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A design of a short course with COTS UAV system for higher education students

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Abstract: This paper aims to propose a short course with a commercial off the shelf unmanned aerial vehicle (COTS UAV) system. From the short course, students can have a conception of a UAV system, and they would have not only the knowledge about the hardware integration but also the theoretical background of the guidance, navigation, and control (GNC) and the situation awareness system. The proposed course consists of two parts; the GNC system for holding the position and the situation awareness system with the marker detection and tracking. A Pixhawk is selected for a flight controller with an open source autopilot, i.e. px 4, and a Raspberry Pi with a downward camera is utilised for the visual navigation of the situation awareness system. The Pixhawk and Raspberry Pi are integrated into the robot operating system (ROS) via the WIFI network, and the MAVROS is adopted for the communication between the Pixhawk and the Raspberry Pi. The first part of the course is designed as the hands-on based lectures, and the second part of the course is adopted the problem-based project.

Keywords: UAV dynamics, control, guidance and navigation; Control algorithms implementation; Avionics and on-board equipment

1. INTRODUCTION

The unmanned aerial vehicle (UAV) has been regarded as a solution for future technologies in a variety of applications from the photography to the package delivery in all over the world (Hardin and Jackson (2005); Byers et al. (2006); Morris (2015)). Also, since a UAV system is a multidisciplinary system, the UAV system is one of the good examples in terms of system engineering education. In accordance with this trend, the UAV has been used in the various engineering education program not only aerospace engineering but also electrical engineering, mechanical engineering, computer science, etc., and the students can obtain an in-depth experience that transcends their majors by using the UAV system. (Antsaklis et al. (1999); Zhang (2002); Chartier and Gibson (2007); Froyd et al. (2012); Huggard (2016); Jacques et al. (2016)).

Also, these days we can easily find many kinds of commercial off the shelf (COTS) UAVs and the commercial autopilots in the market. For that reason, the design of the UAV system for the specific application is not a big deal for the non-expert, and the required period for the environment setup is also significantly reduced. Mostly, Since the learning objectives do not require the dynamics of UAV itself, if it should be focused on its application, the COTS UAV could be an excellent option in an aspect of the efficiency(Krajník et al. (2011); Nitschke et al. (2014); Wlodyka and Dulat (2015)).

As mentioned before, since the UAV system is a multidisciplinary system, project-based learning is an excellent option to deal with the UAV system, and the UAV system has been adopted for the project-based learning for the students. The project-based learning allows the students can proceed with the engineering design cycle; exploring the options, conceptual design, detailed design, test and simulation, hardware implementation, and verification and validation. In addition, if by using the group design project, students can learn to work in a team and solution synthesis skill which is necessary for an engineer(Blumenfeld et al. (1991); Jarrah (2005); Capraro et al. (2010); Beddoes et al. (2012); Mourtos (2012); Gnsaunderstudelftnl et al. (2012); Capraro et al. (2013); Roggow et al. (2015)). Some literature introduced the advice and suggestions to make the project-based learning working well, and the proposed course is designed by considering the challenges of project-based learning which are reported in the literature. Stauffacher et al. (2006); Bell (2010) advised that a strong scaffolding is highly recommended at the initial stages of the project, and the proposed course adopts the time-tabled sessions to provide background knowledge about the UAV system. It can be a guideline by showing the limitation, and it helps the student prevent the overstretch regarding the time-scale. In order to maintain motivation during the entire project, Blumenfeld et al. (1991) recommended having the relationship between the real world and the project. In this point of view, the application of the UAV system is selected by the students in the proposed course, and the application should be related to the real

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world system. Most of the common challenge of project-based learning is that the students should work as a team. Cheung and Chow (2011) suggested each team member should be allocated specific roles to give them ownership of the project, and the proposed project specifies the five kinds of tasks, and it can have flexibility according to the size of the groups.

In this context, a project-based course with a COTS UAV system for higher education students is proposed. The proposed course consists of five themes; UAV platform implementation with the robot operating system (ROS), the gain tuning of the attitude controller using an open source ground control system, the implementing the marker detection with the image processing, the design of the extended Kalman filter for the marker tracking and the design of the position controller with the vision navigation.

The basic background of each theme is delivered by using the hands-on based lectures and lab session on the first two weeks, and on the second half of the course, the students will choose an application which can be designed by utilising the technology which is delivered at the first half of the course. There are three oral presentations which the instructor can check the progress of the projects. At each oral presentation, the instructor can give comments to students, and it is helpful to dilute the disadvantages of project-oriented learning for slow learners.

