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QuadLab
A Project-Based Learning Toolkit for Automation and Robotics Engineering Education

David Fernando Zapata García · Mario Andrei Garzón Oviedo · Joäo Ricardo Pereira Valente · Antonio Barrientos

Abstract It is frequently claimed that the students must have an active role in building and transforming their own knowledge, and the teacher's labor is to provide the students the necessary tools in order to reach specific learning objectives, included in a course program. This paper presents an aerial robotic system as a toolkit, and proposes a series of activities focused on the learning in automation and robotics. These proposed activities have been designed based upon the project-based learning methodology, and they facilitate the achievement of the learning objectives presented by *Spanish automation committee*(CEA) in conjunction with *The International Society of Automation* (ISA) to satisfy the *Accreditation Board for Engineering and Technology* (ABET) standard. The toolkit and the activities are oriented to impulse the practical teaching, giving the student additional motivation and, in consequence, improving his or her active role. Besides, the toolkit and the activities give the teacher a tool in which it is possible to assess the students learning process.

Keywords Aerial robotic platform · Practical teaching · Project-based learning · ABET

D. F. Zapata García (✉) · M. A. Garzón Oviedo · A. Barrientos
Centro De Automática y Robótica, UPM-CSIC, Universidad Politécnica de Madrid, Calle José Gutiérrez Abascal, 2., 28006, Madrid, Spain
e-mail: david.zapata@etsii.upm.es

M. A. Garzón Oviedo
e-mail: ma.garzon@upm.es

A. Barrientos
e-mail: antonio.barrientos@upm.es

J. R. Pereira Valente
Department of Systems Engineering and Automation, Universidad Carlos III de Madrid, Av. Universidad, 30, Leganés(Madrid), 28911, Spain
e-mail: jvalente@ing.uc3m.es

1 Introduction

Due to the rapid dissemination and interest in mini Unmanned Aerial Vehicles (MUAV) that have been observed in the last few years, the number of students that show interest in working in related fields is increasing. However, most of them are undergraduate students, who usually do a short-term stay in the research groups, no longer than an academic semester in most cases at our institution.

Working with MUAVs implies that the student must understand the vehicle principles, how to steer it when working on manual mode, also how to send and receive data and commands to the vehicle and finally how to set up the system and perform maintenance. Learning and acquiring expertise in those tasks is often very laborious and requires a lot of time since the students have to overcome many problems during the learning process.

In order to optimize the work performed by those students, the objective of this work is to present a series of activities focused on the learning in automation and robotics based on the use of an aerial robotic system. This proposed aerial system is oriented to give support in the automation and robotics (AR) engineering program at our institution, providing both, students and teachers with a toolkit and a set of activities that are able to complement the necessary knowledge to reach international standards proficiencies in engineering education.

These proposed activities have been designed based upon the project-based learning methodology, following the model suggested by the Northwest Regional Educational Laboratory [17]; and at the same time, those activities meet the competences presented by CEA/ISA [4] and the international standard ABET [1].

Project-based learning (PBL), in addition to its systemic nature and ability to work both with vertical skills (in our case control, computer technology, electronics -in many of its fields-) and horizontal (teamwork, ability to design experiments, design capacity, creativity, multidisciplinary skills, use of generic resources engineering, planning work), fits well into the design of this learning platform, since this toolkit is divided into small problems or projects that come together to be part of a real application.

Furthermore, the proposals are fully open to be adapted by the teacher to the knowledge or skills in which it is desired to emphasize, either by the type of discipline to be targeted or the level of complexity required, as of course, the student must have cognitive foundations that give a starting point to explore possible solutions. This kind of flexibility in the formulation of the problem requires the platform to be modular, so the teacher can include or omit information that he or she gives to the student.

The aerial robot is a low-cost and open-source integrated system with sensors of different types, and with the ability to add others, this means having a multidisciplinary system that can have real application in different fields, such as electronics, embedded systems, control, aeronautics, and robotics. The system is exposed to variations in its environment like noise and perturbations; this makes the student to deal with an additional complexity that makes a clear difference between the theoretical concepts and real world. Also, the toolkit treated as a whole system presents a high complexity, but treated as subsystems, the complexity may vary. This allows a wide range of difficulty in the proposed practices, ranging from simple (e.g. linear mono variable) to the study of the whole system. It is also a system that can be approached from different areas of knowledge. As a low-cost system, it has a very good relationship between cost and performance; this makes it easy for inexperienced users to gain experience without significant economic consequences, and to face these platforms with greater confidence. The type of the system used is highly attractive to new users, as it is a product that uses the latest technology for both academic and entertainment applications, and their commercialization has been increasing in recent years. Being an air system that does not require a fixed base station means the students can perform all activities in different geographical areas, eliminating the space and time constraints inherent to traditional methods, likewise promoting outdoor engineering practices.

Finally, the aerial robotic system can be used in various real applications. This brings the student to a training oriented to its future professional activities. It is necessary that the proposed activities will allow the student to respond to the challenges posed to national and international level in the training of engineers. This can be ensured through the application of standards and norms. It is also necessary to have an integrated modular system, such as the activity that the user addressing is not disrupted by obstacles of a technical or management of additional tools necessary for the development of the practice.

This paper is distributed as follows: first, Section 2 presents related educational projects in AR engineering field. Then, Section 3 establishes the framework in which *QuadLab* is used in the learning process, as well as the definition of the scope in the methodology and standards. Afterward, Section 4 describes the aerial platform and Section 5 exposes the toolkit, describing all elements and showing how it could be used. Finally, after knowing how *QuadLab* works and defining the methodology to be used and the standards to be met, Section 6 suggests a series of projects that could be developed with *QuadLab* and shows how those projects encompass the learning objectives.

2 Related Educational Projects

The availability of practical courses and practices during the formation of an AR engineering student are important to gain experience and understanding of the real systems. It is therefore, the way as pedagogues establish a bridge between the theoretical foundations of autonomous systems and their realistic assessment. Many universities and educational centers made an effort to provide such components and systems in different contexts and backgrounds, ranging from classroom, laboratories or contests to related initiatives.

Nowadays, many AR engineering courses are programmed to be lectured both in classroom and laboratories. Probably, the most common case are control system courses. Herein, the students have the opportunity to study dynamics and control through miniaturized process plants, simulations, or other simplified system built to this end, e.g., [9, 12, 19, 21]. A good overview about three different control laboratories approaches is also given in [13].

The PBL methodology is also applied in the AR engineering training. For instance, courses using Lego Mindstorms robots as a training platform are reported [5, 15], project-learning through robotic contests can also be found in [2, 8, 20].

Regarding to teaching with aerial vehicles, there is not too much work found about it. In [11] it is studied a low-cost aerial system for study and research purposes, but without any methodology. Also the MUAV team from the University of Applied Sciences Technikum Wien in their work [10] expose an autonomous airplane used to teach electronics and control theory where the goal for the students is to build an aircraft from scratch.

The work proposed here can be distinguished from the related projects in several aspects. First, by having a toolkit and a series of activities that are based on two different standards for education in engineering (EC2000 criteria and CEA/ISA competences), and combining those with the project-based learning approach, which help to increase the quality of the laboratory practices and at the same time allows to cover a wider range of items from the requirements established by the standards.

Another difference is the fact that the proposed activities not only use a very well known and affordable platform but it offers the possibility of performing changes in the hardware and software. This allows the student to start from an functional base, which he or she can use to observe and study several behaviors without requiring deep knowledge of the platform. Also, errors or unexpected misbehaviors that may appear when working with systems built from scratch are avoided. However, the since platform is not closed, the proposed toolkit allows the student to modify both its hardware and software.

