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Delivery Race Game: a Stimulative Approach to Engage Youths in Robotics and Control^{*}

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Abstract: This paper proposes a new educational game designed for popularizing science activities. The game consists of a robot race in which an automatically controlled robot and a manually controlled robot compete to deliver tennis balls in a basket. This playful approach, combined with interactive explanations and exercises, enables children to discover different engineering areas related to autonomous mobile robots. The themes covered are Control, Image Processing and Robotics. In the form of an interactive workshop, this paper aims to make children develop an interest for science.

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Keywords: Control Education, autonomous systems, teaching and learning experiences, Project Based Education, serious game, PI control, pedagogy, image processing, Robotics.

1. INTRODUCTION

In classroom, students often remain passive, with their attention waning as the lecture progresses. Therefore, teachers are looking for new methods to motivate their students such as *learning by doing* methods. One approach is the development of serious games, e.g., Krath et al. (2021). These games turn students from passive listeners into active learners, e.g., Haugom et al. (2006). For example, in business schools, games are employed to teach students about managing companies (see Huang et al. (2022)).

In Control Engineering and more generally in engineering, it is essential to illustrate course concepts, as students often find it challenging to understand complex notions. Tools such as Matlab/Simulink simulations, videos, images and even cartoons (see Douglas (2022), Cojan et al. (2024)) are frequently utilized to enhance understanding. Additionally, in Robotics, experimentations during laboratory practice (e.g., Stoica Maniu et al. (2020)) can enhance theoretical lectures, especially given the numerous applications of Robotics that make this approach effective.

Developing games with robots can result in innovative educational tools (Zhang et al. (2010)). In a previous paper (see Bertrand et al. (2024)), the development of a Pong

game named “DroPong” with two robots and one aerial drone was presented. The goal of this game was to help students in understanding Robotics and Control principles while also motivating teenagers to pursue studies in engineering. Such games have shown positive feedback on emotional and intellectual progress of children (Lei and Rau (2023)). However, the “DroPong” game requires a room equipped with a motion capture system and protection equipment (a net, protection glasses, etc.), which are usually expensive. Most elementary, secondary, and high schools do not have this equipment or access to flight arenas.

Therefore, the current paper proposes a new educational game focused on a human versus robot delivery race. Therefore, one ground mobile robot is manually controlled and the other robot is automatically controlled. The goal of the game is to grasp tennis balls and bring them back to a specific location. This game aligns with the growing trend in the development of autonomous vehicles and automated warehouses, where mobile robots navigate to retrieve customer items (Bormann et al. (2019)). The gamification makes concepts in Robotics and Control engineering such as Proportional-Integral (PI) controller accessible to beginners, and also introduces elements of Image Processing for objects detection. To further enhance the learning experience of the students, a set of activities has been prepared to explain the different technical concepts behind the game. Preliminary trials of the game have indicated

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strong potential for enhancing learning outcomes. A key contribution of this paper is related to *learning by teaching* using mobile robots. Indeed, a group of four undergraduate students from CentraleSupélec:

- (1) Firstly, developed this game during their project within the “Pedagogical Innovations and EdTech” Projects Cluster in CentraleSupélec,
- (2) Secondly, developed and taught an interactive workshop for teenagers in collaboration with the OSER students’ association on social inclusion and equity (see OSER (2016)).

Some advantages of this new pedagogical game are: the game does not need any additional motion capture system or a net protected zone, it involves robust robots that can be transported in schools, it is funny and engaging, it can be adapted to children of several ages, etc.

The paper is organized as follows. Section 2 provides a detailed description of the game and its technical aspects. Section 3 outlines the workshop description, and Section 4 discusses the feedback from participants and lessons learned, before concluding remarks in Section 5.

Terminology. In this paper, the following terms are further used:

- The term “students” denotes the undergraduate students of CentraleSupélec. Therefore, during their project, the students developed engineering skills via a *learning by teaching* approach.
- The terms “learners” and “participants” designate the children participating to the developed pedagogical workshop. Therefore, the learners developed basic engineering skills via a *learning by doing* approach.

2. GAME DESCRIPTION

2.1 Delivery Race Game

The game involves one player and consists in a race between two robots (A & B) that have to fetch two tennis balls each (one by one) and put them in a basket (see Fig. 1). Robot A is controlled remotely by the player via a joystick (Fig. 2), while robot B is controlled automatically via a Python program.

