MOTION CONTROL AND COORDINATION PLATFORM FOR MOBILE ROBOTS

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ABSTRACT

The training of a mechatronics engineer requires the application of a variety of skills in different projects. The "Robotics Project" optional module is aimed at 5th year Electromechanics students, who will be able to read up on a wide range of subjects such as embedded systems, sampled systems, automatics, robotics, machine control, programming and IOT, all of which form part of the training curriculum for Mechatronics engineers (standards 1,2,3). The implementation of a servo-controlled mobile platform highlights the different variants listed in a pedagogical approach that links these different modules in a single project. This project provides engineering students with a global vision of their field, putting into practice a range of knowledge that students may not see in the modules in question or in previously developed projects. This generalization of practices touches on knowledge encompassing several modules. This approach takes the form of a workshop to review the theoretical notions already studied and link them up with the project (standards 4). The first workshops focus on embedded systems and machine control, using microcontroller boards to read encoders and set the appropriate command. Then, the interpretation of velocity is done through the choice of an echo frequency (standard 5). To finalize the work, we are connecting each robot so that it can send back its position wirelessly via an IOT communication protocol (standards 6,7,8). A second version of the project is developed this year with a different robot model. To achieve more satisfactory results, we have introduced more guided sessions to focus more closely on the desired learning outcomes through skills-based learning scenarios. The results of this second approach are still in progress. The whole platform is used as a validation tool for a group robotics platform to test different group motion algorithms. A positive results of student survey highlight the crucial role of practical projects in preparing mechatronics engineers for the dynamic professional landscape, with continuous improvements ensuring the module's sustained efficiency.

KEYWORDS

Robotics, Embedded Systems, IoT, Integrated Learning, Syllabus: 1, 4, Standards: 1, 2, 3, 5, 6, 7, 8.

INTRODUCTION

Mobile robotics has become an integral component of mechatronics engineering, bridging theoretical knowledge with practical applications. In recent years, the field has witnessed significant advancements driven by the convergence of embedded systems, automatics, and the Internet of Things (IoT) (Seeja, Reddy, Kumar & Mounika, 2021). As educational institutions adapt their curricula to meet the demands of a rapidly evolving technological landscape, integrating a dedicated robotics module becomes imperative.

The "Robotics Project" optional module, tailored for fifth year electromechanics students, aims to provide a hands-on experience that consolidates diverse knowledge gained throughout their studies. This initiative aligns with the evolving landscape of mechatronics education, where interdisciplinary skills play a pivotal role (Jenabi, Shahri & Beyad, 2016). The choice of functionalities in the project is rooted in the emphasis on skills acquired in previous modules. As mobile robotics encompasses a wide spectrum of engineering domains, the project serves as a culmination of theoretical concepts from embedded systems, automation, electronics, and IoT (Sackey & Bester, 2016). This amalgamation of skills ensures that students are not only well-versed in individual disciplines but also capable of synthesizing their knowledge for practical implementation.

The significance of introducing a robotics module towards the culmination of the engineering curriculum is underscored by the need for students to connect theoretical knowledge with real-world applications (Suarez, García-Costa, Perez, López-Iñesta, Grimaldo & Torres, 2023). Robotics projects facilitate a holistic understanding of mechatronics, fostering problem-solving abilities and critical thinking. The project unfolds in a series of workshops that cover fundamental aspects of motion control, starting with open-loop DC motor control and progressing to complex tasks such as trajectory planning and odometry. The design of the first robot model incorporates microcontroller-based boards aligned with IoT communication protocols and specifications similar to those encountered in 'Embedded Electronics' and 'Advanced Embedded Electronics' modules (Romeo, Petitti, Marani & Milella, 2020). In response to initial results and student feedback, a second model is introduced, refining the motorization, and enhancing autonomy during tests. This iterative approach aligns with contemporary engineering practices, where constant improvement and adaptation are key to addressing emerging challenges (Wei, 2016). As mobile robotics continues to play a pivotal role in engineering education, the integration of practical projects like the one presented herein ensures that graduates are well-prepared for the dynamic and interdisciplinary nature of the modern workplace (Baranowski, Kucharska, Kawalec, Malinowski & Piwowarski, 2023). Daniela & Lytras (2018) worked on conceptual model of technology enhanced learning development to lead the student from the lower level of thinking, characterized by simple digital skills, to a higher level of thinking, which is characterized by the design of new knowledge and the creation of new products. On another hand, the CDIO community is addressing this research theme by developing robotics teaching platforms with the help of the CDIO initiative, enabling students to apply their existing knowledge to real-life problems and situations (De Carvalho, 2016; Sánchez, Morales, Londoño, Sánchez & López, 2017; Daniela, 2019; Bravo, Hurtado & González, 2020). Through our work, we aim to move forward and guide sessions to focus more closely on desired learning outcomes through competency-based learning scenarios.

