Lego Mindstorms EV3 for teaching the basics of trajectory control problems

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***Abstract*— This Research to Practice Paper aims to illustrate how real-life projects can be used to teach students engaged in an academic course in robotic science the basics skills in control theory and computer vision. To design of modern control systems, engineers must be familiar with a range of technical fields. The range of theoretical knowledge and skills provided to the students include trajectory control, adaptive control, computer vision, as well as the capacity to build of complex mechatronic systems, all of which form part of an integrated curriculum. The paper describes how, using a LEGO educational set, the students are assigned a real-time project consisting in the development of a control system for a mobile car-typed robot. The stated objective is for the assembled robot to be able to move from a starting point to a goal pose while bypassing potential obstacles. At the end of the course, students must present their results, with a demonstration of the robot completing a given task together with a report. The project entails monitoring on the students progression and technical mastery as well as how the work process helps increase students interest in their studies and translate their theoretical knowledge into practice.**

***Index Terms*—Active learning, constructionism, zone of proximal development, laissez-faire, control system theory.**

I. Introduction

Robots have penetrated our daily life, as self-driving cars or drones, and smart mobile home appliances such as automatic vacuum cleaners are becoming an ordinary thing. More students aspire to become specialists in robotic science then ever before and learn how to develop smart systems with a life-improving potential. Educational programs must aim to combine theoretical knowledge on control theory, computer vision and programming with practical assignments that can test the skills acquired during class on the field.

While a hands-on approach to education has long been recognized as a key motivator, the basic practical resources available to tutors were usually well suited for either complete beginners (secondary education initiation courses) or advanced students in research programs, but mid-level projects tailored for university freshmen in robotics were scarce. This team of pedagogues wanted to design a course that, while serving the crucial purpose of training their end-of-second-year students to solving problems of the right degree of complexity, would fill that gap.

A. Project Purposes and Description

The key assumption behind the project was that, while the target students are only getting familiar with the basic concepts used in robotics, they are also fully operational adult minds that respond to a range of standard stimuli such as empowerment, result expectations, full agency and delegated responsibilities.

It was decided to observe whether, when instructed to complete a final result (produce a mobile-car type robot capable of movement and reaching its assigned position while avoiding obstacles) and provided with the full range of technical means for action (start algorithm together with reference literature, laboratory, hard devices) but only minimum guidance from their tutors, the students would succeed in putting together a robot that fulfills the requirements.

Practice is a critical part of the training for which specific equipment is required. When looking for a convenient teaching tool, considerations pertaining to cost, easy accessibility as well as inherent technical specifications such as flexibility were applied. Based on these, the Lego Mindstorms set appeared as an optimal choice of working platform able to replicate real-life conditions, and therefore a good fit for educational purposes in basic robotic science.

B. Project Pedagogical Background

The authors believe that a practical approach is instrumental to increasing the interest of apprentice engineers in science and ensuring that their intellectual training is finally formed. This was defined as constructionism, a theory suggesting that the best way to ensure that such intellectual structures form is through the active construction of something outside of one's head, that is something tangible, something shareable [1]

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The challenge faced by the tutors was to keep the motivation of the students at a high level, to ensure that assimilation of the skills acquired was optimum. To achieve this, the technical level of the project needed to strike a golden balance: challenging enough to keep the groups awareness stimulated, while simultaneously avoiding features that were too complex for the students to solve.

Prior research run by the pedagogical team to identify suitable projects revealed that similar preoccupations as to the correct level of difficulty were shared by other colleagues, as in [2].

Our work was inspired by the cognitive reconstruction theory developed by Vygotsky in 1962 (as already noted and applied to the field of robotics) [3] that the potential for development and learning heavily relies on social interactions (in our case, between students and their immediate mentors) and are optimized in the zone of proximal development, when the learners are required to complete tasks according to their level of knowledge already attained (the problems to solve should be of a slightly more advanced level, to develop new skills) and following the right sequencing.

In addition, to sustain the students level of interest in theory class, the real-life project needed to reflect the pace and progressions of the concepts as these were being taught.

This article aims to complete this body of works with a new project featuring the novelty of giving to the students a notable degree of freedom and autonomy and appealing to their sense of responsibility.

