Development of Control Engineering Curriculum for Advanced Research and Undergraduate Education: A Practical Approach to Bring Theory Closer to Practice Using Quanser® Products

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Abstract

Undergraduate control engineering courses are considered full of theory with complex mathematical procedures, which turns into a difficult task for students. Herein, the real-time implementation of control strategies is crucial to bring theory closer to practice, and to enhance the engagement of the students. Academic minors fit these characteristics. However, it is necessary to analyze the curricula holistically to balance the control engineering concepts with the soft and technical competencies required to allow the experiential learning (learning-by-doing). Thus, considering a well description content and design of a minor is missing in the literature, in the present work the autonomy of unmanned aerial vehicles minor is presented. Here, the course and lab sessions are carefully designed to promote different and complex competencies required by ABET Criterion.

The overall minor consists of 400 hours, in which 132 hours are related to theory while 268 hours are designed to attend a real industry problem; this, to prepare the students for the real-world engineering context. The lab sessions are carried out using products of the Quanser® company, which is a world leader in the design and development of an interdisciplinary ecosystem for engineering education and research. Moreover, the Matlab and Simulink® computing software with QUARC™ are used to validate real-time applications on hardware. Roughly speaking, the minor is taught by a group of Professor experts in vision systems, machine learning, and advanced control strategies such as: modern control, model predictive control, nonlinear control, and robust control. To design the lab sessions, 20 Professors received 120 hours of training sessions from the R&D Manager in charge of Academic Applications of Quanser® company. After that, the leaders of the academic minor designed their own lab practices and solutions. Hence, the lab practices are aligned to the actual curricula from mechatronics, robotics and mechanics careers; this, to guarantee the versatility of the teaching material.

During the first semester of implementation, to test their own control strategies through the lab practices, students used the following products: DC Motor (under both configurations: inertial disk and inverted pendulum), Aero 2 (using the three systems: 1 DOF, Half quadrotor and helicopter).

On the other hand, considering that engineering education emphasizes technical skills to prepare graduates for the real-world engineering context, during the third period of the academic minor, learners must work into a challenge entitled: “Advanced control strategies in UAV’s for fuel theft detection in Mexico”, which is an actual problem in this country. Here, based on the designed advanced control strategies, the drone can be flight in automatic mode to detect illegal taps and reject external disturbances. Professors provided tutoring on: vehicle dynamics, main concepts of Drone Studio, and path/waypoints programming control. The first advanced control

strategy to implement is a Cascaded Model Predictive Control Architecture developed and published in an indexed journal Q1 by the leaders of the academic minor, as an outcome of a research collaboration between Universities from Mexico and United States.

Introduction

Student engineers need both clear theory understanding and excellent technical training to solve real-world problems [1]. Minors fit these characteristics [2]. In recent years, a growing number of institutions of higher education offer these minors as a secondary program that complements a primary area of study in a bachelor's degree program [3][4][5][6][7][8]. In [4], the materials engineering technology minor carried out in Purdue University Fort Wayne is presented. Here, the coursework provides the type of materials knowledge necessary for process engineers, manufacturing engineers, and design engineers. Moreover, to prepare the students for the sustainable use of ocean resources, Texas A&M University at Galveston developed and implemented two new minors [5]. The first minor in marine engineering technology is designed to increase awareness about marine engineering careers, and the second minor in marine electro-technology is designed to introduce students to the cutting-edge technology now on vessels. Also, Texas A&M University designed the cybersecurity minor [6] in which the students acquire a basic understanding of programming, and a firmly grounded understanding of cybersecurity, to include cyber ethics [9]. On the other hand, considering that global economies are moving towards decreasing their carbon footprint, Drexel University and University of Texas at El Paso (UTEP) offer green energy and sustainability engineering technology minor. Here, the students explore the principles, characteristics and operation of various renewable energy sources, storage devices, and energy conversion systems [7]. Similarly, as a result of collaboration between Southern University, A&M College, and Lucian Blaga University of Sibiu, the implementation of a power and energy engineering minor is carried out. This minor aims to train students in advanced engineering background to help manage the challenges faced by energy and power sectors [8]. However, major challenges faced with these minors are the lack of adequate laboratory facilities, software licenses, and properly trained teaching assistants. In fact, some of them either use simulation software programs or adopt emerging technologies such as virtual reality systems for training in a classroom. Thus, considering that automated control courses in undergraduate curricula are usually considered difficult [10], and in recent years, the use of unmanned aerial vehicles technology has notably increased [11][12], Tecnológico de Monterrey, Campus Monterrey, designed, developed and implemented autonomy of unmanned aerial vehicles minor. Here, the students implement their own control algorithms, applying the competencies developed in the focus stage of their study plan. Moreover, as laboratories and experimentation are an important part of the engineering curricula and education [8], the lab sessions are carefully designed to promote different and complex competencies required by ABET Criterion; this, based on supplement technical workshops, in which professors acquired hands-on experience on products by Quanser®, a world leader in the design and development of an interdisciplinary ecosystem for engineering education and research.