In fact, this paper is structured as follows: the first section describes the initial approach, which involves conceiving a standardized robot model. The section covers session proceedings, achievements, and limitations of this approach in detail. The subsequent section discusses the second approach, titled "A new training approach updating the robot ", revealing the design of the robot, as well as the updates and the innovations in learning techniques. Furthermore, we present and discuss the obtained results endorsed by simulations and achievements of studied robots, proposing specific additional requirements. Additionally, the results of a student survey are outlined, ensuring the continuous improvement of the Robotics Project module. Finally, we conclude the main work and provide insights into few perspectives.

"ROBOTICS PROJECT" IMPLEMENTATION

Firstly, the functionalities of discussed optional module are determined and chosen by the skills emphasized in the diverse modules studied previously. The Table 1 summarizes the skills and the functions expected of the robot designed. This work consists of the implementation of two solutions. The first conceived robot presents standardized model for effective teaching across various workshops, minimizing the need for familiarity and maximizing learning outcomes tailored to each workshop. The second approach involves enhancing the designed robot with electronic upgrades to boost accuracy and autonomy, with detailed insights into the learning outcomes for this solution.

Table 17. Skills and functions expected of designed robot

Module Taught	Parts to be highlighted	Robot functionalities
Embedded electronics	GPIO, ADC, Timer, PWM	▪ Reading encoder outputs ▪ Reading a potentiometer to vary a control parameter
Advanced Embedded Electronics	Internal Interrupt, External Interrupt, Hardware Debugging UART communication	▪ Calculate speed at each Internal Interruption ▪ Calculate position for each external interrupt ▪ Monitor parameter evolution in real time Hardware debugging
Machine control	DC motor control	▪ Varying the speed of a DC motor
Automatic	PID control	▪ Design a speed control algorithm for a motor
Robotics	Behavioral modeling	▪ Modeling robot motion
IOT	Setting up connected nodes via the MQTT protocol	▪ Return robot coordinates via MQTT protocol

To follow-up pedagogical activities, a schedule of activities is represented in Table 2. The schedule is strictly controlled by the module manager under the supervision of the teacher in charge of teaching. During the monitoring of the implementation process, the head of department invited the teacher in charge and the module manager, where appropriate, to analyze incoming methods and principles to correlate them with the competencies-based learning method already in place and adjust them if necessary to the targeted skills. Indeed, the curriculum is designed with mutually supporting disciplinary courses (standards 2) with a regular review and revision of the program learning outcomes (Standard 3). This enabled the teachers to stay focused on the pedagogical objectives, and the students to properly converge and merge their skills and knowledge of mobile robotics development in an interdisciplinary and physical environment around problem-solving activities through active and experiential learning methods (Standard 8).