C. Project Methodology

The teaching team started with identifying students for the project. Rather than conduct the experiment with a full class, the choice was to select a small number of 4 individuals (for the sake of easy communication among the group) previously involved in extracurricular activities with the university that already presented a high degree of motivation and similar level of skills developed. To balance the workforce (young motivated students with time to dedicate to the project) with a degree of higher technical expertise, 2 additional students at Master degree were added to the taskforce.

A timeline of 2 weeks was delimited, that would allow for daily meetings of the group and productive working periods of 4-5 continuous hours, to keep the focus and enthusiasm for the project until completion while respecting the need for students to address parallel curricular obligations.

To concentrate all resources, the project was conducted in the university lab, to which the group of students was given fulltime, unlimited access. This was critical in creating a sense of involvement and value for the trust that both their professors and the institution placed in them.

The option was taken to afford only restricted guidance to students and give them much freedom as to the means and paths to take in order to create their own robot. Once armed with the theory knowledge and references to Computer Vision, Control Theory and Software Engineering, the students had to work their way through the structure and progression of the project, as well as work allocation among the team. The involvement of the supervising teacher was felt only at the level of the 2 advanced Master participants. This was done to replicate the organization of work in a professional project structure, where the project manager will normally only communicate with the supervisors of each team.

During the first week, the attention focused on assessing the progress of students in terms of correctly analyzing and separating the range of problems and distributing the task of solving those to avoid duplication of work in view of the strict timeline. A crash-stop session of debriefing was contemplated, at the end of the week, with all participants, in case the project did not show enough progress but was finally deemed unnecessary as students proceeded very early in the work (Day 2) to dividing their work (creating a unit focused on robot movements and another one on vision problems, each supervised by a Master student).

To allow the teacher to monitor progress, regular check-ups after the lab sessions were also organized to determine whether the technical sequencing was correctly phased. At the end of each critical phase, the 2 Master students were asked to report on critical difficulties met, and their opinion as to the level of optimism and confidence in their respective groups. Finally, the interaction of each group of students was closely monitored on a bi-weekly basis, via conferences with both Master students.

At the end of the project, the students were asked to do a series of presentations summarizing their contribution and justifying their choice of task organization and technical options. At this stage, the main professor for the project intensified interaction with the students directly, to discuss with them whether other options could have been preferable; rather than telling them what to do, the idea was to let students design their own project and slowly progress the ultimate goals, and only after full completion, point to more efficient alternatives. In this way, students would only get to discover state-of-the-art, having first gone through the inventive process and technical learning curve to match the pace of innovative projects in real life. Finally, upon completion of the project, the students were asked about their assessment of how the experience had helped them consolidate their theoretical knowledge and improved their sense of practical requirements for building robots.

II. Project Implementation

A. Project Technical Content

The course totaled six sessions as presented under Section II corresponding to the progression of topics bellow:

(A) car-type robot and its mathematical model
(B) implementation of the robots movement
(C) modeling and developing of the trajectory controller
(D) implementation of the path-finding algorithms and use of OpenCV [4] library for general mapping
(E) implementation of local planners
(F) joining all the parts together

The idea was to monitor how undergraduate students would manage to break down the work to corresponding to logical progressive steps in the construction of a robot, as well as to review how they would fend (amount of mentors involvement needed to solve the technical difficulty and move to next step) in each labs topic.

B. Car-type robot and its mathematical model

In this first session, students are shown how to assemble their own working robot from a Lego Mindstorms set, and are presented with a mathematical model.

This session was mostly passive on the part of the student, with mentors providing them with an expos of the key concepts and mathematical models.

C. Implementation of the robots movement

At the beginning of this session, the students took initiative in order to break down the project into technical stages of a process. They discussed all areas to focus on, and clearly saw the necessity to divide the work. As they identified movement control as a key component, one team composed of a mentor and 2 undergraduates was asked to concentrate on this, for which the mentor's technical leadership proved crucial. This session showed that organization of work was spontaneously raised by the students.

The session focuses on how to equip the robot with capabilities necessary for it to move around the experimentation plane with precision: this includes the ability to take into consideration its current location and speed and to convert the desired velocities into electrical signals that can be sent to the DC motors.