Background and Institution Context

Tecnológico de Monterrey was founded in 1943, located near a concentration of manufacturing industries in Mexico, including automative parts manufacturers, heating, ventilation and air conditioning (HVAC) companies, aerospace plants and medical devices makers. Until 2024, this private, non-profit, and independent institution has educated early 96,040 undergraduate and graduate students in a diverse range of schools such as: engineering and sciences, architecture, art, and design, medicine and health sciences, social sciences and government, humanities and education, and business.

The school of engineering and sciences is recognized as one with the highest number of enrolled students year by year. Here, the Department of Mechatronics has been offering the Bachelor in Mechatronics Engineering (BME) since 2002. This 4-year undergraduate program aims to train professionals with a solid base in a wide range of areas, including robotics, production lines, automated systems, and medical, automotive and aerospace devices, among others. It is a relatively new program when compared with the traditional engineering programs; however, the program is ABET already accredited and requires a minimum of 144 credits.

Moreover, considering in engineering education a “learning by doing” experience is irreplaceable [13], in 2019 Tecnologico de Monterrey implements the Tec21 model. It is a new model in which students develop solid and integral competencies where the learning style is achieved by solving challenges linked to real problems [14]. Hence, to obtain the academic degree, the student goes through the following stages:

> Exploration. This stage occurs before the students choose a career. They acquire the fundamentals of the area which allow them to determine the career.
>
> Focus. Here, the students develop the core competencies of their career through more focused challenges.
>
> Specialization. During this stage, the learners continue to strengthen their skills. Here, based on their personal interests, passions, and plans, they can choose through the wide range of minors, stays, and certificates.

The specialization stage plays an important role in the Tec21 model; this, because during the seventh semester, the students not only complete a prescribed number of credits, but also they can give the personal touch of their careers. Until 2023, the Department of Mechatronics offered the following main minors:

> Aeronautics Engineering. This course incorporates fundamental concepts from the aeronautical engineering area, in which you will understand the flight principles and

design of an aircraft, its component or systems, propulsion, control systems and its supply chain.

Automotive Engineering. Here, the student understands the importance of the automotive industry in Mexico, the impact of technological and mobility trends in automotive engineering. The student models and simulates the dynamic behavior of each of the vehicle's parts and the vehicle as a unit.

Biomechanics and Sports Engineering. It is an advanced level course in the biomechanics field, which intends for the student to acquire the skills to develop engineering solutions to help patients at risk of a locomotor injury, as well as support the rehabilitation process.

Cyber-Physical Systems. The student is intended to solve a challenge in the area of cyber-physical systems. Requires prior knowledge of control systems, digital systems and programming.

Then, considering that real-time implementation control strategies in quadrotors for a wide range of applications has increased [10], by August 2024, the minor entitled unmanned autonomy of aerial vehicles was offered by first time in Tecnológico de Monterrey, Campus Monterrey.

Course Design Framework

As it is mentioned in [15], a well description content and design of a minor is missing in the literature; then, in this section, the key details such as: hosting department, course level, curricular requirements, learning outcomes and required courses are rigorously presented for the unmanned aerial vehicles minor.

The minor was developed by volunteer professors from different engineering programs to promote progressive curriculum design [2]. Here, the professors always kept in mind three main considerations. First, even though the minor is offered by the mechatronic department, it should be developed for students enrolled in the following bachelor's degree programs: mechatronics engineering, robotics and digital systems, electronics engineering, and mechanical engineering. Second, the minor must be focused on the needs of the students and local industry [4]. Third, the overall academic minor consists of 18 credits equivalent to 400 hours.