It is important to remark that this work does not present teaching experiences, since carrying out this experiencestakes relatively a lot of time in implementing and comparing, but we have this in mind for future work.

Finally, for the best of our knowledge, our work is one of the first to contribute with a novel understanding and use of mini quad-rotors for education purposes, which can be very interesting for students and therefore result in an extra motivation for developing the practices. We believe that is a step forward to the future of AR engineering students.

3 Learning Elements

This section exposes the basic course learning elements and then describes how this work is part of it. First it is fundamental to describe how the courses are designed; Felder and Brent [6] describe three general domains to be covered: *Planing*, *Instruction* and *assessment*. Planing is about to identify and define the learning objectives, Instruction is the way or methods that help the student to reach the learning objectives, and assessment refers to the procedure of determining how well the methods lead to a successful achievement of the learning objectives.

In order to put *QuadLab* into this scheme, there must be characterized each element described before. The first step is to define the planing, for this work the learning objectives are given by CEA/ISA, then for achieving these learning objectives it is necessary an instruction or methodology, and here is where the PBL makes use of the robotic platform to address the learning process. Finally, it is necessary to assess how well the learn objectives are achieved by the student. This assess closes the learning cycle, producing a continuous improvement by giving feedback to the methodology and suggesting if the instructions need to be modified in order to obtain a better achievement of the learning objectives. The assessment, although is an important part in the learning cycle, it is not part of the scope of this work. However, as good evaluation tools that fit well into the PBL and therefore this toolkit, there are: Portfolios, written project reports, oral presentations, memos, interviews, concept maps, among others. The use of multiple assessment methods improves the evaluation results [6], and also the student could do a better self-evaluation, team-evaluation and methodology evaluation. At this point it is important to remark that the toolkit is not strictly linked to the PBL methodology or CEA/ISA learning objectives. The toolkit is totally open to modifications and could be used with other methodologies such as cooperative learning or traditional laboratory (where all the activities are pre-established).

3.1 Project-Based Learning

Project-Based Learning is an alternative to traditional methods of teaching, based on the comprehensive development of a project. This project will aim to solve a problem posed by teacher and requires that the student finds resources and then develop activities to solve the problem. This type of training potentiates the binding between *knowing and doing*, as students should address the concepts as they are required for project execution.

Mills et al. [14] make the distinction between the terms *project* and *problem*. PBL typically takes more time to complete, besides they are more focused on the application of knowledge, and Problem-based learning to acquire knowledge. Engineering projects in the short term may require a single area of engineering, but the long-term projects require multiple areas and composition of groups with individuals specialized in different areas. As it can be seen, the projects are more related to a professional environment, increasing social skills, such as cooperative learning.

3.2 Standards for Education in Engineering

Two main standards have been studied, the first one is known as *Engineering Criteria 2000* or EC2000. It has been crafted by the Accreditation Board for Engineering and Technology (ABET) [1] as the criteria that should be assessed by the engineering programs in order to obtain the accreditation. The EC2000 specifies 11 learning outcomes, oriented to both technical and professional skills, the list of outcomes is presented in Table 1.

The second standard was developed by the Spanish Committee for Automation (*Comité español de automática* - CEA) in cooperation with the International Society of Automation (ISA). They have elaborated a document outlining the competences that an student of the technical Industrial Engineering degree should acquire to fulfill the industry requirements regarding the automation and control area [4].

The reason for selecting those two standards is as follows: The EC2000 is probably the most widely used criteria for international accreditation in engineering programs, therefore its relevance is without question. Nevertheless, the outcomes that are pointed

Table 1 List of learning outcomes required by the EC2000 criteria

	EC2000 learning Outcomes
a	An ability to apply knowledge of mathematics, science, and engineering.
b	An ability to design and conduct experiments, as well as to analyse and interpret data.
c	An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
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.

Table 2 Relationship between CEA/ISA competences and EC2000 outcomes

	CEA/ISA Competences	EC2000 Outcomes
A	Knowledge about fundamentals of automation and control methods	a, e
B	Knowledge and skills for modelling and simulation of systems	b, e
C	Knowledge on automatic regulation and control techniques and their applications in industrial automation	a, b, k
D	Knowledge of the principles and applications of robotic systems	a, e, k, d
E	Applied knowledge of industrial informatics and communications	b, e,
F	Capability to design control and industrial automation systems	b, k, c

out by that criteria are very generalist making it more difficult to use them as a direct criteria to propose a laboratory project. The CEA/ISA guidelines are mainly known and used in Spain, but, in contrast with the EC2000, those proposed competences are much more specific and punctual, and they are directly oriented towards the learning of automation and control. This allows to target these competences in a more direct way using laboratory activities.

However, the best results will be obtained if both criteria are aligned, in order to do so, an relationship between the competences of CEA/ISA and the required outcomes pointed out by ABET must be studied. The result obtained will be highly helpful for the efficient design of the activities proposed in Section 6.

Table 2 shows the relationship between the competences from the CEA/ISA guidelines and the outcomes required by the EC2000 criteria. As it can be observed, the fulfilling of each CEA/ISA competence can help obtaining one or more of the EC2000 outcomes. Since the CEA/ISA competences have a technical focus, even if all of them are obtained, not all of the EC2000 outcomes will be covered, specifically the points *f,g,h,i,j*. This points however can be partially approached using complementary methodology such as team work, documentation, evaluation and oral presentation of the work carried out by the student as well as the results and conclusions that they can obtain from it. It should also be pointed out that the relationship may be subjective and depends on the specific objectives that may be proposed in each project or activity. Moreover each CEA/ISA is subdivided in several points, and the laboratories can only target some of those points.

Another relationship between EC2000 and CEA/ISA can be established by complementing the work of Ma y Nickerson [13]. In that work, 60 articles related with laboratory practices, are analysed and the result is a four-dimensional goal model for laboratory education and finally, the EC2000 educational outcomes are consolidated into those four goals. This work builds on that, by also framing the CEA/ISA competences into those four educational goals. Having this, it is possible to obtain an indirect relationship between the two standards, which is based on some well defined laboratory goals.

This relationship is clarified in the Table 3 where the laboratory goals are specified, also the EC2000 outcomes and CEA/ISA competences that can correspond to those goals are marked.

From Table 3 it can be observed that the social skills are the less covered of the four goals being directly targeted by only one of the EC2000 outcomes and by none of the CEA/ISA competences, which can be expected because the later standard is focused on the technical skills.

Regarding the relationship between the two standards, it can be observed that several CEA/ISA competences can be related to each laboratory goal, while the EC2000 outcomes have a more direct relationship with the goals. This is explained because the CEA/ISA competences are more "*vertical*" in the sense that they are designed to cover several skills, while the EC2000 has an more "*horizontal*" approach, meaning that they relate more directly to any of the required skills.

It should also be pointed out that not all EC2000 outcomes can be targeted using practical learning. Moreover, the items *a,b,d,e,k* can be more directly covered using laboratory practices such as the proposed in this work. Also, and the mentioned set of items can be correlated with the "*hard*" learning objectives mentioned by Shuman et al. [18] which are

Table 3 Laboratory goals and standards for educations

Laboratory goals	Description	EC2000 outcomes	CEA/ISA competences
Conceptual understanding	Extent to which laboratory activities help students understand and solve problems related to key concepts taught in the classroom	a	A, C, F
Design skills	Extent to which laboratory activities increases students ability to solve open-ended problems through the design and construction of new artifacts or processes	b, e	B, D, E, F
Social skills	Extent to which students learn how to productively perform engineering-related activities in groups	d	-
Professional skills	Extent to which students become familiar with the technical skills they will be expected to have when practicing in the profession	b, k	D, E, F

more focused on the technical aspects of the engineering learning, in contrast with the "*soft*" or "*professional*" skills. The CEA/ISA competences on the other hand, can be directly targeted with the practical learning approach, because the laboratories can be designed to cover any of the required competences. The social skills, which are not directly related with the CEA/ISA competences, can be covered by the project-based learning approach which integrates several requirements that can help complementing this areas.