This paper is organised as follows. In section 2, the intended learning outcomes and teaching methodologies are introduced, and the detailed structure of the course is suggested in section 3. The conclusion is remarked in section 4.

2. INTENDED LEARNING OUTCOMES AND TEACHING METHODOLOGIES

2.1 Learning target and project structure

The course provides a combined structure between the hands-on project and problem-based project. The first phase is based on the hands-on project to master the necessary background of the conventional vision navigation and hardware integration. The students might have different backgrounds with each other, and the hands-on project can reduce the gap of the understanding of the target system between each student. Also, in the second phase, the problem-based course gives students the design experience to solve the practical problem by selecting the methodology by themselves, and the students have experiences of the engineering design process.

2.2 Intended learning outcomes

The intended learning outcomes(ILO) of hands-on based learning include the following:

- To pilot the UAV using MAVROS
- To design the attitude controller of the UAV
- To implement the maker detection in an onboard system
- To design the vision navigation filter
- To implement guidance algorithm for landing

The intended learning outcomes(ILO) of the problem-based include the following:

- To identify the requirement of the system
- To identify the gap between the theoretical model and the real system
- To manage time and budge of the project
- To design validate and verification plan
- To identify the risk and prepare the mitigation plan

2.3 Methodology

In the first phase of the project, instructors present the overall guidance of the project and have a Q&A session. After then, the lectures and lab sessions are delivered by the hands-on materials. On the first week, the lectures deal with the guidance and navigation part such as the dynamics model, autopilot, and simple guidance algorithm of the UAV. The students can complete the dynamics model using the mathematical equations in the Simulink environment, and the attitude controller and position controller are designed in the Simulink environment. Finally, the controllers are tested in the simulations in the loop test(SILT) environment. In the integrated system, the attitude controller runs on the Pixhawk, and the position controller is working on the companion computer via MAVROS. The integrated system is running with the robot operating system (ROS).

On the second week, the lectures cover the situation awareness part like the image processing, target detection, target tracking, and basic filtering algorithm. The fundamental camera geometry and camera calibration algorithm are introduced to the students, and the students can learn the basic image processing algorithm, the colour and marker detection algorithm. Finally, the Kalman filtering algorithm is presented to give the students the concept of the navigation filter. In the last session of the second week, the students build teams for the design project.

On the third week, the students discuss the real application which they can utilise the guidance, control, and navigation algorithm and the situation awareness algorithm with their teammates, and they have to figure out the requirement of their system. After then, the last session of the third week, they prepare an oral presentation of the system requirement review to identify the requirement of the project, and the student presents the interim design results in the fourth week. On the last day, students show the final results of their design in the final presentation. The course is based on the various learning format as shown below:

- The formal lecture-based learning method is applied in the first and second weeks of the project, and during the lecture, the instructor and student can interact using free question and answer sessions.
- The practical lab sessions are prepared to supply the practical skills and enhance the understanding of the application of the hardware and software system.
- The students present the three oral presentations, and they can learn effective communication skill via the technical presentation.
- The several students become a team, and they can learn how to work with a teammate. The students

develop the project management skill through the team-based design project.

Table 1. Course timeline

Week	Tasks
1 Week	**Introduction** - The instructor presents the overview of the project **Lectures&Lab session 1 (hands-on)** - Implementation of dynamics of a UAV in simulink - Design the attitude and position controller of a UAV (software/hardware) - Simulation in the loop test environment setup with MAVROS
2 Week	**Lectures&Lab session 2 (hands-on)** - Camera geometry and camera calibration algorithm - Image processing and colour/marker detection algorithm - Basic Kalman filtering algorithm
3 Week	**System requirement review (problem-based)**
4 Week	**Interim design review (problem-based)**
5 Week	**Final presentation (problem-based)**

3. COURSE DETAILS

3.1 Hardware implementation

The system consists of two onboard computers and one laptop. The Pixhawk is the autopilot of a UAV, and we use the attitude controller only. The guidance command will be generated by the Raspberry Pi, which is a companion computer of the Pixhawk. The downward camera and lidar sensor are wired to the Raspberry Pi, and the image processing algorithm for the marker detection and simple navigation filter algorithm run on the Raspberry Pi. For piloting the Pixhawk, the MAVROS is installed on the Raspberry Pi and the Raspberry Pi and the laptop are connected by the robot operating system (ROS) via the WIFI network. The laptop can monitor the status of the Raspberry Pi and Pixhawk as a ground control system(GCS).