Therefore, the design process of the minor began with brainstorming a list of learning outcomes [16]; this, to empower interested students in control engineering concepts and to conduct experimental work in the unmanned aerial vehicle areas. Thus, at the end of the course the student must develop the following disciplinary and transversal skills:

Disciplinary competencies. Performs theoretical and experimental modeling of process (SMR20301B), design strategies to automate process (SMR0302B), and implement automation proposals (SMR0304B).

Transversal competencies. Solve real problems and questions, based on valid and reliable methodologies (SEG0502C), and evaluate the own and other´s reasoning based on the identification of fallacies and contradictions (SEG0503C).

Moreover, prior knowledge of modeling and automation, and control system design is required. Then, designers identified three curricular courses as prerequisites:

MR2023 Modeling and Automation. This intermediate mechatronics engineering course focuses on mathematical modeling to enable students to represent the dynamic behavior of a system or process and apply the same in automation and automatic control. Here, Students generate mathematical models of systems using differential equations and Laplace transform to obtain the transfer function and model in the state space.

MR2025 Design of Control Systems. In this intermediate mechatronics engineering course, students acquire knowledge of and develop skills to design automatic control systems based on the desired performance requirements. Students solve control problems that require process modeling based on continuous and discrete control.

MR2002B Analysis of Control Systems. This intermediate mechatronics engineering course focuses on modeling and analyzing open- and closed-loop dynamic systems. Students design, implement, and validate classical controllers for physics problems, considering the principles of stability and observability.

Additionally, to avoid the stubborn idea that technical knowledge alone can be used to identify and solve real-world problems, known as "technical instrumentalism" [1], theoretical classes are considered during the minor. Herein, the course schedule consists of the following ten units taught in 132 hours and are useful to cover critical aspects related to advanced control strategies real-time implementation:

Unit 1: Introduction to Control Systems. The student reviews contents from courses on classical control systems, focusing on mathematical and experimental modeling of first and second order systems, methods for stability analysis and design of compensators and PID controllers.

Unit 2. Introduction to State Space Representation. The student is introduced to dynamic systems analysis through state variables, learns to model a system with the state and output equations, and comprehends how the system's essential characteristics are described by the matrices and their canonical forms.

Unit 3. Design of Control Systems in State Space. The student takes the state-space representation of a system and learns to design a state-feedback regulatory controller and obtain a feedback gain matrix to achieve pole placement, while also learning to develop servo control.

Unit 4. Introduction to Model Predictive Control for Multivariable Processes. The student is introduced to predictive control and the concept of developing control strategies that can handle constraints, focusing on becoming familiar with the main concepts behind the strategy.

Unit 5. The Advantages of Model Predictive Control. The student begins to approach predictive systems and their applications from a theoretical perspective, starting to comprehend concepts as steps ahead and prediction horizons.

Unit 6. Ingredients of Model Predictive Control Design. The student acquires mathematical knowledge to approach MPC, beginning to analyze the characteristics of predictive systems in mathematical terms towards modeling and designing a predictive control system, while also being introduced to the concept of a cost function.

Unit 7. Model Predictive Control for Linear Time Invariant Systems. The student learns to develop the state-space model of LTI systems suitable for MPC and is shown how to formulate a cost function for a defined control objective and constraints.

Unit 8. Definition of the Control Law. The student becomes familiar with establishing control laws for reference tracking of both unconstrained and constrained systems, focusing on optimization problems and the design of cost functions.

Unit 9. Introduction to Nonlinear Control. The student is introduced to nonlinear systems and their differences with linear systems, while acquiring the theoretical and mathematical knowledge to approach the concept of linearization.

Unit 10. Control Design for Nonlinear Systems and Vision Systems. The student learns advanced techniques to solve nonlinear control problems, while developing theoretical and applied knowledge of vision systems for implementing inspection, recognition, and perception capabilities into autonomous systems.

Although textbook selection is closely tied to learning objectives for each course [4], it was difficult to find one that matches the needs of the students for the minor. This, considering that most control engineering books focus heavily either on linear systems or nonlinear processes. Furthermore, the books center very lightly on vision systems and signal processing for real-time implementation of control strategies. Therefore, professors provide the students with comprehensive lecture notes, which are part of their Editorial Digital Tec “Real-time control strategies implementation” future book. Recommended textbooks are: Ogata, K. Modern Control Engineering. 5th Edition, Pearson, 2010; Alamir, M. A Pragmatic Story of Model Predictive Control: Self Contained Algorithms and Case-studies. CreateSpace Independent Publishing Platform, 2013; and Khalil, H. K. Nonlinear Systems. 3rd Edition, Prentice Hall, 2002.