As result of this study it can be said that the EC2000 outcomes and the CEA/ISA competences can complement themselves, and the design of laboratory practices, taking as reference both standards as well as the project-based learning can effectively result in a more complete training.

4 Robotic Platform *QuadLab*

The aerial platform base kit involves two mainly parts, the MUAV and the ground station control (GCS). The MUAV used to this laboratory is a quad-rotor type because of its stability, safety and controllability; The model adopted is a low cost AR.Drone Parrot.

As a commercial project, issues like price, safety, ease of use and repair are very important, and with the quad-rotor inherited characteristics, fit accurately in academia. Seeing that it is easy to use and designed for a mass audience, does not require the students to have any experience, and that somehow generates confidence regarding security concerns.

All these features and its high stability make obvious that the student will be more focused on the objectives for practice and have not to worry in deep about technical issues (low-level control, communication drivers, data acquisition) or different from those that are required for the preparation of laboratory activity. This section gives a review of both hardware and software *QuadLab* components. For more detailed information about the whole system refer to [22].

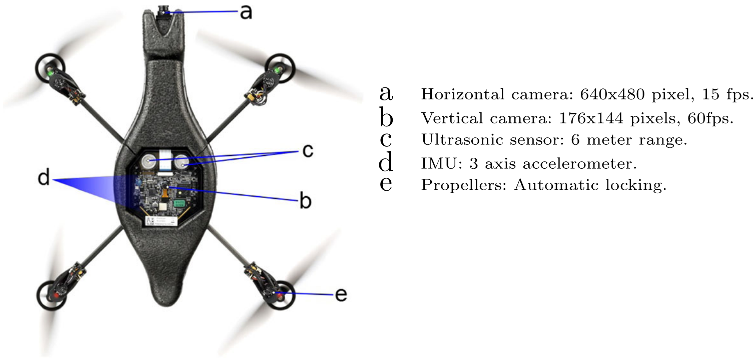
4.1 Mini-UAV

The MUAV can fly at a maximum speed of 18 meters per second and a fly autonomy near to 12 minutes. Its on-board computer system is a processor ARM9 RISC 32-bit 468 MHz with 128 MB DDR RAM memory, Linux OS, and it is communicated using a Wi-Fi ad-hoc connection, through UDP/TCP ports, the MUAV sends navigation data, status, and the images captured by the cameras, and receives control commands and configuration parameters. Figure 1 shows the basic information about the hardware on board the MUAV. For more details, refer to [3].

4.2 Enhanced System

An electronic circuit has been added in order to improve the MUAV capabilities, expanding the number of applications and providing more controllability and robustness to the MUAV, as well as the capacity to add more advanced laboratories. This circuit was designed to collect data from one (or multiple) external sensor (e.g. a GPS and/or an altimeter) and send them to GSC through a wireless connection.

Fig. 1 AR.Drone hardware. **a** Horizontal camera: 640x480 pixel, 15 fps. **b** Vertical camera: 176x144 pixels, 60fps. **c** Ultrasonic sensor: 6 meter range. **d** IMU: 3 axis accelerometer. **e** Propellers: Automatic locking



The final MUAV has been endowed with an external wireless GPS system, which adds location information (latitude, longitude and altitude). The addition of a GPS allows knowing the absolute position and programming the MUAV to return to base (taking advantage of the MUAV's automatic taking off and landing features), among others capabilities. Figure 2 shows two different prototypes of enhanced MUAVs, using different brands of GPS. In order to have the drone weight between the original range, the hull is removed.

Figure 3 shows the final configuration of the aerial platform; In the marked *UAV* box are the hole AR.drone system and the additional plug-in mentioned, that comprises GPS and communication unit (e.g. XBee wireless modules). The GSC box contains another communication unit (which is paired with the one in the MUAV). This unit sends all information in transparent mode to a software application, who collect data and integrates all the telemetry of the MUAV and works as a user interface.

4.3 Ground Control Station

Besides the MUAV itself, the robotic platform must have a GCS which works not only as the interface between the MUAV and the operator, but also as a data collector for analysis or study purposes. The design of the GCS implies essentially two modules, one to communicate with the MUAV (send, receive and collect data) and another module to communicate with the user (i.e. graphical user interface GUI). It is evident that both modules are necessary in order to use the robotic platform, but the level of complexity of each one depends of the target that will be presented to the student. The fact that there could be different levels of complexity gives the teacher the flexibility to manage the difficulty of the assignments.

In order to establish communication with the AR.Drone, there is a software development kit (SDK) provided by Parrot. The AR.drone SDK also features pattern recognition and tracking. Despite being very basic, these features are useful to develop new control algorithms.

This tool is oriented to game developers so the use of the SDK requires high skills in programming. This could be a disadvantage specially for new students. Looking forward for a more friendly framework, ease of use and with more graphical tools (thinking in the GUI), this work takes advantage of *QT*, a modular, cross-platform and adaptable application framework that fits very well the BPL.

Fig. 2 MUAV prototypes used in the development of practices. **a** Prototype 1. **b** Prototype 2

(a) Prototype 1 (b) Prototype 2

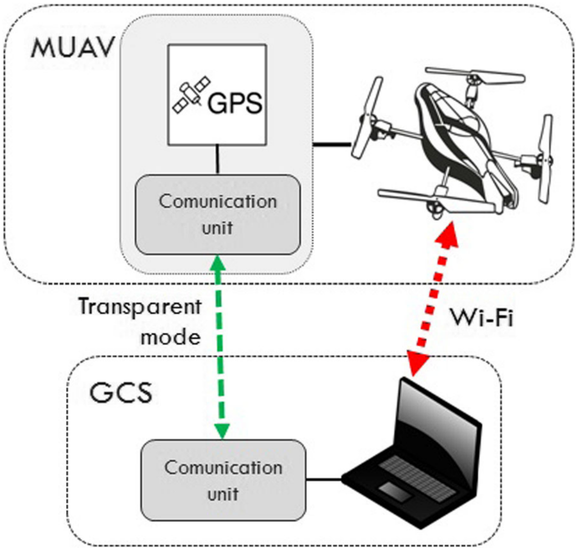


Fig. 3 Overall system diagram

Figure 4 shows the GCS's software architecture of *QuadLab*. The central module (box) is the core or main process and each surrounding module represents a thread or service. This implies that each service could be enabled or disabled. The main process is closely tied to the GUI and is in charge of manage all the information. Then, there are four modules providing all the interface with the MUAV (dotted line arrows), the "AT commands" module serves as the channel to send all information to the MUAV (i.e. configuration data and flying commands), then The "video", "telemetry" and "configuration" are only reading modules.

The manual control module permits to connect an input device as a gamepad for free flying or to take control in case the automatic control does not work correctly. In the automatic control service there can be implemented and configured algorithms or rules for autonomous navigation. Above the "AT commands" that serve as an interface for sending datagrams to MUAV command module was introduced, is important to clarify that this module does generate the datagrams from the control information that comes from Manual or Automatic control modules.

The "ROS node" module is a special feature that makes possible the integration with external robotic systems. It is based on ROS, an open-source modular framework that help to design complex and efficient robotic systems. The code is maintained by an extended international community and can also be re-used [16].