Table 2. Schedule of Activities

DATE	ACTIVITY
From 13 to end of September	Submission of the requirements The system flow design
1st Week of October	The architecture of the system
2nd Week of October	Partial Checking of Equipment's, Software systems, and manuscript
3rd and 4th Week of October	Create initial system design. Follow-up checking / Presentation
1st Week of November	Final checking of Video Tutorial, System Manual, Robotic system, and manuscript
2nd Week of November	Final submission of all the requirements. Lacking requirements

FIRST APPROACH: STANDARDIZED ROBOT MODEL

An initial model is developed for this purpose, in collaboration with other disciplines, to guarantee the functionality of all the modules. The first objective was to build a standard model to ensure a didactic model not only for this module but also for a multitude of workshops to provide the framework for robotics engineering practices (Standard 4) for different levels and disciplines including multiple design-implement experiences (Standard 5). The aim of this approach is to minimize familiarization with the model in order to maximize learning by varying the learning outcomes to suit the workshop in question in a physical learning environment (Standard 6). The aim is to standardize the equipment to facilitate maintenance and reduce the time required to assimilate the different parts of the robot, while retaining functionality adapted to each level and specialisation. Each level in the electromechanical cycle will study a series of functions to harness the robot's potential in the 5th year.

First model design

A preliminary two-wheel drive model has been designed using two microcontroller-based boards. The first board is dedicated to robot control, while the second focuses on communication. This type of motorization is designed for robot vacuum cleaners. We felt that this kind of device would be an additional asset to immerse it further into the field of service robotics (Mugure, 2019). The Figure 1 illustrates the design of the first robot implemented.

One of the advantages of such a solution is to ensure the most compact motorization possible from an industrial environment. Careful consideration was given to align these boards with those utilized in IoT modules for the communication board, and closely mirror the specifications of the 'Embedded Electronics' and 'Advanced Embedded Electronics' modules for the control board. The development software platforms were also selected to closely match the specifications of these modules. The design and implementation of this model occurred independently of coaching sessions, with mechanical design not being a primary focus to align with the pedagogical objectives of other modules.

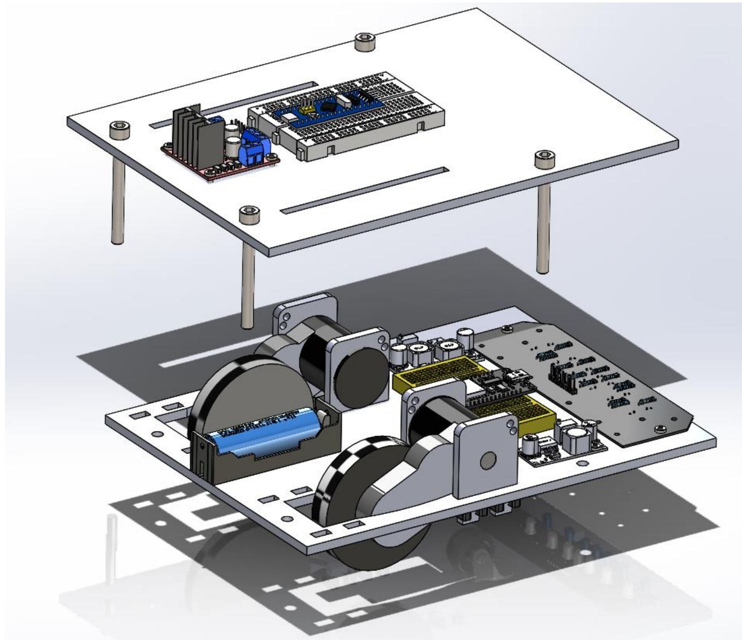

Figure 20. Design of the first robot model

The first step of the workshop is to control the DC motors in open loop. Generating PWM signals via the control board and varying the motor speeds is established. The PWM signals is controlled via the Timer configuration. Students are encouraged to choose a PWM signal frequency according to electrical and mechanical properties, and to determine its impact on motor torque and speed. The next phase involves reading the value from a potentiometer and adjusting it for control. Subsequently, the workshop will cover reading encoder values from manual wheel movement. Using GPIO and external interrupt for reading encoder values and determining wheel position is an integral part of this section. The determination of velocity is the next phase in the training. This phase involves using internal timer interrupt. Students are required to set a sufficient sampling frequency to ensure smooth reading of values, considering the control loop. The control part will connect the PWM motors control and speed reading in its regulation phase. This stage is researched and implemented to find the appropriate PID coefficients. Testing, interpretation, and validation as the coefficients are modified gradually develop critical thinking and analytical skills in engineering students. The subsequent phase includes trajectory calculation and planning. Students need to grasp the process of transforming the task of trajectory planning into a sequence of motors setpoints through the creation of a model for robot's displacement. In addition, the simulation tools are employed to verify the behavior. The following part will focus on robot geolocation through odometry. This geolocation will serve to relay the robot's position and orientation to the network to correct the trajectory. Data transfer from the robot is occurred from the control board to the communication board via the UART protocol.