Materials and Methods

This section describes the first three phases of the minor implementation: lab equipment selection, assignments and assessments development, and challenge proposal. The goal is to create a match between theory and practice which helps the students to face real-world practical problems and projects. This is a challenging task for professors, further complicated because it must be accomplished using often limited resources and within very stringent time constraints of the already designed course [8].

Lab Equipment Selection

The initial step towards providing practical real experience for students corresponds to select an adequate and versatile laboratory facility, which became a valuable asset [17]. During the minor, the following Quanser® equipment is used for various experiments, while emphasizing on different facets of modelling and control engineering analysis:

Quanser® Qube Servo 3. This product was chosen considering that nowadays servo motors have been widely used in robotics, aerospace, home automation, and mobility devices due to their high closed-loop performance and reasonable cost [18][19][20]. The system is equipped with a high-quality direct drive brushed Direct Current (DC) motor, two encoders, an internal data acquisition system, and an amplifier, Figure 1. Then, it is supplied with two standard items:

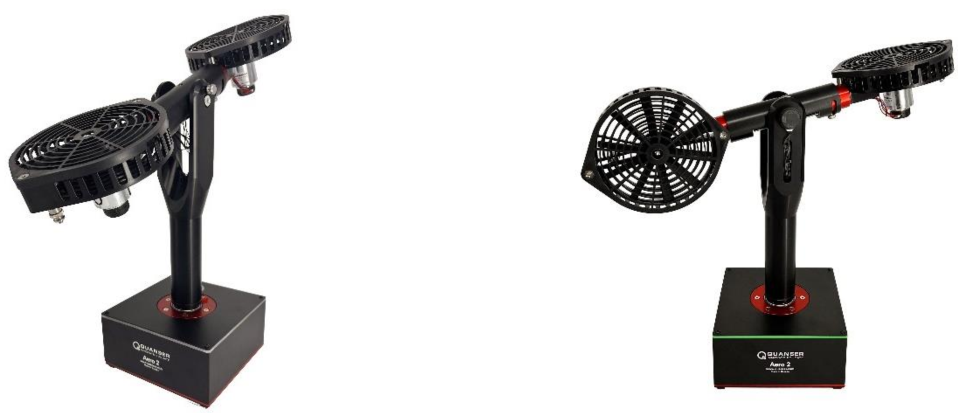
a) Interia disk. **b) Inverted pendulum.**

Figure 1. Quanser Qube Servo 3 consigurations [21].

Inertia disk. A small aluminum part is mounted to the equipment using magnets, Figure 1 a). It is one of the most used devices in mechatronics [22]. Here, using one encoder to measure the rotation of the DC motor's shaft itself, first, the students must obtain the velocity model. Then, they can determine constraints, degree of mobility and maneuverability of the DC motor for velocity and position control purpose using Real-Time Hardware-in the-Loop (HIL) Implementation Lab [23].

Inverted pendulum. The inverted pendulum is mounted to the equipment with magnets, Figure 1 b). The Furuta pendulum, is a mature and well-established system for designing controllers in different engineering areas such as transportation, military industry, space field, anti-seismic control of buildings and field robotics. Here, the encoder provides an additional sensor input to the system [24]. Then, the students must design a regulator control to preserve the vertical position of the rotatory inverted pendulum, mathematically and tested at the HIL implementation level.

Quanser® Aero 2. It is a fully integrated aerospace lab experiment. Here, two rotors provide thrust and allow users to safely control the device’s dynamic response. Furthermore, it has interchangeable propellers, user-adjustable thrust vectors, and the ability to lock axes individually to vary the Degree of Freedoms (DOF). Then, this equipment is capable of abstracting a variety of aerospace systems, such as:



a) 1-DOF VTOL (Vertical Take Of Landing), Half-quadrotor. **b) 2-DOF helicopter**

Figure 2. Quanser® Aero 2 configurations [21].

1-DOF VTOL. In Figure 2 a), the pitch axis is unlocked, and yaw axis is locked. Both rotors are horizontal.

Half-quadrotor. The pitch axis is locked, and yaw-axis is unlocked. Both rotors are horizontal, Fig 2 b).

2-DOF helicopter. In Figure 2 b), the rotors control the pitch and yaw dynamic response when axes are unlocked, 2-DOF.