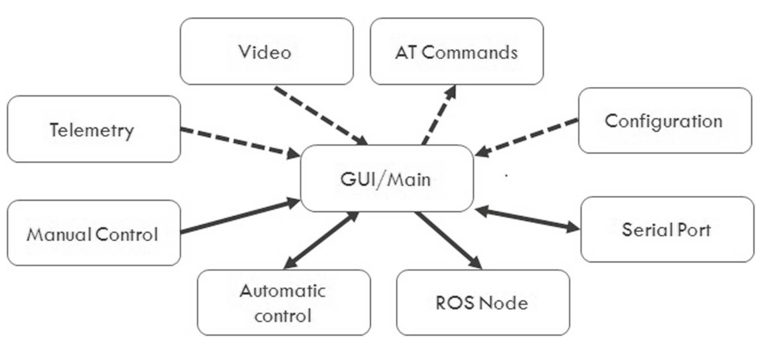
ROS has a message-passing philosophy, which means that each individual ROS package created is able to publish and to subscribe messages of different types, such as commands or sensor reading. In a ROS-based system it is also possible to enable communication between nodes running on different computers [7].

4.4 Graphical Interface

A graphical interface was made for helping out the development of the different activities proposed (Section 6). For that reason, this interface is modular, scalable and totally open (Fig. 5). Figure 6 shows two different possibles user-interfaces, as it can be seen it is possible to add, modify or remove different types of elements. Those elements will be explained next.

There are three mainly areas in the interface: video area that shows images from cameras; status area when the nautical angles are showed, battery and connection status and emergency stop; and finally the tab area that comprises:

Fig. 4 GCS software architecture



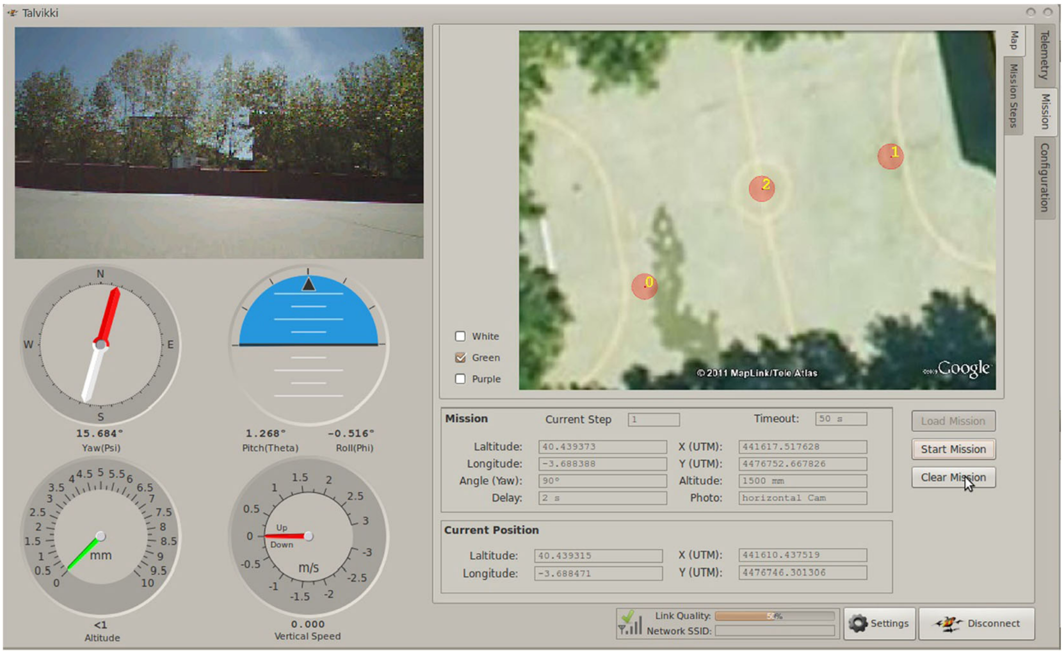


Fig. 5 Mission interface

- The telemetry tab, shows all navigation data above mentioned. In this tab it is showed when the system sets an alarm and what type of alarm occurs. It also has a special box for system identification, PID parameters for automatic flying and vision telemetry which is activated when the front camera detect one of the predefined patterns, these features are used in the activity 5.2.
- The mission control tab, shows everything related to way-points navigation (Fig. 5). It shows the current coordinates of the MUAV, then shows information about the current waypoint (target coordinates, altitude and angle), and finally shows graphically over a georeferenced map, the complete set of waypoints (a.k.a. mission) and the MUAV's current position. All the waypoints and configuration about the mission is introduced to the GUI by a XML file, this tab was designed for the activity 5.3.
- The configuration tab, has in it some tools for supporting the learning process, including reading of internal parameters of the AR.drone, sending specific PWM value to each motor, managing of serial port, exporting KML file (for view the mission in Google Earth), coordinates converter, among others.

There is a file system associated to the GCS, in which is stored all the flying data, the captured images, the maps and the mission files (XML file mentioned above), besides the source code.

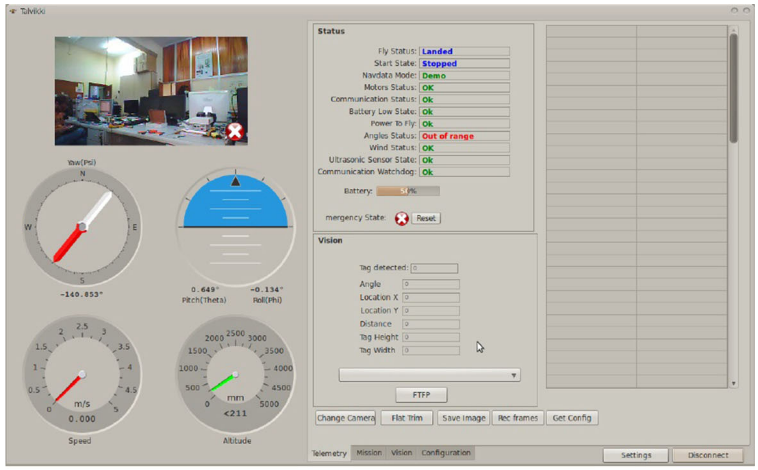
5 Toolkits

This section shows how the designed robotic platform could be used by mean of solving small projects (for more technical information refer to [22]), which will be proposed in the next section as projects for the students to solve. Once more it is remarkable that those activities are open to modifications, as well as there is more than one way to suggest and solve each activity.

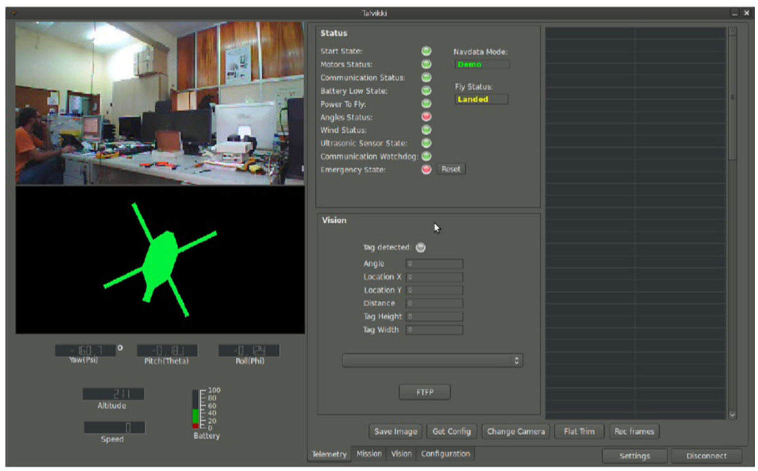
5.1 System Identification

For this practice, it has been used a simple AR.Drone model structure (Fig. 7) based in the presented model by Krajník et al. [11]. Taking into account that the AR.Drone's internal control guarantees the output angles and vertical speed, this model takes as inputs

Fig. 6 Different developed interfaces. **a** Interface 1. **b** Interface 2



(a) Interface 1



(b) Interface 2

the pitch and roll reference angles as well as yaw and vertical reference speeds, and as a outputs the pitch, roll and yaw angles, the altitude and x and y axes speeds. Also it is considered that movement on each axis is independent of the others axis (e.g. x-axis movement only is affected by the pitch angle).