Session proceedings

The initial sessions were conducted in the form of workshops. The first workshop consists of a practical scenario of assembling and wiring the robots. Students were familiar with the equipment used, as most of them had already used it in other projects. The use of a board similar to the one used in the Laboratory work facilitated learning and accelerated progress. In addition, the use of laboratory work resources ensured the deepening of knowledge and skills acquired in previous sessions were further developed.

In this regard, the inclusion of the "PWM Signal" and "ADC" laboratory works in motor control streamlined the workshop. The "EXTI" and "Timer" practical works facilitated the assimilation of encoder reading. The workshop, structured in the form of practical exercises, concluded with the implementation of the PID control structure. The remaining sessions took the form of supervision, allowing students the critical spirit to test and validate their own work. The teacher's intervention occurred to validate a phase or to guide the group in their project development process.

Approach results and limitations

Most of students grasped the purpose of the topic with an understanding of the robot's functionalities. The variety of tools used in the development of the second part (supervision part) fostered an exchange among the groups to arrive at a reliable solution leading to the acquisition of disciplinary knowledge, as well as initiative-taking behavior and teamwork (Standard 7). Nevertheless, the time spent on research and solution development is substantial and is conflicted with the finalization of the connection and odometry phases.

The first prototype limited learning in the level of robot autonomy. The limited autonomy created dead times during recharging. Students encountered issues with connections, resulting in errors during the assembly and disassembly of the cell for recharging, consequently causing damage to the equipment used. Single-channel encoders constrained the work involved in regulation tasks. Mounting the electronic boards on two levels restricted accessibility and increased the assembly's complexity. All the aforementioned shortcomings were confirmed during various discussions with students. The students' feedback and technical suggestions will be taken into consideration in the development of the second prototype.

SECOND APPROACH: A NEW TRAINING APPROACH UPDATING THE ROBOT

The necessity for a new model emerged from several issues identified with the initial model. The electronic circuits are upgraded while preserving the same educational goals. This update is conducted autonomously from other modules.

Second model design

The concept of collaborative work to create a unified robot is redefined, opting for a functional model for each module and subsequently seeking a robot that integrates the entirety, rather than designing it from scratch initially. The outcomes of one project will be discussed in another article. The motorization has been changed to achieve greater precision in control strategy. The battery is modified to ensure more autonomy during tests. In this new approach, students are empowered to determine the robot's design, including the placement and arrangement of components within the MDF structure, and initiate the manufacturing process. This modification aims to enhance student engagement in the project and provide them with a sense of ownership over the robot. The design of conceived example of second robot model is shown in Figure 2.