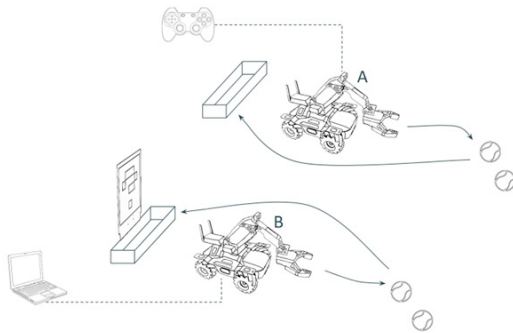


Figure 1. Schematic description of the delivery race

The aim of the pedagogical game is for the players to beat the computer by putting the tennis balls first in the basket. Part of the game is also to compare the behaviour of the two robots and to imagine how a program can mimic the way they play, serving as a basis for the teaching session.

2.2 Equipment

The DJI RoboMaster EP¹ model was used to develop the game, as it was considered to be better adapted to games compared to the RoboMaster S1 model, thanks to its mobile robotic arm and gripper that can be used to interact with the environment. The DJI robots also come with some markers that can automatically be detected by the built-in methods of the DJI RoboMaster interface. Such markers have been used to locate the baskets, to facilitate their detection by the the autonomous robots.

The program to remotely control the robot uses the Python SDK developed by DJI to control their robots, which is a specific module named `robomaster`². This library allows access to the status of the components of the robot (e.g., position, battery status) and also allows to remotely control their movement, to play sounds, to change the robot LEDs color, etc. As this module does not seem to work on the most recent Python versions, a virtual environment linked to Python 3.8 was used to conduct the coding and testing phases of the game.

Furthermore, as the game is intended to oppose a player-controlled robot and an automatically controlled robot, an additional program has been developed using the Python library `pyjoystick`³ to allow a human player to control the robot by using a joystick, which is easier to use (especially for children) compared to a keyboard-based approach. To help the player get started with steering the robot, an intuitive interface has been developed in this game by the CentraleSupélec students, as shown in Fig. 2, to show all available controls.



Figure 2. Interface to help getting started with the manual control of the robots

2.3 Processing the camera stream to detect a tennis ball

The robot is equipped with a camera that allows image processing tools for objects detection on the camera screen. It was decided to use tennis balls for the game, because they have a characteristic yellow color that is distinct from other colors in the testing zone in the flight arena of CentraleSupélec. Then, inspired by the steps developed in Rosebrock (2015a), a recognition algorithm has been developed to detect the nearest tennis ball on the screen.

The process is summarized in Fig. 3 and consists of multiple steps:

¹ <https://www.dji.com/global/robomaster-ep>

² <https://robomaster-dev.readthedocs.io/en/latest/index.html>

³ <https://pypi.org/project/pyjoystick/>

- (1) Read the current frame from the video stream sent by the robot;
- (2) Convert the RGB (standing for Red-Green-Blue) values of each pixel to the corresponding HSV (standing for Hue-Saturation-Value) values. Previous materials such as Ramanath and Drew (2020) and Ajmal et al. (2018) have shown the effectiveness of HSV filtering compared to RGB filtering, especially for a real world game application where many different lightings and shadows can change the perceived color of the tennis balls;
- (3) Apply a filter that only keeps the HSV values that are in a given range, which corresponds to the color of the tennis ball (these are the white points on the picture in the middle of Fig. 3);
- (4) Detect all contours in the filtered frame and only keep the largest one. Further verify that the surface of this contour is larger than a reference value to ensure that it is indeed a tennis ball that has been detected;
- (5) Derive the position of the ball on the screen from the properties of the encompassing contour and return it.

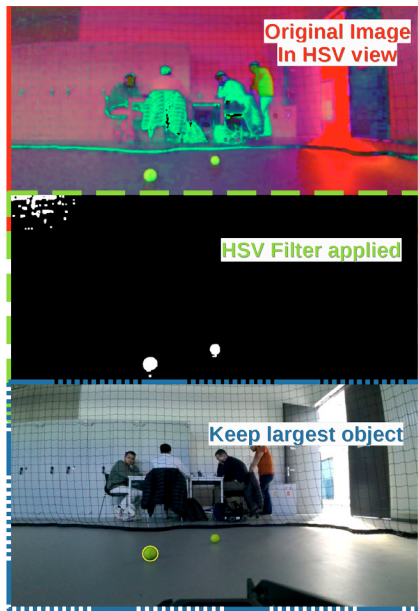


Figure 3. Summary of the tennis ball tracking algorithm

This algorithm allows for a simple way to detect the tennis balls by only using the camera of the robot. It can also easily be adapted to detect other objects with a distinct color by changing the range of the HSV filter that is applied.