3.2 UAV's attitude controller design and vision guidance algorithm

The attitude control loop, which is implemented in the px4, can be used directly, but in order to consider the expendability of the system, the customized attitude controller is implemented in the firmware of the px4. Therefore the students can change their attitude control structure in the px4 easily. The position controller is also designed and implemented in the Raspberry Pi. The linear dynamics model is provided to the students, and the students can design the controller in the Simulink environment. The two kinds of control structures are covered in the lectures, and the first structure is the proportional integral derivative(PID) control system and the second structure is the backstepping control scheme. The student can choose the control structure when they design their UAV system.

The vision-based guidance is separated into two stages. At the first stage, the guidance algorithm will control the

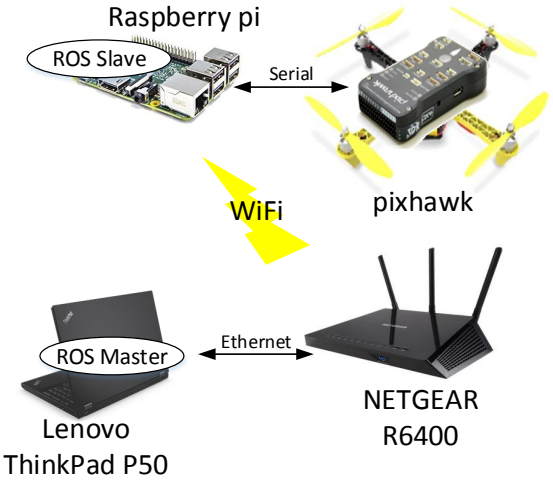


Fig. 1. The Hardware configuration of the hands-on

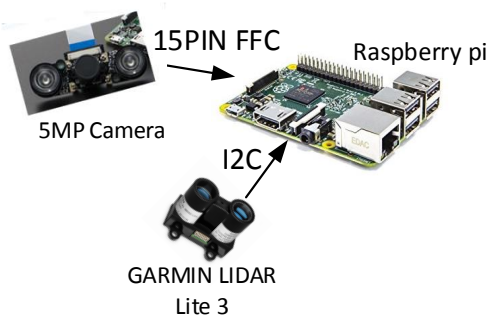


Fig. 2. The Sensor integration on the Raspberry Pi

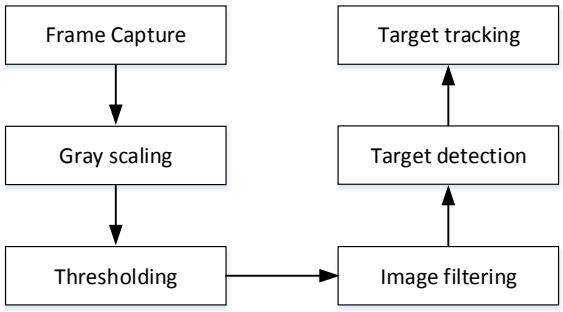


Fig. 3. The flowchart of the target detection and tracking

UAV to make it positioning the centre of the image frame. At the second stage, the UAV is controlled to reduce the relative distance, which is measured by a lidar range meter.

3.3 Target detection and tracking filter design

For the marker detection part, the OpenCV library is utilised. Since the OpenCV provides the various functions for image processing, the students can use it for image

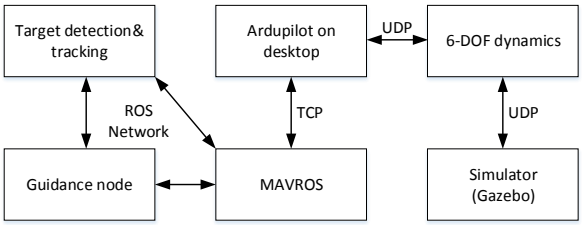


Fig. 4. The software in the loop test for the Pixhawk

acquisition and marker detection. In the lecture, the student can learn the theoretical background of the image processing and detection algorithm, and the lecture of the marker detection starts from the image acquisition. In the lecture, the students can make the raw images simplifying by using the grayscaling, thresholding and image filtering algorithm, and then students can choose the detection methodology. The colour detection and marker detection algorithm are presented during the lectures and lab session, and the student can choose the other detection algorithm as their application in the design project.

The basic Kalman filter theory is covered during the lecture, and in the computer lab session, the example code is provided to the students. The tracking filter provides continuous tracking results. The states are the position and velocity of the target in the image frame. The velocity can be known by the optical flow or the derivative of the target position. The measurements which can utilise are the position and velocity of the target in the image frame.