D. Modeling and developing of the trajectory controller

For this session, students heavily relied on Master mentors help and guidance including the indication of IT tools to be used, while at the same time a certain degree of comfort in applying class theory material to this project was developed.

E. Implementation of the path-finding algorithms and use of OpenCV library for general mapping

This session was conducted by the other team of students in charge of vision control, and again, the students took the lead in identifying difficulties and exploring several sets of solutions. Their reliance on the mentor's guidance was less in this case.

F. Implementation of local planners

This session was the most intense in relation to student-mentor exchanges. Also, this session was the first time when both teams had to consolidate their respective works and join efforts to produce an operation result, so team coordination and soft leadership was critical. The outcome was positive, as students learned to take each team's specific constraints in consideration and integrate those in the unifying work process. Once the difficulty identified, undergraduates relied on collaboration with their Master counterparts to design workable solution paths and the type of aide to use.

G. Finalizing the operation device

At this stage, the undergraduates had gained considerable confidence in their own capabilities and were able to conceptualize all steps needed to complete this workshop on their own.

A video showing the results of a complete system developed during this project can be found at [5]. All projects of the Control Systems and Informatics department of the ITMO University are available on the youtube channel [6]

III. Project Results

A. Review of the Learning Process

As a whole, via regular debriefing and catch-up sessions with the 2 Master students, the project supervisor was able to keep track of the students learning progress. The project never reached a point where a major difficulty would have required him to personally get involved in order to rectify direction or avoid significant delays.

It was established that each of the 6 lab sessions covered by the students enabled them to successfully cover the range of skills and solve the technical problems presented to them. Also, the underlying theory taught to them was confirmed sufficient to arm them with the technical capacity to advance the construction work, while still presenting a challenge: most problems in relation to implementation of algorithms were solved by the students alone, sometimes with the help of their Master level mentors.

A key step at the beginning of the project was the students decision to break down the team in two groups, each focusing on a specific aspect (respectively, robot movement and vision control). A review of the exchanges among the undergraduate students at this crucial time shows that the choice to allocate resources based on criteria of optimization of each contributors strong points in order to rationalize efforts was a bottom-up decision. However, once that initial stage was passed, the daily analysis on the work covered in each lab session also showed that directions provided by the 2 Master mentors were critical to the project: coherent mapping of the 6 sessions, orderly progression towards the ultimate goal, correct allocation of resources. This points to a limit to what undergraduate students can reach in terms of technical capabilities on their own, while organizing and dividing the work as well as directing resources towards a goal correctly was successful without supervisors involvement.

B. Assessment of Project as a Teaching Experience

As reported by the 4 undergraduate students, the project was a highly positive experience that they would recommend be integrated as a permanent feature in their years curriculum. Their comment was that experiencing the technical difficulties first-hand allowed them to master a complicated theory course and get in-depth understanding of the underlying principles behind some of the courses taught, such as control theory. They also confirmed that the experience helped them develop soft skills such as working with Git Hub, time management and team work.

The practical result (an operational robot, matching all the technical requirements and functionalities set forth) and overall satisfaction of the students with the project confirm its success as a teaching experience, and comforts the pedagogical premises that practical tasks are an accelerator to consolidating theoretical knowledge in students. It also underlined that students could produce their own working methodology and progressive course, when only tasked with achieving a determined end-result and given all the necessary means. However, all insisted that the contribution and leadership provided by the senior members of the taskforce was instrumental to success.

Although they succeeded in completing the project within the two-week deadline, the students reported that this was an intense experience that was probably not workable on a larger group level. Therefore, for future expansion from this pilot to a complete class, a full semester for the project is considered.

IV. Future Work

Following the encouraging results of this pilot, the 4 undergraduates helped design an adaptation of the project for a full-class scale over a semester at the Control Systems and Informatics department of ITMO University. It appears that the project is the right format for students at second-year level, challenging but void of insurmountable technical difficulties so as to allow success, with a minimum amount of guidance from senior students. At the groups request, it is planned that they will also be involved in future follow-up by reviewing the feed-backs and results from their peers, after the project is deployed, and help compare it with their own take-away from the project.

In addition, the students have suggested that a similar approach could be introduced in courses dealing with comparable subjects such as web-designing and programming, where students and educators must also deal with a ratio of motivation vs. technical difficulty to overcome as part of their training process.

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