A Comprehensive Experiment to Enhance Multidisciplinary Engineering Ability via UAVs Visual Navigation

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***Abstract*—This Research to Practice WIP presents a UAVs visual navigation based comprehensive experiment to enhance multidisciplinary engineering ability in Aerospace engineering education. In traditional courses, aerospace-related disciplines are independently distributed in different courses, and there is rarely a hands-on platform which includes signal processing, control theory, and artificial intelligence into Aerospace engineering. Facing this problem, this paper designs a multidisciplinary comprehensive experiment, aiming to provide a hand-on platform and flexible project-based program to students of aerospace engineering professions. First of all, in order to let the students understand actual aerospace problems, a multidisciplinary simulation platform containing UAVs and remote objects scenarios is constructed for them to explore in the experiments. Second, the content of the experiment is designed into three stages including data acquisition and processing, conceptual design and simulation, in-flight validation, during which the multidisciplinary engineering ability runs through the whole process of the activities. Finally, Project Oriented Design Based Learning is also introduced here to combine engineering design education with innovation and creativity. Through the project demonstration and presentation at the end of the experiment, the multidisciplinary engineering ability of each student can be effectively evaluated. The UVN comprehensive experiment enables students to work on real-world aerospace engineering problems through a hardware-software integration framework, which may greatly stimulate their curiosity and interest in autonomously learning. It also provides students unprecedented opportunities to immerse themselves in projects that cross disciplinary boundaries, improve their professional ability and enhance their exploration competence in aerospace areas.**

Keywords—Multidisciplinary Engineering Ability; Comprehensive Experiment; Aerospace Engineering; UAVs Visual Navigation

I. Introduction

Aerospace engineering is a field of engineering concerned with the design, development, construction, testing, and operation of vehicles operating in the Earth's atmosphere or in outer space. As one of the most important majors, aircraft control and information engineering determines the intelligence and autonomy of the spacecraft, which is intrinsically a multidisciplinary domain in which classical studies like signal processing, computer science gradually merged with more domain specific knowledge like control theory, navigation guidance as well as artificial intelligence [1]. The professional cultivating objective is not only to educate students become experts in various fields, but also to become comprehensive compound senior talents. Therefore, it is highly desired to educate students in a multidisciplinary manner, so that they can systematically learn knowledge of different disciplines and integrate them. However, in the traditional curriculum setting, the related disciplines for aerospace engineering are independently distributed in different courses. For example, the students learn control theory and automatic control in Cybernetics classes, and learn object detection and recognition in Pattern Recognition. Since different disciplines have their theoretical and practical teaching emphasis, it is difficult to effectively penetrate the knowledge points of different disciplines in one theoretical course. Thus, the comprehensive experiment course is a very good way to provide students with a multidisciplinary platform, which is able to design the content and implement the teaching process freely.

As the development of related technologies such as microcontrollers, wireless communication, and computing power, Unmanned Aerial Vehicles(UAVs) has become more and more popular in our daily life, which now is widely used in mining, health, industrial and agriculture [2]. Due to their versatility and reliability, UAVs have also attracted the educator's attention as a very extensible platform covering both specific disciplinary and system-level design [3]. Subhan Khan et.al. [4] presents a MATLAB-based application to teach the guidance, navigation, and control concepts of a quadrotor to undergraduate students, using a graphical user interface (GUI) and 3-D animations. Gaponov I et.al. [5] describes a sample syllabus for the undergraduate course based on quadrotor helicopter system, which provides the students with both theoretical and practical knowledge in the areas of mechanical engineering and design, system integration, hardware programming, and control system design and implementation. Mattia Giurato et.al. [3] develop an interdisciplinary UAV design course in which students are comprised of students with different backgrounds, covering the whole design cycle for a multirotor UAV, from conceptual design to in-flight validation, with specific reference to modeling, simulation, identification, and control. However, few of them focus on signal processing and intelligent technologies under Aerospace background. For students major in Aerospace engineering, they need to learn the difference of the problem between Aerospace and others. Also, their multidisciplinary ability not only includes control or navigation, but also be able to use technologies such as pattern recognition or AI to help improve the performance of the systems.

Facing this challenge, this paper designs a comprehensive experiment based on Unmanned Aerial Vehicles (UAVs) Visual Navigation (UVN) to provide a multidisciplinary practice training environment for the students of aerospace engineering professions. As one of the most important practical courses for undergraduates majoring in aircraft control and information engineering, comprehensive experiment is most suitable for interdisciplinary and engineering training courses. Therefore, in this article, we aim to explain how to build a new platform and teaching model in comprehensive experiments so that undergraduates can immerse themselves in interdisciplinary engineering projects and improve their professional and problem-solving skills. First, we construct a multidisciplinary simulation platform with a variety of remote sensing target detection and recognition scenarios. Then, the students are asked to realize an intelligent visual navigation system to track the free movement of the certain vehicle on the remote platform automatically, which includes three parts: data acquisition and processing, simulation, and in-flight validation. And finally, Project Oriented Design Based Learning was introduced in the comprehensive experiment to simulate the interests and self-motivation of the students as well as encouraging the interaction and learning between them. Based on it, the teacher could propose tasks that involve the related knowledge on aerospace, while the students could have the chance to explore the solution to the real problem on aerospace engineering with autonomously learning.

