Droning On: Reflections on Integrating UAV Technology into a Computer Engineering Design Laboratory

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ABSTRACT

Unmanned aerial vehicles, also known as drones, are often characterized as representing the next big disruptive change in our everyday interaction with technology. Indeed some commentators have suggested that their impact will be as significant as that of the Internet. It is thus incumbent upon modern, foresightful educators to integrate these platforms into the curriculum in order to more fully equip the next generation of professional engineers and computer scientists with the skillsets and competences needed to realize the full potential of these devices.

In this paper we reflect on the challenges encountered when integrating drone technology into an existing project-based freshman design module. The objective was to introduce the drone as a relatively seamless extension of an existing problem set for a design project involving an autonomous vehicle. In doing so, critical factors such as engineering ethics, health and safety, and regulatory constraints; in addition to implementation challenges; are directly addressed and quantified. Lessons learned and reflections on best practice for the use of drone technology in the laboratory are adduced and articulated.

Keywords

Unmanned Aerial Vehicles; Drones; Collaborative Learning; Engineering Design; Practical; Laboratory; Experiential Learning

1. INTRODUCTION

The goals, content and means of delivery of many electronic and computer engineering design modules has evolved radically over the past decade due to the rise in the availability of affordable, open-source programmable, microcontrollers and accessible wireless communication devices [28] [15] [26] [14].

Many engineering modules have evolved or have been extended to more closely integrate the underlying technologies and systems with modern engineering practice. One of the more enticing recent developments is the commoditization of unmanned aerial vehicles (UAVs) or drones. Whilst many commentators have focused on public fears over the intrusiveness of drone technology, they have a wide range of real-world applications, and the full potential of these devices has yet to be explored by either industry or educators [21].

It is clear that drones offer enormous potential for engaging students and developing new classroom learning paradigms [21] [20] [30]. Drones offer a challenging evolution for existing computer engineering design modules where students presently face challenges in electronics, control, programming and project management. Educators seeking to incorporate drones within their modules must be cognisant of both the new technical challenges, and the necessity to create a safe environment in which students can gain hands on experience with the technology.

In this paper we reflect on the challenges encountered when integrating drone technology into an existing project-based freshman design module. In particular, we address the challenges facing those who wish to implement or extend robotic laboratory tasks to incorporate the use of unmanned aerial vehicles, and propound some thoughts on best practice for same. The paper identifies the technical constraints that bound any such endeavor and describes how they may be addressed in the context of experiential learning, ethical awareness and the development and reinforcement of responsible professional practice.

The contributions comprise i) a strategy for the inclusion of drones within the existing wireless control activity and requirement set for a freshman laboratory; ii) a functional description of the implementation of a "hypervisor" to safely enable (wireless) direct student control of operational drones in flight; iii) requirements of an enabling layer that provides technical translation, validation and control capabilities, whilst also policing and enforcing responsible use and engagement. The paper concludes with reflections on lessons learnt and best practice for managing the incorporation of drones within the curriculum.

2. UNMANNED AERIAL VEHICLES

UAVs are generally autonomously functional, remotely controlled and reusable. They entered the populist consciousness approximately a decade ago through their use by the military in battle and conflict scenarios. More recently drones have been attracting attention for the broad range of civilian and industrial uses to which they are being put. Some have referred to the advent of wide scale domestic drone deployments as being akin to a "flying Internet" in

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terms of the green-field opportunities it presents to innovators and entrepreneurs alike. It is clear from the diversity of use-case scenarios currently being pursued, for example in conservation, search and rescue, surveying and commercial delivery, that drones will have a marked impact on many future workplaces and, consequently, on the employability skill sets educators should be targeting for their students.

Figure 1: An Unmanned Aerial Vehicle [5].