This work only presents system identification of the forward-backward movement (blue shadow in Fig. 7) since it is the same procedure for the other movements. The first step is to give the MUAV an input sequence and then read the *log* file for the system responses. Using a time series model (e.g. ARMAX) it is possibly then to estimate a valid model for the system, Fig. 8 shows the step response of the real system and the estimated model.

5.2 Pattern Tracking

The idea of this activity is, using the frontal camera and the drone's internal pattern recognition system, the MUAV has to recognize one of the patterns predefined in the SDK provided by parrot, and then tune in a controller to track the pattern.

Figure 9 shows the control scheme for pattern tracking, where the inputs are the desired position of the pattern into the image and the distance between the pattern and the MUAV, and outputs are the current pattern position and distance. In this specific case it is desirable that the controller sets the pattern centered in the image; because of the cameras resolution are different, the image is scaled to a $1000x1000\,pixel$ matrix, then to keep the pattern centered the

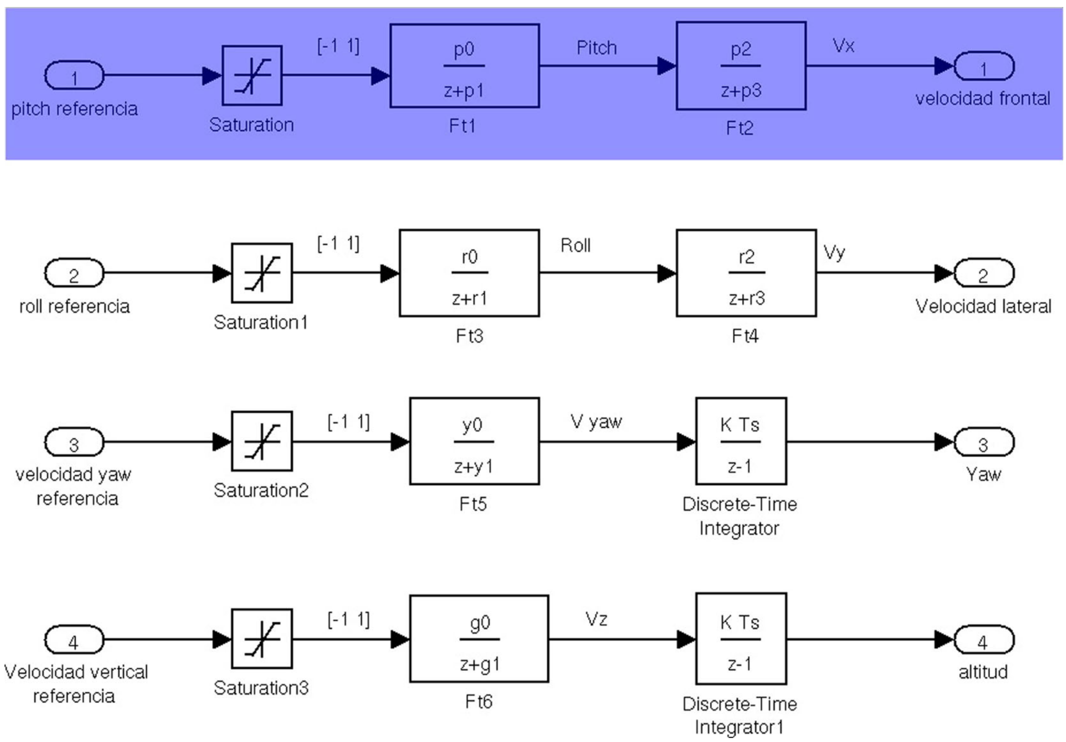


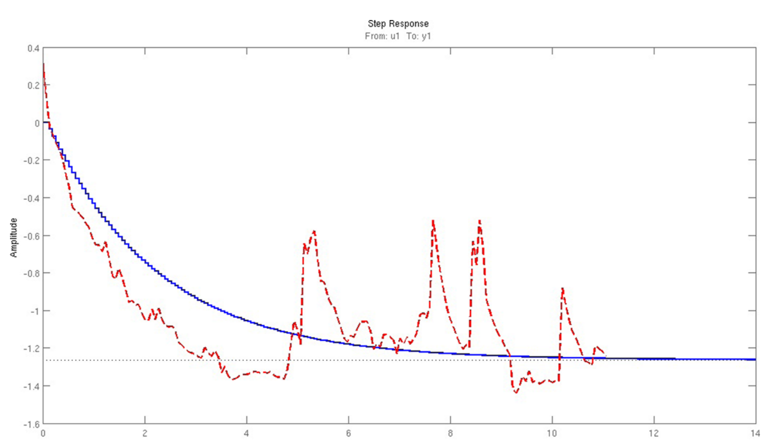
Fig. 7 Simplified MUAV model

reference position (x and y) must be $500 pixel$ in both vertical and horizontal positions. For the distance reference it has been set in $150cm$ in order to avoid light interference and noise.

The procedure for this activity starts giving the GCS the pattern to be identified following by to check the correct recognition, then in the same tab, it could be tuned up the controllers and read the data in the log files for analysis.

There are two ways to do pattern tracking, and it has to do with the horizontal control or holonomics. It can be done by modifying the roll angle (holonomic system) through a proportional controller(blue block in Fig. 9) or the yaw angle (nonholonomic system) through a proportional-derivative controller(red block in Fig. 9). Both types of control gave good results as the Fig. 10 shows, but the yaw angle controller (Fig. 10b) is more accurate and stable.