Quanser QDrone 2. Two devices were acquired to implement advanced control strategies to fly a drone in automatic mode, Figure 3. They are equipped with a powerful on-board NVIDIA® Jetson Xavier™ NX system-on-module (SOM), multiple high-resolution cameras and built-in

WiFi. This open-architecture research-grade drone is tuned to accelerate innovation in multi-agent, artificial intelligence, machine learning, and vision-based applications.

Figure 3. Quanser® Aero 2 configurations [21].

Drone Studio Research Architecture. It is designed to provide key functionalities required for multi-vehicle research through a variety of customizable modules, Figure 4. Each module is powered by QUARC's communication framework. This enables researchers to build high-level applications and reconfigure low-level processes supported by prebuilt modules and libraries. Using these building blocks the student can explore topics in advanced flight control, machine vision, SLAM Visual Simultaneous Localization And Mapping, and autonomy.

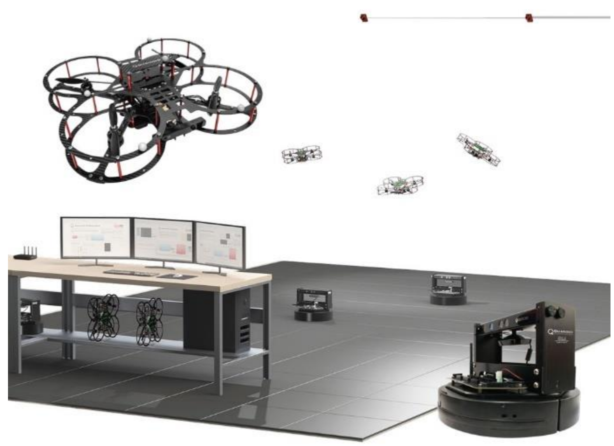


Figure 4. Quanser® Aero 2 configurations [W].

Then, once the equipment is acquired, Professors expressed that to implement and teach advanced control strategies using the equipment is a challenge and complex enterprise. This, due to the lack of: instructors and teaching assistants fully proficient in Quanser® technologies, and the appropriate handbook on the subject of the minor.

For the first concern, based on the material available on the Quanser® website, the leaders of the minor identified the practices needed to guarantee technical understanding. Then, in the 2024 winter and summer, a hands-on laboratory experience was carried out by the R&D Manager in charge of Academic Applications of Quanser®. Here, several faculty, staff and students gathered 14 times from 8:00 a.m. to 5:30 pm.

For the second concern, the Professors decided to develop their own material according to the minor curricula. This allows the student to get the opportunity to apply as many of the concepts presented in the theoretical and lecture portions of the course, acquiring hands-on experience and receiving training in practical aspects [8].

Assignments and Assessments

Once the new facility was supplemented by workshops with fully rendered high-fidelity experiences on Quanser® labs [5], the development of assignments and assessments became the first task of the Professors [25]. Here, an assignment is defined as a student task set by the instructor that both teaches students and tests their learning in a specific control topic. Meanwhile, the assessment involves a group of topics designed to provide frequent feedback Here, students doubts are not allowed; this helps to inform and improve teaching and learning students' progress. Then, the assignments and assessments serve as part of the individual evaluation process of the student.

Henceforth, considering the student learning outcomes previously presented, the Professors develop twelve assignments, and three assessments. Additionally, these were assessed to demonstrate that the proposed curriculum meets ABET criteria. The Accreditation Board for Engineering and Technology oversees accreditation of academic programs to ensure that it meets the quality standards to prepare graduates for their respective profession. The third ABET criterion focuses on program outcomes, these being skills, knowledge, and abilities that students are expected to acquire through the program. Here, the program must demonstrate through evaluation that the outcomes can be attained by the students completing the course, ensuring that they acquire competencies required for the professional field. The outcomes evaluated in engineering courses are the following:

A. An ability to apply knowledge of mathematics, science, and engineering.
B. An ability to design and conduct experiments, as well as to analyze and interpret data.
C. An ability to design a system, component, or process to meet desired needs.
D. An ability to function on multidisciplinary teams.
E. An ability to identify, formulate, and solve engineering problems.
F. An understanding of professional and ethical responsibility.
G. An ability to communicate effectively.
H. The broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
I. A recognition of the need for, and an ability to engage in life-long learning.
J. A knowledge of contemporary issues.
K. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Based on the criterion, both assignments and assessments were assessed to map the outcomes that can be attained by the students through completing each laboratory practice. The assignments, assessments and outcomes are mapped in Table 1:

Table 1. Activities mapped by ABET criterion.