There are a wide variety of commercially produced UAVs available for purchase, ranging in cost from c.$40 to tens of thousands of dollars. Regardless of cost, these UAVs share many similar features in terms of the available on-board equipment e.g. cameras, GPS and the wireless communications protocols used e.g. WiFi. Two UAVs that have been successfully used in educational settings [22] [10], [25] are the Parrot AR.Drone 2.0 [1] and DJI Phantom 2 Vision [5]. These relatively low cost UAVs are equipped with cameras and WiFi. The latter not only enables the UAVs to transmit images it also permits the end-user to control them using mobile devices. For both of these drones the SDK provided [2][4] allows the device to be controlled using Simple API commands. The typical battery lifetime is such that the drones can fly continuously for up to 25 minutes.

3. UAVS AND THE LAW

The military applications of UAVs have been discussed in the media for well over a decade [29] [23]. However, interest in the potential civilian and academic uses of these devices has only taken off in recent years [21].

Governments are being proactive in their support of the much anticipated UAV revolution as they are fast-tracking the development of the law and policy needed to enable their deployment. For example, the European Commission has drawn up a policy framework which will enable the progressive development of the commercial drones market while safeguarding the public interest [3].

The response from the existing aviation regulators, such as the U.S. Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA) has also been positive: the FAA are developing regulations for the use of UAVs in public airspace [21] while the EASA are developing a new regulatory approach for safely operating UAVs [19]. These new standards will address issues such as safety, security, privacy, data protection, insurance and liability.

The international demand for changes in the law and in policy in relation to the civilian use of UAVs has been driven by multi-nationals such as Google and Amazon and by collective bodies such as the Small UAV Coalition (www.smalluavcoalition.org). There has also been demands for regulatory changes from those in academia as they seek to explore the full potential of these devices for both research and educational purposes.

4. UAVS IN THE CLASSROOM

While many recognize the potential of unmanned aerial vehicles in the classroom, there has been little focus on their integration within the existing curriculum. This may be due to concerns related to safety, security, privacy and liability. However, such arguments are invalidated by the fact that many have successfully incorporated UAVs into their existing outreach activities to encourage students to pursue careers in science and engineering [20], [8], [25]. One possible reason for the slow uptake of this technology may be that they are often viewed as "toys" (as, for example, in [8]), rather than as autonomous aerial vehicles with the potential to revolutionize the computer engineering curriculum [13].

Where UAVs have been successfully integrated into the curriculum, these are often in the form of single classes or one day events. Nitschke et al. have developed a one day contest that is suitable for undergraduate and taught postgraduate students [22]. The interdisciplinary design competition required participants to make use of open-source libraries to develop a program capable of autonomously guiding a UAV from a start point to a destination. The UAV navigated its way along the course using visual markers. The authors found that while there was a steep learning curve, the students developed a deep understanding of the potential and limitations of the technology. Yokokawa et al. used the UAV to develop teaching materials for a single freshman class. Their study found that the teaching materials developed were successful in motivating students to learn more about control engineering and image processing [25].

Eriksen, Ming and Dodds explored the use of a UAV in the implementation of a location based "lab-escape" challenge [12]. The UAV was placed in a previously mapped room and the challenge was to determine its location and then proceed to the exit. Their study detailed the prototype that was developed using a UAV [1] and a Microsoft Kinect sensor, however, it did not extend to the actual deployment of drones in a classroom setting.

Winterfeldt and Hahne [30] developed a master's level module that integrated UAVs into an application design module taken by a group of 17 students. The objectives were to design an application to make use of several input devices, e.g. an android phone or a gamepad, to control the UAV. The course was split into 12 units where each unit lasted for three hours. The authors found that the use of UAVs in the classroom led to an effective, application-based learning approach that engaged students and improved performance on the module. The study did not explore how such a module could be scaled to classroom scenarios beyond the small group setting described.