Fig. 8 Step response, real vs. model



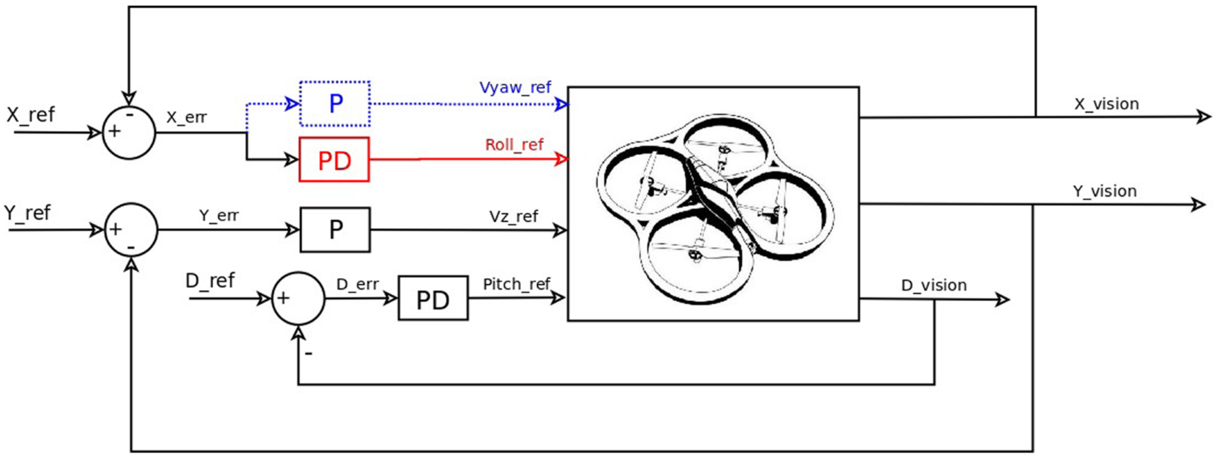


Fig. 9 Control scheme for pattern tracking

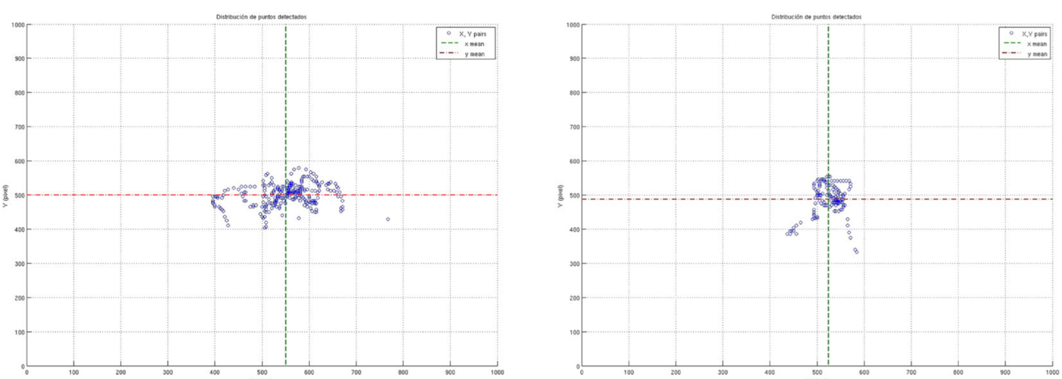
5.3 Waypoint Navigation

This activity requires the MUAV to do an autonomous navigation visiting predefined waypoints. Due to the enhanced system, the trajectory could be traced by simple separated position controllers in x and y axes (UTM coordinates); even so, the system lacks compass, making a requirement that the MUAV heads north in order to relate the x movement with the roll angle.

Figure 11 shows a general overview of the mission, viewed in the GUI and the real trajectory. The configuration data is loaded through a XML file that contains the coordinates, altitudes, delay times and margin of errors of each waypoint. As well as general configuration and the maximum and minimum coordinates that define the mission area (useful for georeferencing) among others. In this specific activity the mission has only two waypoints with a tolerance of $4m$ in each waypoint (due to the GPS has an error of $\pm 3m$). In Fig. 11b it can be seen that the MUAV seems to be lost at the beginning of the trajectory, this is because the GPS measurement quality (would work better with a Kalman filter) and the mission area is only about $800m^2$. It is recommendable to keep the GPS reading data for about 10 minutes before start the mission. Even so, the MUAV gets through the waypoints and land in the second waypoint.

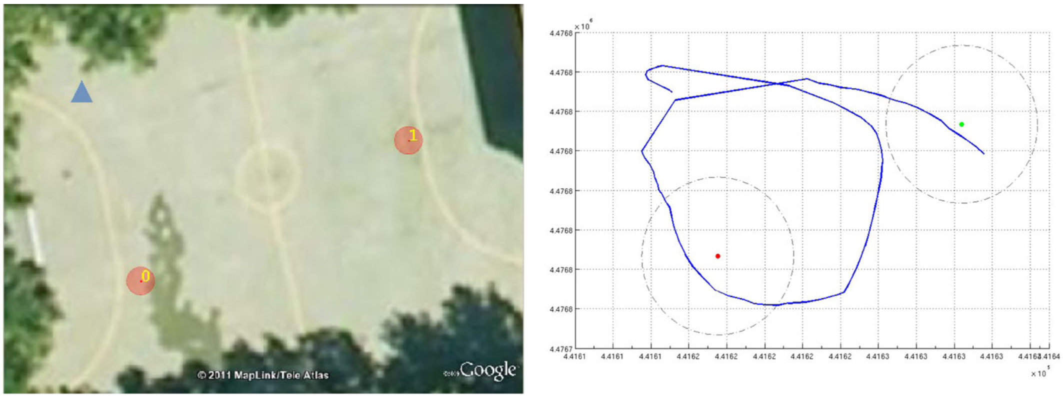
6 Activities and Assessments

This section proposes a series of projects/activities that can be developed using the toolkit presented in this work. Those activities have been designed taking into account both the capabilities of the platform



(a) Roll angle control (b) Yaw angle control

Fig. 10 Pattern position inside the image. **a** Roll angle control. **b** Yaw angle control



(a) Mission in the GUI (b) Real trajectory

Fig. 11 Waypoint navigation mission. **a** Mission in the GUI. **b** Real trajectory

described in Section 4 as well as the standards and requirements discussed on Section 3.

Table 4 shows the five projects proposed in this work (refer to the Appendix A for detailed information about each project). These projects are highly related with the developments presented in Section 5 so both the students and the teachers can benefit from the tools that are already available. Moreover, the projects are presented in a modular manner, and for some of them some previous developments are necessary. However, this does not implies that any of them cannot be developed independently from the rest, nor does it implies that there is a predefined order in which the activities can be carried out.

It should also be pointed out that, both the activities and the solutions can be taken as guidelines. They are designed to cover a very wide group of subjects and there is not a great number of details. Moreover, there may be several variations, additional requisites or limitations given to the students. This has been done according with the purposes of the toolkit which is to be flexible and with the ability of adapting to different learning objectives.

6.1 Learning Objective Assessment

It is possible to estimate how the proposed projects achieve the learning objectives, and in consequence, how they satisfy the ABET criteria points established in Section 3.2.

Table 5 shows the assessment of the learning objectives covered by each project. It is noteworthy that the idea is not to reach a 100 % of coverage, but cover as more learning objectives as possible in a reasonable assessment; as well as to measure how well the project addresses the achievement of the objectives. These data was measured by relating each project with each theoretical contents contented in each CEA/ISA learning objective [4], and then calculating the whole assessment per each learning objective.

The first appreciation is that the learning objective *E* is covered by all the projects since all projects require the student to get involved in the communication interface between the MUAV and the GCS. *P3* and *P4* do not have good enough assessment due to the GCS, developed in this work, is given to the student as a tool (see Appendix A.3 and A.4). Although

Table 4 Proposed activities

Activity	Project name
P1	Design and construction of a data acquisition circuit, and its integration with the MUAVs communication system.
P2	Design, Programming and Integration of a Basic Ground Control Station.
P3	Modelling and Identification of a Dynamic System.
P4	Following an object detected by a camera.
P5	Designing and implementation of a waypoint navigation control system.

Table 5 CEA/ISA Learning objective assessment by each project

	CEA/ISA Learning-objectives	P1	P2	P3	P4	P5
		Projects				
A	Knowledge about fundamentals of automation and control methods.	1	-	2	3	1
B	Knowledge and skills for modelling and simulation of systems.	-	-	3	-	2
C	Knowledge on automatic regulation and control techniques and their applications in industrial automation.	-	-	2	-	3
D	Knowledge of the principles and applications of robotic systems.	-	2	2	1	2
E	Applied knowledge of industrial informatics and communications.	2	2	1	1	3
F	Capability to design control and industrial automation systems.	3	-	2	1	2

1=project encompass learning objective slightly, 2=moderately, 3=substantively

for *P5* the GCS is also given, the student has to develop a different kind of learning objectives (see Appendix A.5).

Objectives *A*, *D* and *F* are well covered, too. The *P4* covers the learning objective *A* in the best way since this project is focused in the MUAVs flight control. *P3* is moderately related to this learning objective because it is necessary to study modeling methods. In the case of the learning objective *D*, the projects do not include it in a substantively way for the reason that *QuadLab* itself is a specific type of robotic system and can not be compared against other robotics systems types. Learning objective F is well encompassed by the *P1* in the way that this project contains activities related to data acquisition and sensorics. For their part, *P3*, *P4* and *P5* cover the learning objective in the sense of control algorithms implementation.