3.4 Software in the loop test

Since the proposed project requires hardware integration, the software in the loop test is necessary before doing the hardware test. The ArduPilot and px4 which are the firmware of the Pixhawk can operate the software in the loop test. It means that the onboard firmware is running in the computer independently, and it can emulate the Pixhawk's behaviours. In addition, the flight simulator gazabo can be utilised for the dynamics model of the UAVs and the visualization of the UAV.

3.5 System requirement review

After the hands-on based lectures and lab sessions are finished, the students build several small teams. Each team decides the application which can utilise the onboard tracking system with UAV, and define the system requirements for their application. In order to review the system requirement, students prepare the system requirement review. The system requirement review requires to ensure whether the system is ready to start the initial system design, and the functional and performance requirements of the system are defined regarding the cost, period, matured level, and the system constraints. The students should prepare the initial capabilities document to register their system requirements. By preparing the system requirement review, the students can know the gap between the theoretical background and real world, and the students can obtain a deep understanding of the outline of the UAV system.

The example of the required items for the system requirement review is as follows:

- Introduction
  - Analysis of the proposed application
  - Objectives and aims
- Requirements of the system
  - Functional requirements
  - Physical specification, i.e., Number, size, weight, flight time, and cost
- Conclusion
  - Analysis of the expected risks
  - Team organisation (sub-teaming results)
  - Time scheduling

3.6 Interim design review

The interim design review is a design review combing preliminary design review and critical design review. The students address the results of the trade-off between requirements and suggest the system architectures which ensure that the system is able to fulfil the reasonable expectation of satisfying the requirements within the available resources. Also, the design results and configuration should be addressed under considering the producibility in the hardware aspect. In addition, the students should show the validation and verification plan to assess their system.

The example of the required items for the interim design review is as follows:

- Summary of System requirements
  - Mission Statements
  - Requirements
- Methodology
  - Describe selection rationale, selected concept and characteristics
  - Describe the subsystems that are required to accomplish the objectives
  - Describe performance characteristics for the system and subsystems
  - Show the integrated system scheme
- Validation and verification plan
  - Determine the evaluation and verification metrics
  - Describe the verification plan and its status
  - Determine the precision of instrumentation and repeatability of measurement
- Conclusion
  - Summary of progress and next plans of each subteam
  - Time scheduling
  - Budget plan

3.7 Final review

In the final review, the students show the final results of the implemented system, and the flying test should be one

of the validation results which should be shown in the final presentation. The validation and verification results are analysed to assess whether the proposed requirement is fulfilled. The final presentation encourages the analysis of the validations and verifications rather than the successful operation. Therefore the students can learn the self-reflection methods by evaluation and analysis of the success or failures.

The example of the required items for the final review is as follows:

- Introduction
  - Mission Statements
  - Requirements
- Validation and verification results
  - Summarise of the integrated system design
  - Analyze the verification and validation results
  - Discuss the finding and recommendations
- Conclusion
  - Summary of the project
  - Team organisation
  - Time management
  - Budget management

4. CONCLUSION

In this paper, a short course which utilises the commercial off the shelf(COTS) UAV was designed for the higher education students. The type of the proposed course is a project-based learning methodology. The first phase of the course provides the hands-on based learning by using the lectures and lab sessions, and in the second phase of the course, the students can design their UAV system considering the application, which is chosen by the students. Through this short course, the students can have a comprehensive understanding of the UAV system and can obtain the theoretical background and practical point of view at the same time.

REFERENCES

Antsaklis, P., Basar, T., DeCarlo, R., McClamroch, N.H., Spong, M., and Yurkovich, S. (1999). Report on the NSF/CSS workshop on new directions in control engineering education. *IEEE Control Systems Magazine*, 19(5), 53–58.

Beddoes, K.D., Jesiek, B.K., and Borrego, M. (2012). Identifying Opportunities for Collaborations in International Engineering Education Research on Problem- and Project-Based Learning. *Interdisciplinary Journal of Problem-Based Learning*, 4(2), 9–19. doi:10.7771/1541-5015.1142.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The Clearing House*, 83(2), 39–43.

Blumenfeld, P.C., Soloway, E., Marx, R.W., Krajcik, J.S., Guzdial, M., and Palincsar, A. (1991). Motivating Project-Based Learing: Sustaining the Doing, Supporting the Learning. *Educational psychologist*, 26(3-4), 369–398. doi:10.1080/00461520.1991.9653139.

Byers, D.W., Hall, G.A., Hunter, G.D., Kennell, C.G., Macander, A.B., Milgram, J.H., and Strickland, J.D. (2006). Unmanned aerial vehicle for logistical delivery. US Patent 7,059,566.