5. AUTONOMOUS VEHICLES IN COMPUTER ENGINEERING DESIGN

It is widely accepted that engineering design needs to be incorporated across the curriculum [11][9], and that it should not be relegated to a single capstone module that meets the minimum requirements of accrediting bodies [17]. As a consequence many institutions now take an integrated approach to the inclusion of design aspects across the undergraduate computer engineering curriculum. A key feature of many of these design modules is that they foster the lifelong learning skills expected of graduates. In particular, they often incorporate elements of creative thinking, active learning, collaborative learning, teamwork, conflict resolution, decision making and communication. Pedagogically these module are often considered key elements of the curriculum as they contribute significantly to a range of professional accreditation goals, both nationally and in line with Washington Accord [6] outcomes.

Design courses seek to introduce students to all elements of the product development process so they gain experience of what it is like to work as a professional. The technologies, task and professional skills development elements of such design modules are explicitly chosen to be of direct benefit to all students, regardless of their specialism. For example computer engineering design courses may also incorporate elements of mechanical and electrical engineering [14].

Many design modules have focused on the development of small autonomous vehicles that are designed to carry out a specific task e.g. to sumo wrestle with each other [18] [24], or to emulate an urban light rail system [14]. The autonomous vehicles are often equipped with a variety of sensors that enable them to safely navigate their way through their surroundings. They may make use of visual tracking systems to estimate their position and their direction of motion. A wide variety of tracking approaches are possible and these may be categorized as marker and marker-less methods [7]. Marker-based systems follow a known pattern or image e.g. a straight white line on a black background, while marker-less systems may employ Simultaneous Localisation and Mapping (SLAM) techniques to navigate through their environment.

6. EXISTING MODULE OVERVIEW

One of the key objectives of this work is to explore the integration of UAVs within an existing computer engineering design module. The module chosen seeks to introduce students to all elements of the product development process so that they gain experience of what it is like to work as a professional engineer. This module runs over 12 weeks and is taken by approximately 170 second year undergraduate students annually. It is classified as a small group, project-based module. The academic staff who run the module are drawn from the Department of Electronic and Electrical Engineering (EE) and the School of Computer Science and Statistics (SCSS) within the host university.

Each student has four timetabled laboratory hours each week, split evenly between EE and SCSS. In addition there is one lecture hour timetabled each week. This hour is used to provide students with more in-depth information on the technologies they encounter in the course of the module. It is also used to provide broad guidance and advice on the tasks they should be engaging in at each phase of the design project. Students are expected to engage in self-directed learning associated with this module for an additional twelve to fifteen hours each week. Structured programming support services are also available [27] [16]. While the students taking this module are engineering majors, this module is taken before they specialise into specific branches of engineering. The module is carefully structured to ensure that the technologies encountered, the design task and the key professional skills to be developed are all aligned with the over-arching degree program objectives.

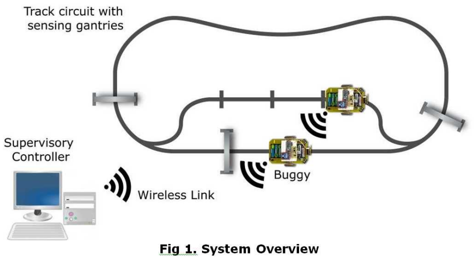

Figure 2: Overview of the Track for the Existing System

7. EXISTING DESIGN TASK

The high level metaphor used in presenting and describing the project task is that of a light-rail or tram system. Such systems travel on tracks laid in the city streets, incorporate points systems for track and junction changes, have remote signaling systems and communications capabilities, and are electrically powered. Students are required to implement a full emulation of such a light-rail system in the laboratory.

A marker based navigation system is deployed using a high contrast black line, known as the track, for the autonomous vehicles to follow. This track has both an outer and an inner “express” loop. Infrared sensing gantries are placed above the track at key locations and are used to help the vehicle determine its location. A PC is used to communicate wirelessly with the vehicles and it acts as a supervisory controller. Fig 2 provides an overview of the high-level system.

Students are tasked with the create of an autonomous vehicle based on a small, two-motor chassis with line following capabilities. Wireless communication functionality between each autonomous vehicle and the supervisory controller is achieved using XBee modules.

