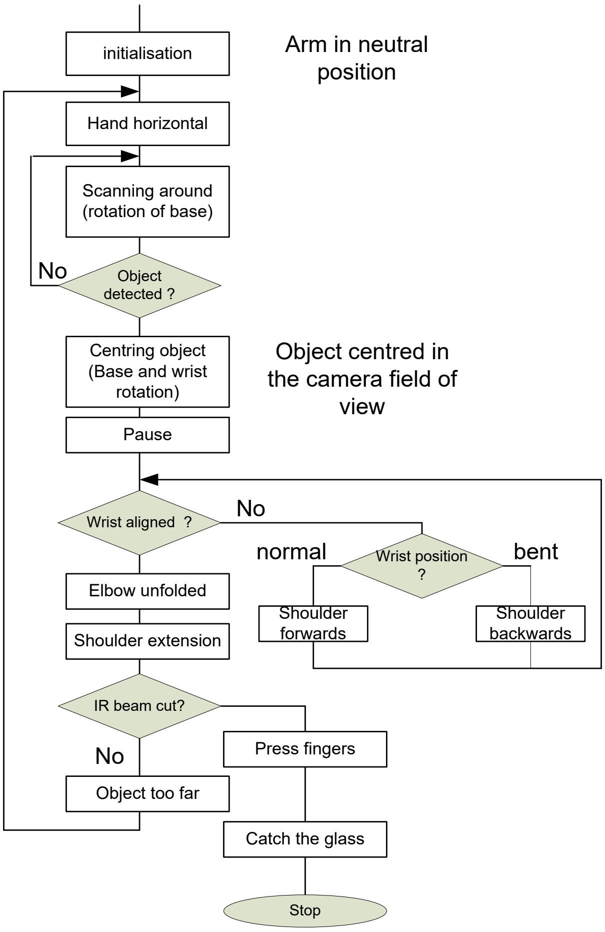


Figure 9: Software algorithm

8. Validation tests and results

Some video clips were recorded. For these tests, the braccio arm is powered by external power supply equipment. The presented pictures (figure 10 series) are captured from the videoclip.