Objectives *B* and *C* are briefly covered but with good assessment. Learning objective *B* is totally covered by the *P3* in tha way that proposes the development of a model for the MUAV. *P5* is the project that best fit within the learning objective *C* since it is clearly a control methods application.

Evaluating the table in this form, the teacher could easily preform modifications to his own projects in order to make the activities encompass the desired learning objectives.

From the project perspective, it can be seen that projects *P3* and *P5* cover most of the learning objectives, but have the problem that they require the previous projects to be achieved. For the other projects, besides they do not cover many objectives, they made emphasis in one specific objective.

6.2 EC2000 Outcomes Assessment

Table 6 shows how well each project addresses the EC2000 outcomes (see Table 1). This table was generated by crossing the Tables 2 and 5 and it is based in the course assessment matrix suggested by [6]. The projects *P1* and *P2* address not all the outcomes moderately, but the projects *P3*, *P4* and *P5* address the outcomes substantively in most of the outcomes. This means, those projects that are focused in solving a real application, have more likelihood of addressing more outcomes.

From the outcomes perspective, outcome *a* is addressed gradually from *P1* to *P5*, this means that for *P1* is not required as many abilities to apply knowledge of mathematics and science as for the followings projects. This indicates that the complexity of the projects raises in a coherent way. Due to the PBL methodology and the experimental nature of *QuadLab*, all projects address substantively the outcome *b*. Outcome *c* is best covered by the *P1* since it requires abilities in control systems design. *P2* does not include this outcome due to this project does not encompass the learning objective *F*, that is strongly relate to the outcome in discussion.

None of the presented projects covers substantively the outcome *d* because all the disciplines implied in the development of the activities are very close to each other (e.g. informatics and electronics). In the case of *P1*, this project does not incorporate this outcome since it only implies one discipline in its realization.

One reason outcome *e* is well addressed, is that each project encompasses substantively one or more

Table 6 EC2000 outcomes assessment by each project

	EC2000 learning Outcomes	Projects				
		P1	P2	P3	P4	P5
a	An ability to apply knowledge of mathematics, science, and engineering.	1	2	2	3	3
b	An ability to design and conduct experiments, as well as to analyse and interpret data.	3	2	3	1	3
c	An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.	3	-	2	1	2
d	An ability to function on multidisciplinary teams.	-	2	2	1	2
e	An ability to identify, formulate, and solve engineering problems.	2	2	3	3	3
k	An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.	3	2	2	1	3

1=project addresses competence slightly, 2=moderately, 3=substantively

learning objectives (*A,B,D,E*) associated with this outcome. In the same way as with outcome *e*, all projects address substantively the outcome *k* for the same reason. In addition, the projects cover well this outcome because *QuadLab* is a platform designed for practical learning.

It is worth mentioning that developing all the projects in the given order ensures the coverage, with a good assessment, of the outcomes within the scope of this work. Lastly, because *QuadLab* is an open source platform, the teacher could set up the projects aiming to specific learning projects and generate these kind of assessments to see how well the projects address the EC2000 outcomes.

7 Conclusions

This platform is presented as an alternative to the traditional laboratories used in teaching of automatics, which generally consist of high complexity, high cost and hermetic systems, and where it is necessary to take supervision to ensure the integrity of both, the system and the user. This paper proposes an open platform, taking some advantages, such as low cost, space and time constraint, and in some cases, the need of supervision and planning. In addition to the characteristics and properties that the AR.Drone owns, it has been implemented an external circuit to improve its performance. There have been presented several prototypes which were tested outdoors in order to integrate a GPS measurement.

A development of a modular ground control station for the robotic system has been performed with the following features: connection to the robot, teleoperation, autonomous control, data acquisition and processing of telemetry and video data, interface for identification, and integration with other ROS-based robotic platforms. Additionally, it contains an interface dedicated to the control and supervision of a mission by waypoints. This paper presents a simple interface for identifying and implementing a controller from a defined model of the AR.Drone. It has also been made a tracking control of an object based on the information provided by the drone cameras. Finally, this work presents a tracking control of a waypoint mission, in which it has been used a extended-UAV prototype and a dedicated interface within the ground control station. As a result, it has been obtained a correct operation for illustrating basic concepts of control systems. Furthermore, although it is possible to perform a mission by waypoints, the platform presented many problems and restrictions on environmental conditions and accuracy of GPS.

The modifications to the MUAV, as the design and development of the user interface and the ground control station, and the design and implementation of autonomous flight controllers for tracking and control for waypoint missions, have been proposed as projects for student. These activities, based on the development of this platform, are framed within a set of learning objectives and the PBL methodology. Activities or projects have been compared with the learning objectives and ABET outcomes showing that the more closer the project is to a real application, the greater likelihood of covering more outcomes.

The PBL methodology fits very well in combination with methodologies which presents to the student an activity where he or she works in a multidisciplinary team in a collaborative environment to propose and implement a solution. In this way, students not only achieve the learning objectives of an active part in the discovery of knowledge, learning and meaningful thoughts, but also reinforces the social and professional goals, which forms a fundamental part of their future in the area of environment engineering.

For future work, mainly is planned to improve the way-points tracking laboratory as an extension, also to integrate another controller devices (i.e., radio-control, kinect, wii controllers) and to improve haptics feedback adding vibration to the controller devices.

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Appendix

A.1 Design and Construction of a Data Acquisition Circuit, and its Integration with the MUAVs Communication System

Project name	Design and construction of a data acquisition circuit, and its integration with the MUAVs communication system
Objectives	Design and implement a system for data acquisition and wireless communication. The system should be designed so it can be embedded into the MUAV, and therefore it should compliant with the specifications of the aerial vehicle in terms of its weight and power limitations.
Previous knowledge	– Physics from the first course of engineering and sciences. – Micro-controllers. – Basic programming. – Basic digital electronics.
Tools	– Electronic design tools (e.g. Eagle, KiCad). – or measurements tools to be integrated. – Micro-controllers, communication modules and other electronics components.
Detailed activities	– Definition and selection of the sensor(s) that are going to be used. – Definition and selection of the data acquisition methodology. – Selection of the wireless communication technique (Technology, frequency, etc.). – Design of the power unit. – Design and mounting of the electronic circuit. – Tests. (Data acquisition, Data processing and Communication).
Description	The activity is oriented to design and implement a data acquisition and wireless communication system. The data is obtained from one or more sensors that will be mounted on-board the UAV and they should be sent to a ground base station, where they can be processed on-line or stored. Both the module and the protocol used to transmit the data should be designed by the student according to the type and number or sensors, sampling frequency, and other parameters that should be defined. The design of electronic circuit must take into account among other requirements: size, weight and power supply. The operation of the circuit must not interfere with the flying capabilities or the communication system of the AR.Drone.

A.2 Design, Programming and Integration of a Basic Ground Control Station

Project name	Design, programming and integration of a basic ground control station
Objectives	Designing and programming a simple ground control station. The program must be able to communicate with the MUAV and act as an user interface. The telemetry data, video feedback and external sensor data should be processed and displayed. It should also include the possibility of teleoperation of the MUAV using a joystick or gamepad.
Previous knowledge	– ROS Framework. – C++ Programming. – QT Programming. – Joystick/gamepad handling over ROS.
Tools	– Framework and libraries from QT. – ROS Framework. – Parrot SDK.
Detailed activities	– Initial Approach, study and start of the parrot's SDK Driver for the AR.Drone. – Creation of a QT project and linking of the main libraries. – Communication with the MUAV. – Integration of the telemetry readings and video feedback in the application. – Integration of input devices and sending control commands. – Integration of external sensors readings from the project described in Appendix A.1. – Storing of telemetry and external sensor readings as well as of video screen shots. – Sending additional commands (Change camera, flat trim, reset, etc.)
Description	An application to communicate with the MUAV, that read its telemetry and control it should be developed. It must use as a base the open-source developments available, such as the AR.Drone SDK, the different ROS drivers, and the QT libraries. An initial approach to those tools is necessary in case the student is not familiar with them, then the basic threads for communication and control should be designed and implemented, and taking that as a base more functionalities can be added to the system. This will allow the student to develop the software modularity among other concepts. It will also be the base for future activities and applications that will use the interface as an starting point.