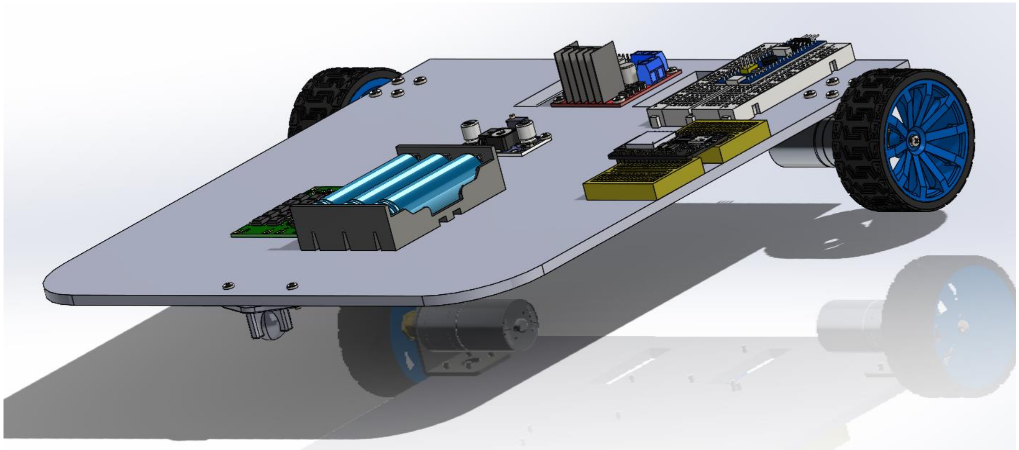

Figure 21. Example of Design of second robot model

A change is occurred in the workshop with additional assistance provided in the odometry and trajectory planning sections. This modification aims to minimize research time and maximize the practical knowledge gained. The subsequent stages of the training process are maintained but with greater detail, including a comprehensive discussion on trajectory planning. Rather than directly addressing the on-board aspect, students will analyze and devise a trajectory planning algorithm based on the robot's mechanical and electrical characteristics. An educational forum has been established for students to share ideas and collaboratively devise a solution. Each student presenting their algorithm is required to explain it to their peers, allowing for analysis and modifications to address any shortcomings. The use of ChatGPT is permitted, provided that the student can articulate the entire proposed code. The subsequent phase involves a discourse on odometry, using the methodology applied in the previous phase.

Results and discussion of the second approach

The modifications implemented in the second prototype have significantly enhanced the robot's versatility across various aspects. Consolidating all components onto a unified platform has notably streamlined access to diverse electronic components. The use of additional batteries with integrated recharging system has effectively mitigated recharging downtime and expedited cell assembly and disassembly processes. Furthermore, the implementation of dual-chain encoders has notably optimized regulatory tasks by reducing workload demands. Nevertheless, it's noteworthy that the utilization of integrated motors, akin to those found in commercial robot vacuum cleaners, underscores a strategic alignment with industrial standards. The inclusion of two discussion phases in the workshop resulted in enhanced learning outcomes. By allowing the use of the ChatGPT tool, students developed a critical mindset in response to the AI's proposed solutions, effectively leveraging its potential and promoting focused exchanges. This enabled an exchange on an educational platform to discuss proposed solutions based on shared documents as well as a more in-depth analysis of the results.

The student-led debates added an educational dimension to the workshop, fostering idea exchange among participants who recognized themselves as key stakeholders. Among the students, 50% successfully implemented the odometry component, while 90% grasped both trajectory planning and odometry during the evaluation. Unfortunately, none of the groups accomplished the IOT connectivity component. Introducing the IOT aspect in practical work during the same year is recommended to alleviate the complexity of the workshop.

To identify the strengths and areas for improvement in the "Robotics Project" module, a survey is conducted with the aim of assessing the module from the students' perspective. Indeed, students (32 in total) were invited to provide evaluations on various aspects of the module, including overall satisfaction with teachers and support, the engagement and informativeness of practical sessions, the relevance of assessments to the taught concepts, the suitability of teaching resources, preparedness for future projects or professional contexts, the usefulness of teacher interventions, the adequacy of time allocated to practical work, and the module's contribution to enhancing robot design skills. The posed questions are as follows:

- Q1: How would you rate the overall level of satisfaction with the teachers and support provided during the module (1 being very dissatisfied, 5 being very satisfied)?
- Q2: How engaging and informative did you find the practical sessions? (1 being not very engaging, 5 being very engaging)
- Q3: On a scale of 1 to 5, how would you rate the relevance of the assessments and tests to the concepts taught?
- Q4: How suitable do you think the teaching resources provided were for carrying out the project (1 being not very suitable, 5 being very suitable)?
- Q5: How well do you think the module prepared you for future robotics projects or professional contexts (1 being not at all prepared, 5 being very well prepared)?
- Q6: How often did you find the teachers' intervention useful in guiding your work (1 being rarely useful, 5 being very often useful)?
- Q7: To what extent did you find the time allocated to practical work adequate for assimilating the concepts (1 being insufficient, 5 being more than sufficient)?
- Q8: How much do you think the module contributed to improving your robot design skills (1 being very low, 5 being very high)?