The remaining part of this work is organized as follows. Section II. describes a multidisciplinary simulation platform constructed for the UAV course. Section III. details the methodology of the UVN comprehensive experiment. Section IV. summarizes the implementation of the experiment. Finally, the last section presents conclusions.

II. Multidisciplinary Simulation Platform

The multidisciplinary simulation platform is a multi-objective aviation teaching and experimental environment, which supplies flexible hardware and software to students with a very typical task in aerospace engineering: remote sensing and autonomous monitoring. It is an extensible practical platform that includes UAVs and remote objects scenarios, as shown in Fig.1.

UAVs are multi-agent coordinated control platform for aerospace services, which includes quadcopters and multi-sensor systems. The remote targets scenarios are built as dynamic typical scenario imaging of sand table for remote sensings, such as vehicles, roads, forests, ports, railways, and overpasses with automatic control of the vehicle, aircraft, trains, and ships.

The multidisciplinary simulation platform includes different disciplines related to aerospace together, such as control theory, information and engineering, image processing and machine learning, as shown in Fig.2. The quadcopter and intelligent vehicle can separately collect information from space and ground, and cooperate with the real scene sand table

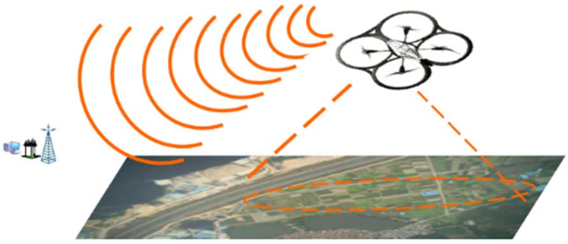

Fig.1. The multidisciplinary simulation platform

to simulate the process of real-time remote sensing image collection and information transmission integrating space and earth. The results of the reconnaissance processing of the quadcopters and the sensing information of the intelligent vehicle can be transmitted to the central control station, and the vehicle can be coordinated to plan the path to the area of interest autonomously and intelligently.

Based on the multidisciplinary simulation platform, teachers can design various projects, such as UAV visual navigation and autonomous landing, including control theory, information and engineering, image processing, and machine learning. In order to improve students' multidisciplinary engineering capabilities, evaluation standards have also been designed to guide teachers in designing course content, as well as assessing students' learning ability on different courses., which are as follows:

- ✓ Control theory: Understand the basic concepts and working principles of automatic control systems, and have the ability to model control problems.
- ✓ Information and engineering： Understand the flow of signal processing and can use Fourier transform to solve the problems of digital signal processing.
- ✓ Image processing：Understand the composition of the image processing system, and have the ability to realize image denoising, image enhancement, image segmentation, object detection, object recognition and object tracking.
- ✓ Machine Learning：Understand the application of machine learning and artificial intelligent, and have the ability to use neuro network, computer vision to solve the practical problems.

With all the evaluation criterias required in the comprehensive experiment listed above, the students can have a better understanding with the whole process for a real engineering project. Also, the multidisciplinary content will be taken into account to the greatest extent at the design stage.

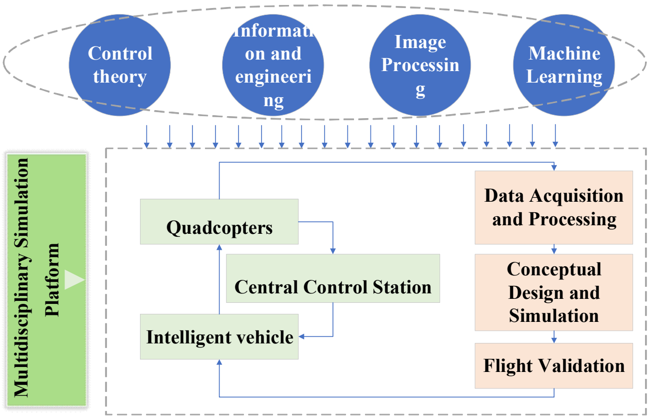

Fig.2. The related disciplines included in the experiments

III. METHODOLOGY

As shown in Fig.2, the content of the experiment is designed into three stages including data acquisition and processing, conceptual design and simulation, in-flight validation, during which the multidisciplinary engineering ability runs through the whole process of the activities.

A. *Data Acquisition and Processing*

For the first stage of data acquisition and processing, students need to learn how to capture images via various remote sensing collection devices, acquire the motion information to calculate the position and trajectory for the UAVs, and use image processing or artificial intelligence to identify the objects of interests.