A.3 Modelling and Identification of a Dynamic System

Project name	Modelling and Identification of a dynamic system
Objectives	Propose a dynamic model of the MUAV and identify the type of system, its order and the corresponding parameters using different techniques. Also, both the input data and the validation approach should be defined.
Previous knowledge	– Dynamic systems modelling. – C++ and/or MatLab programming. – Control theory basics, transfer functions, open loop response, frequency spectrum response.
Tools	– Control and Data acquisition software (e.g. GCS developed according to Appendix A.2) – Numeric computation software (e.g. MatLab, Octave).
Detailed activities	– Design and propose a dynamic model for the MUAV. – Select one or more parameters to identify. – Design an methodology to send the control commands to the MUAV and to store the necessary telemetry

Project name	Modelling and Identification of a dynamic system
	output and integrate them into the Ground Control Station. – Generate an input sequence for a given time lapse (Type of sequence, time step and duration must be determined by the student), send it to the MUAV and store the output data. Repeat the process for the validation data. – Obtain or estimate the parameters of the model proposed previously. – Compare the results of the estimated model against the real data, and obtain the main characteristics of the model.
Description	This project proposes the creation of a dynamic model for the MUAV. A method for performing the identification must be proposed, then the type of the model should be defined and its corresponding parameters must be computed. In order to do this, the student must first determine the input sequence that will be sent to the MUAV (for both identification and validation). Then the received output data can be used to estimate the parameters of the model, after that the model must be compared with the real output and according with those results determine if the proposed model is suitable for the case. The main characteristics such as stability or response time can be obtained, and a control law can also be defined.

A.4 Following an Object Detected by a Camera

Project name	Following an object detected by a camera
Objectives	The objective is to design and implement a controller for the MUAV in order to follow an object detected by the MUAV's frontal camera.
Previous knowledge	– Dynamic of systems and transfer functions. – Control of dynamic systems. – Response on the frequency spectrum and filtering. – Programming in C++ and MatLab.
Tools	– Control and Data acquisition software (e.g. GCS developed according to Appendix A.2) – Numeric computation software (e.g. MatLab, Octave).
Detailed activities	– Design a control schema and establish the reference set points in order to have the identified object in the center of the image plane. – Design and implement an additional module of the ground control station that is able to read the data from the MUAVs detection module, and send back the control commands. – Perform the tuning of the controller parameters on-line or using previously stored telemetry data. – In case it is necessary, perform a filtering process on the received telemetry data, before is sent as feedback to the controller. – Test the performance of the controller first using linear and then planar movements.
Description	This project proposes the development of a control for the MUAV in order to follow a pre-determined object. The detection of the target is not part of this project, therefore the system for detection included in the AR.Drone drivers will be used, by doing so, the MUAV can send information regarding the detection or not of the target and the position (x,y) in the plane of the image. This can be used as input to keep the detection on the center of the image plane using a controller proposed by the student (P, PI or PID). The parameters for the controller must be estimated using the output of the identification task proposed on Appendix A.3. This will allow the student to analyze the sources of error and difficulties that appear when working with such complex systems, and the techniques to overcome those limitations.

A.5 Design and Implementation of a Waypoint Navigation Control System

Project name	Designing and implementation of a waypoint navigation control system
Objectives	Design and implement a waypoint navigation control system, with or without trajectory controlling, integrate the controller with the available information.
Previous knowledge	– Basic autonomous navigation concepts. – Position and/or velocity controlling. – Tuning of automatic controllers. – Classical control structures (FeedForward, ratio, cascade).
Tools	– Expanded MUAV prototype including GPS sensor and data acquisition hardware (e.g. The circuit proposed in project Appendix A.1) – Ground control station with user graphical interface. – GIS application (e.g. *Google Earth, OpenStreetMaps*). – Numeric computation software (e.g. MatLab, Octave).
Detailed activities	– Define the area to be covered or the way-points that must be visited. – Define a task to be performed in each way-point (e.g. Wait for a number of seconds, take an aerial image, record data from sensors). – Design and program a basic mission controller with (Start, pause, resume, cancel, etc.) and integrate it into the GCS. – Design and implement a navigation strategy in order to reach each way-point, the position controller can be of different complexity. – Integrate the controller or navigation module into the GSC.
Description	This project requires that the student develops a system for autonomous navigation of the MUAV using a way-point controller. The trajectory can be predetermined using a priori-known way-points or autonomously computed from a coverage area or any other similar task. Once the way-points are established they must be followed in a strict order, by sending each one to the position controller. Those functionalities are also to be embedded into the Ground Control Station, where it should be possible to input some parameters or additional information. This will require several areas of knowledge to be used therefore preparing the student for more realistic and complex developments.

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David Fernando Zapata García (Medelln, Colombia, 1982) obtained the Electronics Engineer degree from Colombian Engineering School in 2005 and the M.Sc. in Automation and Robotics from the Technical University of Madrid (UPM) in 2012. His research interests in the field of robotics are focused on aerial robots and robotics for education. He is currently working as external collaborator at the Robotics and Cybernetics research group of the Centre for Automatic and Robotic (CAR UPMCSIC).

Mario Andrei Garzón Oviedo (Pasto, Colombia, 1983) received the Electronics Engineer degree from Colombian Engineering School in 2005 and the M.Sc. in Automation and Robotics from the Technical University of Madrid (UPM) in 2011. His research interests in the field of robotics are focused on navigation and cooperation between heterogeneous mobile robots as well as the detection and prediction of pedestrian trajectories. He is currently a researcher at the Robotics and Cybernetics research group of the Centre for Automatic and Robotic (CAR UPMCSIC) where he is also developing his PhD thesis.

João Ricardo Pereira Valente (Lisbon, Portugal, 1982) received his M.Sc. in Electrical and Computer Engineering from the New University of Lisbon in 2008, and both M.Sc and PhD. in Automation and Robotics from the Polytechnic University of Madrid, in 2011 and 2014, respectively. He was a researcher in the Robotics & Cybernetics group from the CAR UPMCSIC from 2008 to 2014. His research interests in the field of robotics are focused on aerial robots, remote sensing, path and mission planning. Currently, he is a visiting professor and researcher at the Universidad Carlos III de Madrid.

Antonio Barrientos received the Msc Engineer degree by Automatic and Electronic from the Polytechnic University of Madrid in 1982, and the PhD in Robotics by the same University in 1986. In 2002 he obtained de MSc Degree in Biomedical Engineering by Universidad Nacional de Educacin a Distancia. Since 1988 he is Professor on robotics, computers and control engineering at the Polytechnic University of Madrid. He has worked for more than 30 years in robotics, developing industrial and service robots for different areas. Currently his main interests are in the aerial and field robotics. He is author of several textbooks in Robotics and Manufacturing automation, and has participated as coauthor in the white books about the state of robotics and manufacturing in Spain. He is also coauthor of more than 100 scientific papers in journals and conferences. He has been a reviewer for several journals and is an Editorial Board Member of the International Journal of Advanced Robotic Systems. Also he is a senior member of the IEEE Antonio Barrientos is currently the head of the Robotics and Cybernetics research group of the Centre for Automatic and Robotic in the Technical University of Madrid Spanish National Research Council.