Each student group is provided with a rudimentary, motive chassis to use in their autonomous vehicle. The underside of each vehicle is equipped with Infrared emitters (LEDs) and detectors. These are intended for use in the line (track) following part of the task. A simple microcontroller is also provided. The main purpose of this microcontroller is to make Infrared detection decisions and to interact with the motor driver circuit.

The students design, lay out, build, test and debug their own motor control boards which must interface with the vehicle chassis. The chassis also contains a “daughter” board that manages and controls the autonomous vehicle’s more complex interactions with its environment.

Evaluation and assessment of student performance and achievement occurs through informal laboratory engagement, formal graded deliverables, an individual quiz and a final practical system demonstration and interview for each group. Feedback from each student on their experience of peer group engagement and learning, and their sense of the strengths and weaknesses of their engagement, is explicitly mandated within each deliverable. A strategy for the extension of this task set to inclusion UAVs within the existing robotic wireless control activity and requirement set is discussed below.

8. INCORPORATING UAVS

The present laboratory task includes a prescribed control vocabulary. Instructions include forward, stop, speed xx, branch, and disco. The branch command causes a vehicle to follow a branch line from the main track for overtaking, parking or obstacle avoidance purposes. Upon receipt of the disco command the vehicle advances to the parking bay, awaits the arrival of all other vehicles on the track and then they all perform a synchronized 180 degree turn so that they all face in the opposite direction. Finally, the vehicles proceed to complete the prescribed tasks in reverse.

Upon successful demonstration of fully supervised control of all vehicles, students were offered the opportunity to extend their activities to include control of an inflight drone. The original task requirements specified that the command set vocabulary be implemented in an extensible fashion within the students control strategy. Open air drone flight necessitates that the current inter command timings for completing the on-track task be linearly scaled in order to achieve similar outcomes in the outdoor arena. This constitutes the first stratum of attainment in open-air drone control for the students.

During these flights the students attention is drawn to the various real world constraints and limitations that accompany drone flights. These include (i) the very limited power source that limits flying time, (ii) environmental factors that affect the predictability, e.g. wind, and viability, e.g. precipitation, of flight, (iii) regulatory issues, e.g. is licensing required to fly and (iv) legal constraints, including privacy, ethical and health and safety concerns. Students then proceed to implement their solutions to these challenges.

The following section provides a functional description of the implementation of a "hypervisor" to safely enable (wireless) direct student control of operational drones in flight.

9. THE "HYPERVISOR"

The hypervisor is the "brain" of the classroom drone management system. In effect it is an electronic "big brother" that assesses, moderates and ultimately penalizes operators, i.e. student groups, based on the likelihood of their instruction resulting in an unacceptable risk or failure event.

In its simplest form, the hypervisor has a geofenced map of the open air arena in which the drones are to fly. It also has mappings for obstacles i.e. physical impediments, that the drone cannot fly into or through. The geofenced area exists as a set of 3D co-ordinate boundary sets. Typically these will be set to ensure that the drone remains above the reach of human hands, below elevations at which it could either require regulatory licensing or interfere with licensed air traffic (e.g. at or below the height of adjacent buildings) and sufficiently distant from neighboring buildings so as to avoid significant airflow disturbance or constitute a significant source of noise pollution. In practice outdoor sports fields make an ideal flight arena for these purposes.

The hypervisor receives incoming commands from the operator, in this case the specific wireless interface to the student group's PC. The commands can be in the form of a complete route with intersectoral timings, or as an ongoing "live" stream of commands. The command is validated by the hypervisor and then translated into an outcome if applied to the current drone position, elevation and speed and direction. The time to intersection with the geofence is approximated and compared with the duration of instruction, if one has been provided. If the requested time is excessive this is recorded and the instruction is amended, if necessary on-the-fly, to cause the drone to continue to the boundary but no further. At all times instructions are subject to processing and validation by the hypervisor prior to being executed. Route following or target hunting activities are deemed complete when the drone positions itself within a defined radius of the goal and hovers there for 10 seconds.