2.4 Estimating the distance through the camera

From the previous section, it is now possible to identify the position of the tennis balls on the camera screen. The next step is then to be able to translate this virtual position into a real world position, so that the robot is able to move towards the detected tennis ball.

The approach used here is based on the methods proposed in Rosebrock (2015b) to approximate how far a known object is from the robot. Considering the objects that the robot is moving towards are known in advance, it is

possible to use their real size to compare to the size that they show on-screen.

Using the coordinates system presented in Fig. 4, and with the following notations, the goal is to estimate the quantities x_0 and y_0 knowing:

- x_0, y_0 the coordinates of the tennis ball in the real world relative to the center of the robot in centimeters;
- r_0 the real radius of the tennis ball that has been measured in advance;
- x_s, y_s the coordinates of the center of the tennis ball on-screen in pixels from the top-left corner of the screen;
- r_s the radius of the tennis ball on-screen in pixels;
- θ_{\max} the angle of the camera;
- f the focal length of the camera;
- w, h the width and height of the camera screen in pixels, respectively.

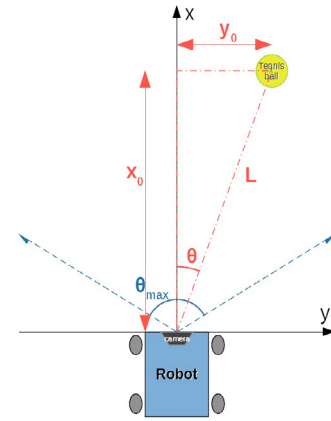


Figure 4. Diagram presenting the coordinates

From all this given data, one can derive the measure of the angle θ between the y axis and the center of the tennis ball and the distance L between the ball and the robot with the following equations:

$$\theta = \theta_{\max} \left(\frac{x_s}{w} - \frac{1}{2} \right), \quad (1)$$

$$L = f \cdot \frac{r_0}{r_s}. \quad (2)$$

From these equations, it is possible to deduce the coordinates x_0 and y_0 of the tennis ball in the real world by using basic trigonometry with:

$$x_0 = L \cos \theta, \quad (3)$$

$$y_0 = L \sin \theta. \quad (4)$$

This method has some uncertainties related to the position of the camera relative to the center of the robot coordinates system, the limits of the depth estimation used to compute L and the uncertainties related to the localisation of the center of the tennis ball using the process described in subsection 2.3. For this reason, it is used as the base for a PI controller that can correct the errors made by this first estimation.

2.5 PI controller

For the robot to catch the ball correctly and not bump into the basket, certain specifications had to be imposed:

- Accuracy: static error < 1 cm;
- Stability: no overshoot on the x -axis, unnoticeable overshoot on the y -axis;
- Speed: irrelevant since the distance between the ball and the robot can change and the speed of the robot is limited.

To achieve these goals, a PI controller was implemented for the input speed. The sampling time T_s is set to 0.1s. Let $\epsilon[kT_s]$ be the distance between the robot and the reference point, computed thanks to the formulas described in subsection 2.4. Then the input speed is given by (5):

$$v[kT_s] = K_P \cdot \epsilon[kT_s] + K_I \cdot T_s \sum_{j=1}^k \epsilon[jT_s]. \quad (5)$$

Depending on the workshop duration and the age of participants, the learners can be guided to adjust the sampling time and the PI controller coefficients K_P and K_I experimentally, to better understand the tuning parameters concept, while respecting the performance specifications.

3. WORKSHOP DESCRIPTION

This section focuses on the educational activities developed to highlight the engineering concepts used in the proposed pedagogical game.

3.1 Target audience

The aim of the developed educational workshop is to target children (at least eight years old) and teenagers in order to awaken their interest in science. The form, content and duration of the proposed workshops should therefore be adapted to the expectations, level and interest shown by pupils of different ages.

3.2 Timeline

Here are the different stages of a session:

- (1) Introducing the workshop organisers, the framework of the project and their institution (university, laboratory, etc.);
- (2) Presenting the robot that will be used throughout the session. It is important for the learners to be able to handle it to familiarise with all its features;
- (3) Explaining the principle of the game and selection of one or more volunteers to take part in the experiment;
- (4) Launching the game, with comments from the presenters to draw attention to important technical points;
- (5) Exercise 1: Finding the different phases of the game and ordering them. Explaining the link between these phases and the programming code;
- (6) Presenting the image processing process to detect the tennis balls;
- (7) Introducing the concept of proportional integral controller;
- (8) Exercise 2: Tuning the 2 proportional and 2 integral tuning parameters (one for each axes x and y) governing the robot movement to the basket.