The results of the survey conducted with 32 students reveal a high overall satisfaction with the respective module, scoring an average of 4.31 out of 5. Practical sessions received particularly favorable ratings, achieving an average of 4.16, indicating an engaging and informative experience. While assessments and teaching resources were deemed relevant (4.06) and suitable (4.22) respectively, opportunities for improvement were identified, notably in teacher interventions (4.03) and the contribution to enhancing robot design skills (4.19). A detailed analysis of student responses, depicted in Figure 3, highlights a pronounced trend towards high scores (4 and 5).

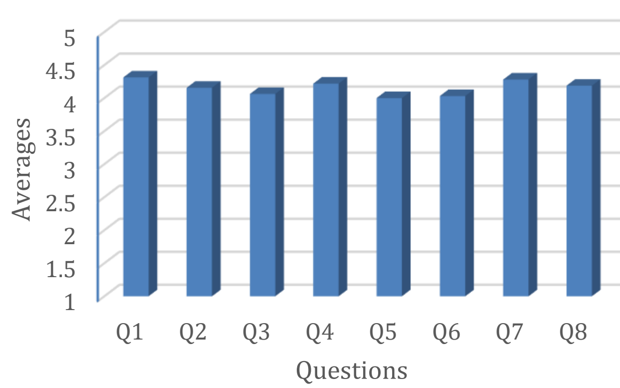

Figure 3. Average of items for each question

Moreover, examining the repartition of student's responses, Figure 4 is established in order to study the overall trend.

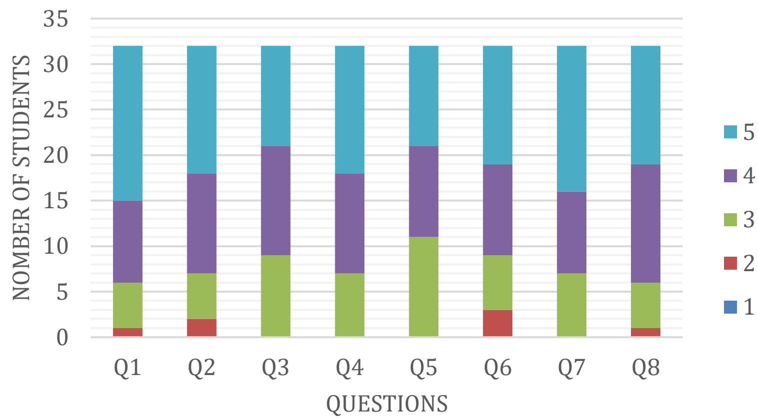

Figure 4. Number of students per item per question

From Figure 4, the results generally reveal a pronounced trend towards high scores (4 and 5) in most questions, indicating an overall satisfaction among students regarding the "Robotics Project" module. This analysis highlights students' preference for positive evaluations, providing a favorable perspective on various aspects of the module. Comparing responses across different questions reveals potential connections, allowing for a deeper understanding of how students evaluate different facets of the module.

In summary, these results, supported by detailed data, offer a solid foundation for targeted adjustments to strengthen positive aspects and address specific concerns of learners, thereby guiding the continuous improvement of the "Robotics Project" module.

CONCLUSION

In conclusion, the "Robotics Project" module for 5th year Electromechanics students serves as an effective bridge between theoretical knowledge and practical applications in mechatronics engineering. While the standardized robot model approach covered essential topics, challenges arose in its finalization. The second approach, incorporating electronic upgrades enhanced learning outcomes despite persistent difficulties with IoT connectivity. Overall, student satisfaction, revealed through a survey, underscores the significance of practical projects in preparing mechatronics engineers for the dynamic and interdisciplinary nature of the professional landscape. Continuous improvements guided by student feedback will ensure the sustained relevance and success of the module.

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