Laboratory Practices		**Outcomes**										
		A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*
P01. Mathematical Modelling of DC Motor Velocity		✓	✓					✓				✓
P02. Step Response Modeling		✓	✓					✓				✓
P03. Second Order System		✓	✓					✓				✓
P04. Stability Analysis		✓	✓					✓				✓
P05. Compensator		✓	✓	✓				✓				✓
P6. Design of PID Controllers	Part A. Motor Position Control - PV Control Strategy	✓	✓	✓				✓				✓
	Part B. Motor Velocity Control - I+P Control Strategy	✓	✓	✓				✓				✓
Case Study: AV´s: a catalyst for urban transportation	Assessment I.					✓			✓	✓	✓	✓
	Assessment I A. Design of steering angle control	✓	✓			✓		✓			✓	✓
	Assessment I B. Design of speed control	✓	✓			✓		✓			✓	✓
P07. PID Pitch Control for Aero		✓	✓	✓				✓				✓
P08. Cascade Pitch Control for Aero	Assessment II A. Rotor Speed Modelling	✓	✓					✓				✓
	Assessment II B. Rotor Speed Control	✓	✓	✓				✓				✓
	Assessment III. PIV Control Design	✓	✓	✓				✓				✓
P09. State Feedback Gain Matrix	Part A. State Space Modeling	✓	✓					✓				✓
	Part B. Regulator Control Design	✓	✓	✓				✓				✓
P10. Modelling & Parameter Estimation for Helicopter	Introduction.	✓										
	Part A. Pitch from Pitch	✓	✓					✓				✓
	Part B. Pitch from Yaw	✓	✓					✓				✓
	Part C. Yaw from Yaw	✓	✓					✓				✓
	Part D. Yaw from Pitch	✓	✓					✓				✓
P11. PD Control for Helicopter		✓	✓	✓				✓				✓
P12. LQR Control for Helicopter		✓	✓	✓				✓				✓
Challenge		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓

Laboratory Equipment:
Inertial Disk   Inverted Pendulum   1–DOF VTOL   2–DOF Heli.   QDrone2

Moreover, suggested activities are also performed. Even though they are not normally graded, they do provide also valuable feedback for instructors regarding student learning [25].

Challenge and Course Implementation

Once the Professors restructured existing courses from Quanser®, developing new assignments and assessments, the next step was to determine the challenge of the minor, performed in 268 hours. This, considering that Tec21 Model works under the challenge-based learning.

Then, working very closely with industry representatives, and attending the national industry needs, the Professors proposed the challenge entitled: “Advanced control strategies in UAV’s for fuel theft detection in Mexico”. This, considering that nowadays, in Mexico the fuel theft is endemic and widespread [26] and it costs close to $2 billion USD per year [27][28]. For this reason, to guarantee Mexico’s energy security, the students must use the drones to detect illegal taps. More specifically, at the end of the minor the learners must:

a) Design advanced control strategies to flight a drone in automatic mode
b) Implement the control system in flight conditions to face external disturbances.
c) Develop case studies in which illegal taps can be detected.

Henceforth, to empower students to use the Drone Studio Research Architecture, the Professors develop lab practices along the following three stages:

Stage 0. Introduction of vehicle dynamics and control. Here, the student be familiar with the main variables involved in the kinematics and dynamics for the system model, including the electronic components as brushless motors.

Activity 0.1: Review the state space model of the drone.

Stage 1. Understand the main concepts of Drone Studio. Here, using the vision system, the student learns how to monitor the drone during automatic mode flight.

Activity 1.1: Camera localization (calibration and rigid body configuration)
Activity 1.2: Data streaming (send and receive data between a basic server client network)
Activity 1.3: Real – time control for flight in automatic mode (i.e, complete mission server to fight the drone in hover position)

Stage 2. Development of activities related to the path/waypoints following drone control. Here, the students become familiar with the generation and command of different types of trajectories. Additionally, the student be able to analyze in detail concepts such as signal processing, logical decision making and state machines.

Activity 2.1: Trajectory command (give basic waypoint or trajectory signals)
Activity 2.2: State machines to fly the drone in real – time.

To develop the challenge, the students are asked to make teams and collaborate with their team members [8]. Therefore, considering assignments provide the raw material for assessment [25], and the students acquired a deep understanding of the drone studio, the complete minor implementation is described in the roadmap shown in Figure 5.