These steps present a non-exhaustive list of scientific points that can be addressed using the delivery game. It can be interesting to link them to other technological and

scientific concepts. For example, the tennis ball detection can be an exciting introduction to Artificial Intelligence.

Sometimes there is not enough time to cover all the topics, which is why several timelines have been created depending on the time available for the workshop. The session can also be adapted to suit the age of the children, to ensure that the lessons are as relevant as possible. Table 1 shows a 30-minute session for teenagers that deals solely with Control notions. It proposes an exercise to check whether the learners have fully understood the role of the different PI tuning parameters.

Table 1. Example of a timeline

When?	What?	Materials
Min -20 - 0 (before workshop)	<ul style="list-style-type: none"> • Test the game • Set up the robots, tennis balls, boxes, and DJI marker 	<ul style="list-style-type: none"> • 2 DJI RoboMasterEP • 4 tennis balls • 2 baskets/boxes • 1 DJI Marker • 2 computers
Min 1 - 3	<ul style="list-style-type: none"> • Present the speakers the venue, and the project 	<ul style="list-style-type: none"> • Slides
Min 3 - 5	<ul style="list-style-type: none"> • Present the robot • Let 1 learner manually control the robot 	<ul style="list-style-type: none"> • 1 DJI RoboMasterEP
Min 5 - 8	<ul style="list-style-type: none"> • Game launch: learner versus robot 	<ul style="list-style-type: none"> • Game materials
Min 8 - 18	<ul style="list-style-type: none"> • Explain basic Control notions (P, PI) 	<ul style="list-style-type: none"> • Slides
Min 18 - 18	<ul style="list-style-type: none"> • Tune the PI so that the robot moves towards the basket 	<ul style="list-style-type: none"> • Graphical User Interface (GUI)
Min 28 - 30	<ul style="list-style-type: none"> • Thanks the learners and ask them to fill in the feedback survey 	<ul style="list-style-type: none"> • Survey

A Python programming exercise (in the form of a cloze test) for implementing the PI controller can be proposed to learners within an advanced-level workshop of longer duration.

3.3 Workshop material

A PowerPoint presentation was created to help the presenters ensure that the session runs smoothly and to make it easier for the children to follow. On this support, slides for each part of the session illustrate the concepts and explain the scientific principles using images. Figure 5 shows one slide illustrating the difference between the considered specifications and the need for an integral action.

As mentioned above, in addition to the delivery game itself, other interactive activities have been developed to capture children's attention.

The first interactive exercise shown in Fig. 6, which can be presented to children of all ages, invites to put in order the different pieces of code that make the robot work (detect the tennis ball, detect the marker, turn around, go to the ball, etc.). Accessible to everyone and lasting a couple of minutes, this exercise enables the children to get a more global view of the game. It can be used in short sessions and with fairly young children. In addition, asking children to reflect collectively before giving an answer creates a

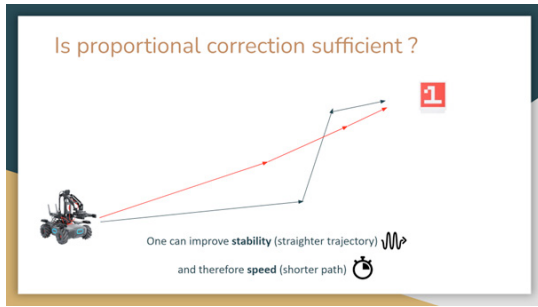


Figure 5. Example of a slide explaining the controller

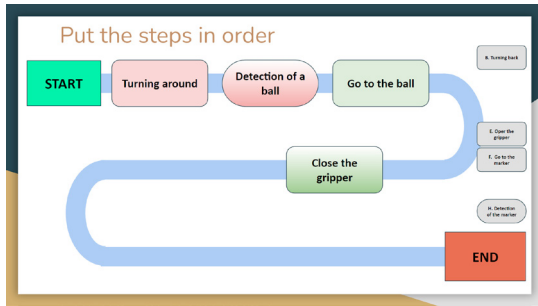


Figure 6. Slide presenting the “Put the steps in order” exercise

collective emulation that involves them even more in the workshop.

The second interactive exercise takes place after introducing the concept of PI controller. It consists in checking and expanding on the concepts covered in order to better understand the role of the tuning parameters of this controller. To do so, the children are guided to enter different values for the PI controller tuning parameters on the graphical interface displayed in Fig. 7 to see the respective effects of these parameters. The aim of the exercise is to get the robot to the marker quickly, accurately and without overshooting. By testing the parameters by themselves, children are more likely to understand the role of each PI tuning parameter. In addition, children get to grips with the scientific approach of Control through (e.g., see Stoica et al. (2023)). At the end of the exercise, the children understand the effects of increasing or decreasing the proportional and integral gains on the robot trajectory.