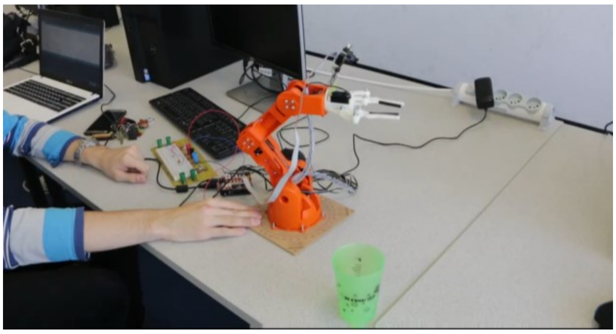


Figure 10a: Searching for the green glass

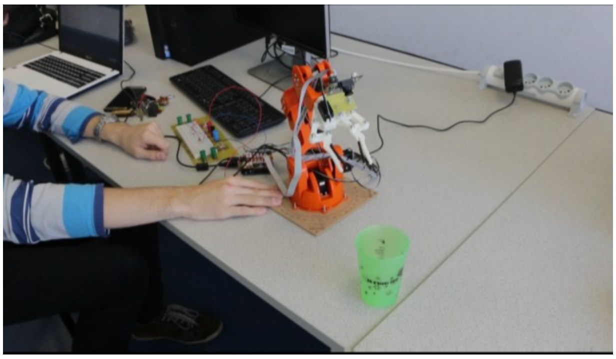


Figure 10b : Looking into the good direction

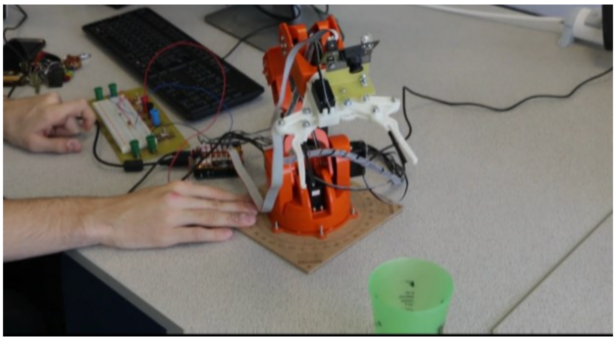


Figure 10c: Opening fingers

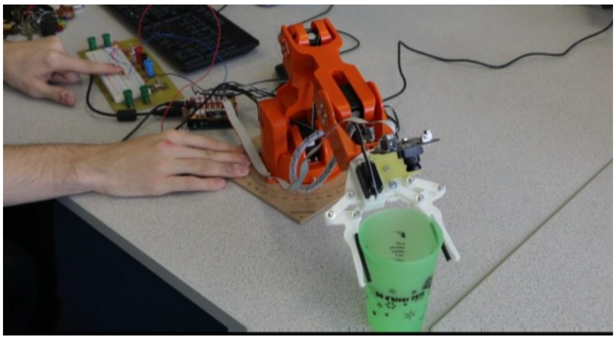


Figure 10d : Catching the glass with fingers

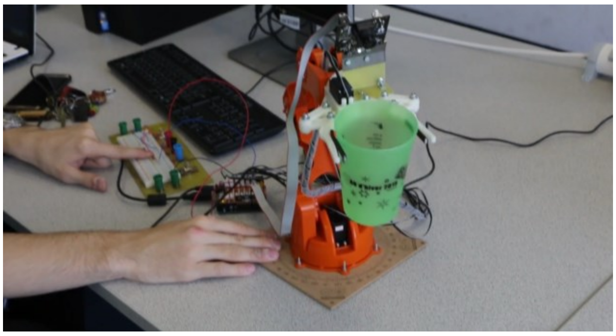


Figure 10e: Taking the glass

Several tests were performed with the glass placed more or less far from the arm. Once the object is detected and the fingers pointed into the right direction, it takes around 7.7 second to catch it. However, the system is not perfect: some erratic behaviors still occur and sometimes the arm misses the glass.

9. Project assessment

9.1 Technical assessment

As explained before, this student project was only a simple initiation to robotics and to image processing. Indeed, within a 40 hours framed project, it is obviously totally impossible to design a so complex and safe system as we can see in automotive industry for example. However, our technical goal was reached. After programming, students were so satisfied to see their small arm moving and catching the glass on the table. A great performance with only modest non-professional equipment (i.e. open source plateform and low cost plastic arm).
The only “black point” is that the students have had only an overview and global approach because the modular design. They use electronics modules like “black boxes” and did not study what is inside in deep. So, some subtle electronic details (like pull resistor on I2 bus, pins current sourcing ability…), and other characteristics were not assimilated.

9.2 Didactical assessment

- Freedom and autonomy during the design gives the impression to the students to be more creative and responsible of their project.
- The practical aspects of the project (the robotic arm is moving) are a source of interest and motivation.
- Even if academic scientific knowledge must be obviously taught and transmitted, this type of project develops the necessary “know how” as supplement of the “knowledge”.
- Absence of high level mathematical considerations during the project leads to a mandatory practical and physical mental understanding of concepts. Instead of applying formulas like automat, the students have to develop other mental paths such as common sense, reasoning, and imagination.
- The system approach allows connecting different fields of electronic (Analogue, digital, sensors, micro programming, and motor driving…) which seem often disconnected for the students because of the segmentation of theoretical courses.
- Lastly -as collateral interest- this initiation project fits the needs of our robotic student’s team and may help them for the participation to the French national and annual robotic contest [19].

9.3 Comparison with previous methodologies

It is quite difficult to compare teaching methodologies since they change at the same time than student’s need and behaviour. To compare properly two methodologies should have required to test on two student’s samples from the same “generation” two method. Unfortunately, this was not possible because of time table constraints.
What we can observe is that learning by project is more suitable today especially after the covid period [20], [21] because the loss of theoretical bases and ability to focus during these last two years.

10. Conclusion

Study and design of a robotic arm with its control camera has been presented, within the framework of our students’s project in second year of study at ENSEIRB MATMECA School. Technical and didactical results are very encouraging. Thanks to a modular design and a system approach, the project was finished on time and students were satisfied with the technical content. It was a good initiation and a good preparation for their ultimate industrial project in third year study.
This didactical and practical work seems to be an interesting answer to the students’ needs and general behaviour evolution. Thus, similar projects will be proposed over the future years.

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