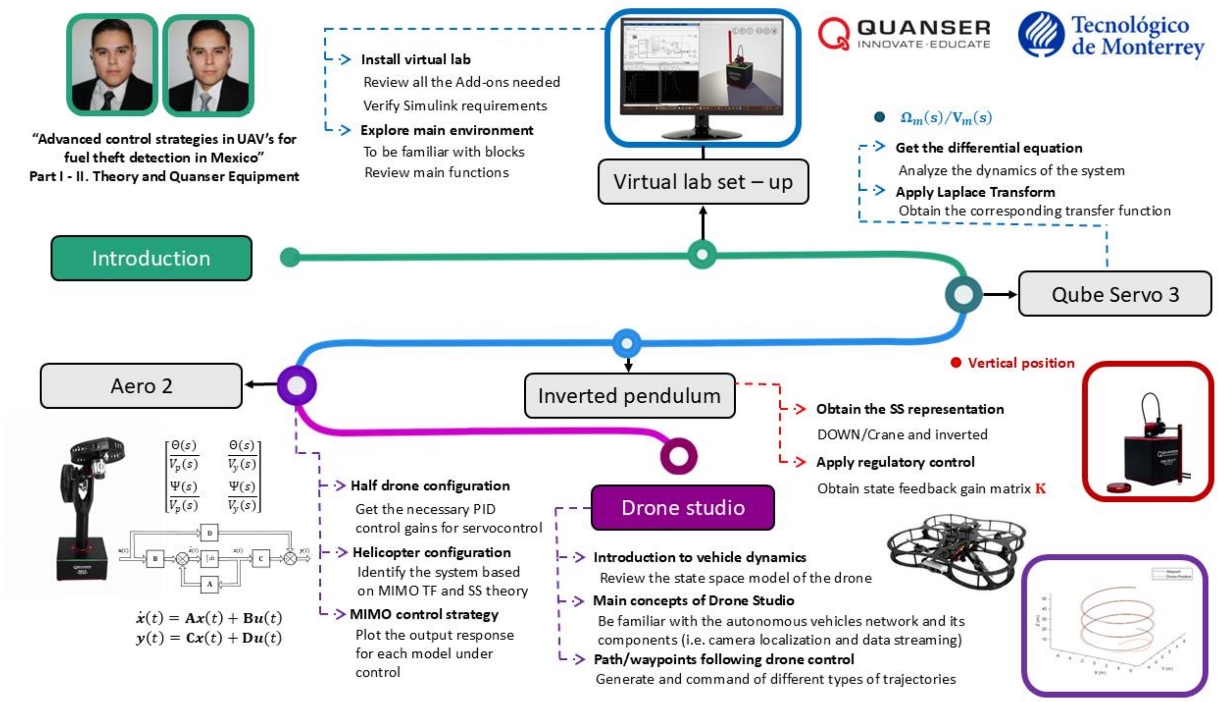


Figure 5. Roadmap implementation for the unmanned aerial vehicles academic minor.

For the final presentation, a proper rubric evaluation is created by the Professors, linking student learning outcomes with the challenge. Moreover, a concise written report is required within five days after completion of the minor [7].

Development of Advanced Control Laboratory

A technical understanding of control systems, underscored by hands-on laboratory experience, is important for control engineering students. There, a further motivation to develop the minor was that the Professors could use a complete lab space provided by the Mechatronics Department, Figure 6. Previously, the space was used either to eventually carry out lab practices using outdated equipment or to have meetings of the Professors.