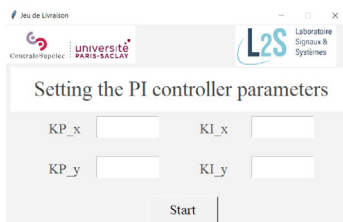


Figure 7. Developed GUI for tuning the PI parameters

4. LEARNERS' FEEDBACK AND LESSONS LEARNED

4.1 Sessions description

The first workshop occurrence took place in the flight arena of CentraleSupélec in the early stages of the game

development. During a spontaneous visit of 15 min, about thirty Spanish high school learners, that had no particular link to engineering, were able to see the robot automatically fetch the tennis ball. During the visit, they seemed genuinely interested in the project and asked questions that guided the team in imagining the focus points of the future workshops.

The second workshop occurrence (30 min) was organized a few months after the former in an open-space environment in CentraleSupélec regrouping several exhibitors (students from CentraleSupélec presenting different activities, not necessarily scientific). The game and workshop were fully prepared and presented to fifteen high school learners during the associative fair organised by the CentraleSupélec students of OSER (2016). This students' association of CentraleSupélec is committed to equal opportunity, inclusion and diversity. It is important to bear in mind that:

- All the high-school learners were part of the OSER (2016) program, meaning they all studied in schools with low cultural outreach;
- Only the high-school learners who wanted to participate came to the sessions. A preexisting interest for engineering might therefore be a bias in the answers to the survey;
- The high-school learners were free to come and go during the sessions so it was challenging for the students' team to keep them focused and motivated.

4.2 Learners' feedback

During the afternoon, fourteen learners participated in the full workshop (one participant only stayed for a few minutes). Among them, there were eight girls, which is encouraging knowing that only 15% of the current students are girls in the French engineering schools. At the end of the workshop, the learners answered the following survey:

- (1) Did you like the game? (Yes 100%)
- (2) Did the workshop help you understand basic programming notions? (Yes 100%)
- (3) Did the workshop help you learn about Image Processing? (Yes 90%)
- (4) Did the workshop help you learn about Robotics and Control Engineering? (Yes 90%)
- (5) Following this workshop, would you like to know more about the topics covered? (Yes 100%)

The survey illustrated that most of the high-school learners were enthusiastic regarding the workshop. A girl even told the CentraleSupélec students team she was now considering studying Robotics. Overall, this result shows that the outreach was effective in spite of the complexity of the topics, even with an audience that was not predisposed to engage in such activities.

4.3 Lessons learned

Learning by doing is a powerful approach that is not used often enough in secondary and high-school curricula. It is therefore important to maximize the number of exercises or demonstrations to engage children in the reasoning. For future sessions, the aim will be for the presenters to talk as little as possible to create more space for experience, guesses and questions.

In particular, it is too ambitious to try teaching all the basics of Control to a group of heterogeneous beginner learners. One should stick to highlighting how it solves the specific problems encountered and drawing parallels with other systems or even human behaviour.

Since playing against the robot is the part the learners prefer, it can be frustrating to select only one player (from a group of several children) for the demonstration. Playing the game several times with different learners is worth the extra time. It enables learners to engage more easily in the workshop, to have more time to spot the features described during the workshop and it keeps them away from frustration.

An important aspect is related to the *learning by teaching* approach. Therefore, the 4 students of CentraleSupélec who developed this pedagogical game increased their skills in Robotics, revised some notions of their Control course, and developed pedagogical and communication skills.

For the CentraleSupélec pedagogical team, this project offers long-term benefits, such as promoting innovative teaching practices and creating opportunities for collaboration with secondary/high-schools, thus making a significant impact within the educational community for the benefit of youth.

5. CONCLUSION

This paper presents the development of a human versus robot delivery game. The objective of the game is to facilitate learning of basic Control Engineering and Image Processing concepts. This game also provides the opportunity for learners to tune the parameters of a PI controller to operate the robot effectively. With the goal of offering a pedagogical platform to the community, the game is openly accessible on GitHub at <https://github.com/L2S-1ab/DeliveryGame>. By making the game open source, the project aims to empower teachers to incorporate interactive and engaging learning experiences into their courses. A video of the game is available on the YouTube channel of L2S https://youtu.be/lei9_nlpf4U.

In the future, more workshops will be planned in the flight arena of CentraleSupélec involving a larger number of learners. Future extensions include using drones for aerial delivery.

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