Capraro, M.M., Whitfield, J.G., Etchells, M.J., and Capraro, R.M. (2010). *A companion to interdisciplinary STEM project-based learning.* Texas A&M University, Texas.

Capraro, R.M., Capraro, M.M., and Morgan, J.R. (2013). *STEM project-based learning an integrated science, technology, engineering, and mathematics (STEM) approach.* doi:10.1007/978-94-6209-143-6.

Chartier, B.J. and Gibson, B.A. (2007). Project-Based Learning : A Search and Rescue UAV – Perceptions of an Undergraduate Engineering Design Team : A Preliminary Study. In *18th Annual Conference of the Australasian Association for Engineering Education*, 1–6.

Cheung, S.M. and Chow, A.T. (2011). Project-based learning: a student investigation of the turtle trade in guangzhou, people's republic of china. *Journal of Biological Education*, 45(2), 68–76.

Froyd, J.E., Wankat, P.C., and Smith, K.A. (2012). Five major shifts in 100 years of engineering education. *Proceedings of the IEEE*, 100(SPL CONTENT), 1344–1360. doi:10.1109/JPROC.2012.2190167.

Gnsaunderstudelftnl, G.N.S.s., Roling, P., Timmer, N., and Melkert, J. (2012). Using the Engineering Design Cycle to Develop Integrated Project Based Learning in Aerospace Engineering Project Education Philosophy at Aerospace Engineering , TUDelft Project Set up Commonality. In *EE2012: International Conference on Innovation, Practice and Research in Engineering Education*, 18–20. Loughborough University.

Hardin, P.J. and Jackson, M.W. (2005). An unmanned aerial vehicle for rangeland photography. *Rangeland Ecology & Management*, 58(4), 439–442.

Huggard, M. (2016). Droning On : Reflections on Integrating UAV Technology into a Computer Engineering Design Laboratory. *The 47th ACM Technical Symposium on Computer Science Education, SIGCSE 2016*, 504–509. doi:10.1145/2839509.2844650.

Jacques, S., Bissey, S., and Martin, A. (2016). Multidisciplinary Project Based Learning Within a Collaborative Framework. *International Journal of Emerging Technologies in Learning*, 11(12), 36–44. doi:10.3991/ijet.v11i12.5996.

Jarrah, M.A. (2005). Teaching mechatronics design course for engineers. *2005 IEEE Workshop on Advanced Robotics and its Social Impacts*, 2005, 97–102. doi:10.1109/ARSO.2005.1511630.

Krajník, T., Vonásek, V., Fišer, D., and Faigl., J. (2011). AR-Drone as a Platform for Robotic Research and Education. In *International conference on research and education in robotics*, 172–186. Springer, Berlin, Heidelberg.

Morris, L.V. (2015). On or Coming to your Campus Soon: Drones. *Innovative Higher Education*, 40(3), 187–188. doi:10.1007/s10755-015-9323-x.

Mourtos, N.J. (2012). Defining, Teaching, and Assessing Engineering Design Skills. *International Journal of Quality Assurance in Engineering and Technology Education*, 2(1), 14–30. doi:10.4018/ijqaete.2012010102.

Nitschke, C., Minami, Y., Hiromoto, M., Ohshima, H., and Sato, T. (2014). A quadrocopter automatic con-

trol contest as an example of interdisciplinary design education. *International Conference on Control, Automation and Systems*, (Iccas), 678–685. doi: 10.1109/ICCAS.2014.6987866.

Roggow, D., Uhing, P., Jones, P., and Zambreno, J. (2015). A project-based embedded systems design course using a reconfigurable SoC platform. *2015 IEEE International Conference on Microelectronics Systems Education, MSE 2015*, 9–12. doi:10.1109/MSE.2015.7160005.

Stauffacher, M., Walter, A.I., Lang, D.J., Wiek, A., and Scholz, R.W. (2006). Learning to research environmental problems from a functional socio-cultural constructivism perspective: The transdisciplinary case study approach. *International Journal of Sustainability in Higher Education*, 7(3), 252–275.

Wlodyka, M. and Dulat, M. (2015). Experience with a Small UAV in the Engineering Design Class at Capilano University - A Novel Approach to First Year Engineering Design. *Proceedings of the Canadian Engineering Education Association*, 1–6. doi: 10.24908/pceea.v0i0.5739.

Zhang, H. (2002). Flying A Blimp–A Case Study of Project-Based Hands-on Engineering Education. In *2002 American Society for Engineering Education Annual Conference &Exposition*, 7563–7570.



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