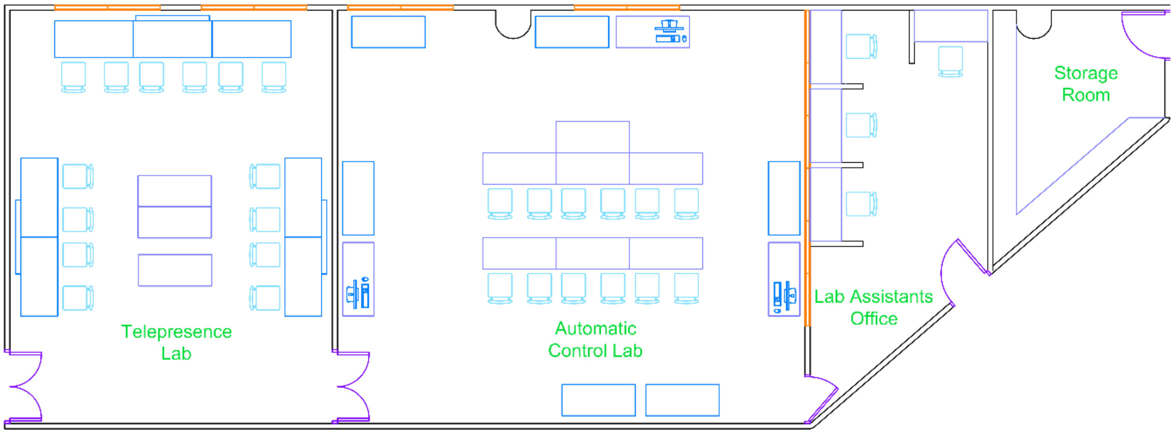


Figure 6. Previous Mechatronics control lab.

Then, considering that the professors developed not only lab-based activities but also proposed a challenge for the minor, the lab space was redistributed, Fig. G. Here, students can be closely monitored and assessed [7].

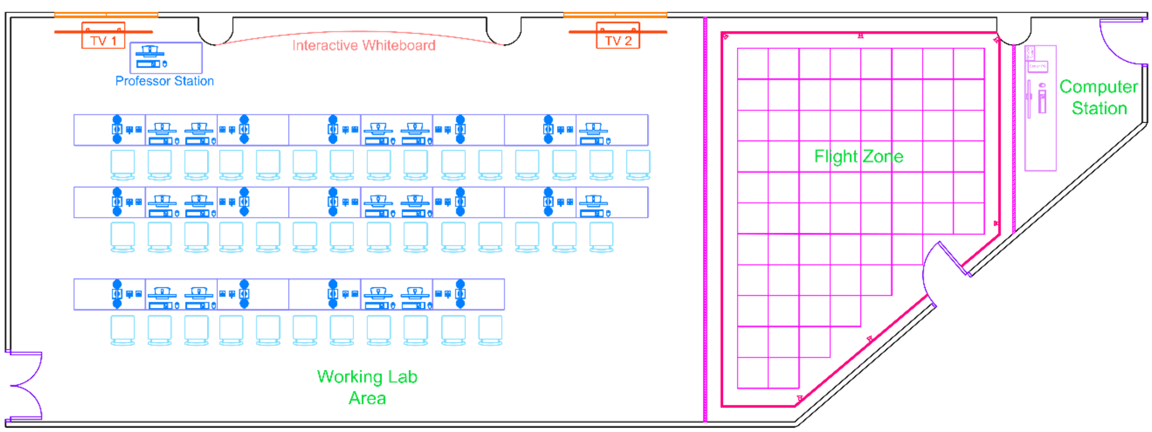


Figure 7. Current Mechatronics control lab.

The overall lab consists of the flight zone, and the working lab area. In the flight zone, the drone studio is mounted, there exists: a computer station with high performance, six OptiTrack cameras for real-time monitoring purposes, and two drones, all of them protected by mats and nets. Similarly, in the working lab area, there are fourteen stations. Each station has a computer, two Qube Servo 3 devices, and one Aereo 2 equipment, Figure 8. This lab is funded by the university and set up by the leaders of the minor with his Master student. Moreover, all the virtual labs are provided by Quanser®. Here, simulation-based learning facilitates experiential learning and allows students to make time-based decisions with repercussions from errors in a controlled environment [5].

Figure 8. Working lab station.

Conclusions

This paper presents in detail the design, development and implementation of the academic minor entitled autonomy of unmanned aerial vehicles. The proposed course is offered in Tecnológico de Monterrey, México by Mecatronics Department for engineering students, who are enrolled in the new educative Tec21 Model. Hence, during their specialization stage of the bachelor, they can learn and implement concepts related to control engineering education. The assignments, assessments and challenge are carefully designed to guarantee that students acquire disciplinary and transversal competencies. In addition, working with Quanser® company, leader in engineering education, the activities are mapped according to ABET criterion. The most concerning part of the Professors involved in the design was the selection of adequate lab equipment. The most heartening part of the design process was the deep interest and support from the university administration. Based on this, a new well-equipped Quanser® laboratory with fourteen working lab stations and flight zone is performed. Then, at the end of the course, the students have an experiential learning where the real-time implementation of control strategies is useful to bring theory closer to practice. In coming years, the use of augmented reality based on animated characters already created will be considered, and the department will monitor the success of the program through alumni surveys and feedback.

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