The hypervisor also has a variety of supervisory override functions that can be triggered remotely by the supervising academics or teaching assistants. In particular, there is an emergency "big red button" capability that immediately overides all ongoing flight and returns the drone at full power to a safe hover in the center of the arena geofence. This is a conservative strategy that maximizes the safety margins in the event of an unknown or unexpected occurrence e.g. significant wind gust or direction shift, malicious command attack, etc. In this mode control is only accepted from a separate, secure, encrypted channel available to the instructor, and the only subsequent command accepted is "land" where the UAV returns to its origin and lands autonomously. There is also a pause command available to the instructors that causes the drone to immediately stop and enter hover in its current location and at its current elevation. This locks out commands from the student operators until the "unlock" function is activated. This allows instructors to safely demonstrate, in flight, how and where potential faults may be developing in the groups control strategy.

The requirements from an enabling layer that provide both technical translation, validation and control capabilities, whilst also policing and enforcing responsible use and engagement is considered below.

10. THE ENABLING LAYER DESIGN

The enabling layer for integrating our existing laboratory based activity with the drone has its origins in the organic fashion in which the extant laboratory structure has evolved.

The present laboratory task uses XBee modules for communication between the robot and the controller PC. The students transmit their control instructions to/from the control station and the vehicle. The drones used for prototyping include the DJI Phantom 2 Vision units [5] as these represent an effective trade-off between price, capabilities and performance. Other UAVs, for example the Parrot AR.Drone 2.0 [1] or the open-source ardupilot (ardupilot.com), would also be suitable. The DJI platform was closed source at the time work commenced on the design of this laboratory experience; however, an API has subsequently been released that provides some of the requisite data and functional access to the DJI flight control.

The key facets of working with the DJI drones, as they pertain to the work described herein, were: control between the ground and drone is across a 5.8 GHz connection, and conveys telemetry and live video preview data. The device remote includes a range extender, based on openWRT, which provides a WiFi network that android and iOS clients can connect to in order to control and interact with the UAV via the DJI provided apps. The flight controller communicates with the drone during flight through port 2001 using a ser2net style connection.

It should be noted that the control system detailed above contains additional complexities due to the way in which the existing laboratory task has evolved and some of the challenges addressed above may not arise in other scenarios. For example, if redesigning the cumulative task from scratch, we would converge on using WiFi as the communication medium between the robot and control station, and between the drone and control station. We would also update our command API and vocabulary definitions to be more readily compatible with those used by DJI and in the open source autopilots that are available.

11. BENEFITS ACCRUING FROM INTEGRATING UAVS IN THE CLASSROOM

The experiential and developmental benefits that result from the use of UAVs for education purposes should not be underestimated. A poorly controlled and operated drone constitutes a hazard for persons, animals, infrastructure, and itself. In this sense it provides valuable opportunities for introducing, reinforcing and evaluating a variety of personal and professional developmental skills that we expect our graduate to possess, but which we, as educators, are often poor at elucidating and conveying.

To take some simple examples, accreditation bodies place strong emphasis on the development of good professional practice, ownership of assigned activities and instillation of strong ethical awareness and responsibility. The extant laboratory activity required, and assessed, all three of these elements as fully as was reasonably practicable. Tools used included summative and formative assessments; for example demonstrations, interviews and individual assessments.

UAV flight implicitly necessitates good professional practice: Their operators must be aware of everything from the environmental factors at play; the potential risks associated with device failure, e.g. due to a crash or power loss; the consequences of poor control or loss of control e.g. crash, damage, injury, lawsuits, etc. In addition, those wishing to use UAVs for commercial purposes may have to overcome some of the negative perceptions that surround them. For example, there has been much public debate on their military use for unmanned aerial assaults and on their deployment for more voyeuristic intrusion into the private lives on celebrities. Introducing UAVs into the laboratory provides opportunities to engage students with wider issues surrounding the use of technology in the real world outside of a formal academic setting.

The hypervisor controls and monitors all instructions received from the operator i.e. from each student group. Any "failure" and corrective action are then reported back to the screen, with an associated penalty weighting to be applied to the overall task performance score. This "penalty" can be conceived as comprising elements arising from failings in good professional practice, failings in ownership of and responsibility for the UAV, health and safety failings through causing a hazard, and failings under the broader "Engineering Ethics" heading. The scale of the weighting is graduated in proportion to the potential consequence of the transgression - a drone instructed to exit the arena at 100% power accrues a much higher penalty than a drone that overshoots slightly whilst slowing itself.

As students are learning to control the UAV it is almost inevitable that they will experience a crash or loss of supervisory control event. Thus they will find themselves confronted with the consequential reality of this failure, and see it recorded as a number or a weighting on their overall grade. The evolutionary responses in strategy to this penalty approach are most interesting and subject to ongoing exploration and research.

Achievable solutions, at this academic stage, include use of GPS elevation data from the drone to maintain consistent flight elevation - thereby reducing or obviating hazard to licensed airspace users; use of GPS speed and position data to ensure that drone speeds and locations are safe and appropriate, and that safety margins to pre-mapped obstacles are maintained. Senior undergraduates could be expected to operate the drones safely in 3D, mapping and maintaining "flight corridors" for separation purposes; and utilizing the camera(s) for target identification, tracking and landing.

Secondary and tertiary assessment examples include accurate management of flight elevation so as not to constitute a hazard to other UAVs or aircraft at higher elevations, controlled target identification and simulated medicines delivery to remote dispensaries, etc. If one wished to extend this experience to graduate students, then they could further develop these concepts through the integration of peripherals into the drone e.g. ultrasonics or LIDAR, with the concomitant benefits that these will bring to safety and performance.

12. REFLECTIONS ON LESSONS LEARNT AND BEST PRACTICE

The system and approach described herein arose from seeking to integrate UAVs into an existing practical line following robotics task for freshman students. There are many similar practical classroom tasks documented in the International literature that can be inspired by, and evolve from, this work.

The approach is not tied to any specific platform or UAV technology, and includes strategies for integrating both open and closed source platforms.

The use of a supervisory control and override mechanism is essential on a number of grounds: health and safety (of students, staff, onlookers and infrastructure), legal compliance, overall drone meta control (both single drones and multiple in-flight drones), and to provide positive reassurance and feedback for both staff and students alike.

It is reasonable to assume that attackers (other groups or third parties) may seek to compromise the simple communications exchanges, so securing the two-way communication between the drone and controller is an important facet of any implementation.

Having a separate, prioritized "master" control channel, supporting a very small number of "safe" behaviors, is advisable. In practice one behavior was found to be sufficient - that of returning the drone to the center of the arena upon activation of the signal. Initial implementation saw the UAV task constitute an extension activity for students who demonstrated fully-supervised control of the ground based robots. In this way the risk profile associated with direct student flight of UAVs was mitigated.

The initial "delta" or step in transitioning from 2D ground-based robotics tasks to 3D air-based UAV tasks must appear small in order to avoid discouraging or demotivating students at the outset. This work describes a simple "scaling" factor that is directly applied to the ground based instruction set to appropriately magnify the in-air duration of each action. Speed and elevation are held constant in this initial transition stage for each group.

A quantifiable focus on professionalism, good practice, ethics and sensitivity to environmental concerns are directly evoked through the task requirements and operation of the hypervisor. This accords well with the educational requirements sought from progammes by professional Engineering and Accreditation bodies.

13. CONCLUSION

This paper provides one of the first descriptions of the structured integration of UAV technology into an existing freshman laboratory based Computer Engineering Design course. A protocol for providing seamless transition from ground based robotic vehicle control to in-flight UAV control is set out, and the supporting software and systems implementations are characterized in detail. Elucidation and assessment of key complementary skills is integrated into the technical framework described, as are the more traditional group and peer learning modalities. The paper concludes with a summary of our reflections on best practice in the integration, design and implementation of drone technology in the classroom

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