In data acquisition, the students are asked to learn the performance of different sensors and their applications. Then, they choose the most suitable sensors according to the different requirements of the projects. The sensors include GPS, laser range-finders, altitude sensors and stereo cameras. The GPS is used for path planning and following. The laser range-finders are for map-building. The altitude sensors are used to maintain constant altitude during the flight. And the cameras can be used to capture the image or the video of the scenarios. Since students are required to implement visual navigation for the UAVs, the camera which can be used to capture the image or the video of the scenarios is the basic sensor for the system. The others can be used to obtain supplementary information.

The data process related to image or video preprocessing, image segmentation, object detection, tracking, and object recognition, as can be seen in Fig.3. Image preprocessing aims to improve the quality of the data, which might relate to denoising, filtering, enhancing and so on. Then, the students can try different segmentation methods such as threshold, GMM, saliency or deep learning, to extract the region of interests. After that, object detection, tracking, and recognition can be realized based on template, Harris, HoG, or Deep Learning based algorithms.

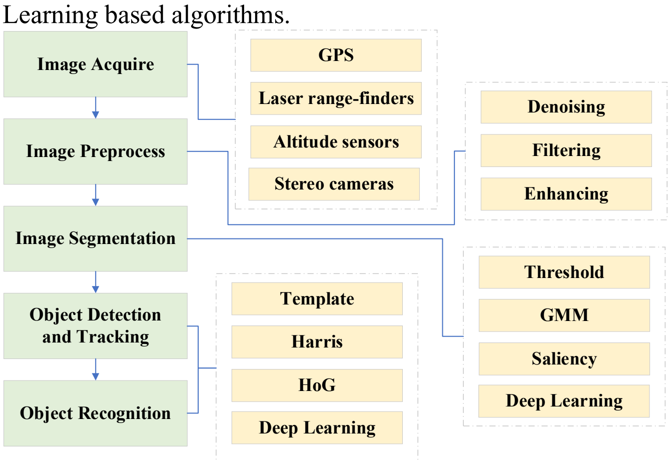

Fig.3. Data Acquisition and Processing

During each step of the data process, students learn the basic methods such as threshold-based segmentation, as well as the more complicated ones like deep learning-based object detection. In the introduction session, the teacher gives a brief introduction to the students about the different methods that might be used in each step. It's flexible to give the students a very good environment to validate their learned professions based in a different direction. After performance comparison and functional testing, they can choose the best algorithms for each of the steps. Finally, the algorithms for data acquisition and processing can be formed completely. By actually getting involved in the whole process, they also understand the pipeline from data acquires to object recognition. Besides, since the data is all based on a multidisciplinary simulation platform, the students can learn the characteristics of the remote sensing data and the particularity of the processing difference with other kinds of data.

B. *Conceptual Design and Simulation*

In the second stage of simulation, the data and information acquired by the first stage can be used for conceptual design and simulate the control and navigation system on the Matlab/Simulink environment.

In this experiment, we adapt Pixhawk [7], which is a mature and widely used open-source aircraft control system, as the flight control system to control the attitude and position of the quadcopters. The system is integrated with the XSENS inertial measurement unit and barometer sensor, which can provide real-time information of 3D acceleration, 3D angular velocity, and altitude of the quadcopters. Using this information, the attitude and the position information of the quadcopters can be calculated. The platform greatly simplifies the development process of the flight control algorithm, helps the students focus more on the development of visual navigation algorithm, and greatly improves the efficiency.

As shown in Fig.4, the students get various data from different sensors on UAVs, thus they can use Matlab/Simulink to design the model of visual navigation. After the model runs well in Matlab/Simulink, the parameter of the model can be used as input of Pixhawk and guide the quadcopters to fly as desired.

During the stage of conceptual design and simulation, the students are asked the following questions to help them design the project with comprehensive consideration :

1、 What kind of problems can be solved by visual navigation? To detect a static object, or to track a moving object from the simulation platform?
2、 What kind of adjustments need to be made if the problems change?
3、 What can be done when the target is lost during the process of target tracking?
4、 How to optimize the route planning for the UAVs?
5、 How to control the velocity of all the motors simultaneously to make the quadcopter fly in the required direction?

…

By constantly asking students questions before and during the design and simulation experiment stage, discussing the feasibility of various schemes with them, the instructor can enrich students' views on the problem from multiple perspectives. Thus, the students can view the experimental problems from the perspective of engineering as comprehensively as possible in the process of model design and simulation.

Besides, the developing of AI technologies combined with aerospace engineering creates the need not only for advanced automation but also more autonomy, and even intelligence to develop innovative aerospace engineering systems. So, the teacher can also introduce AI technologies into the experiment design and simulation stage, inspire students to consider what role AI can play in the aerospace area and remote sensing technologies. Combined with control model and the artificial intelligent, a variety of intelligent missions such as intelligent perception and evadible system, intelligent path planning decision, intelligent flight control, airspace integration technology and visual navigation can also be realized. Teachers can motivate students to investigate and understand intelligent tasks related to space, stimulate students' depth and width of exploration, and guide them to realize simulation in a laboratory environment.

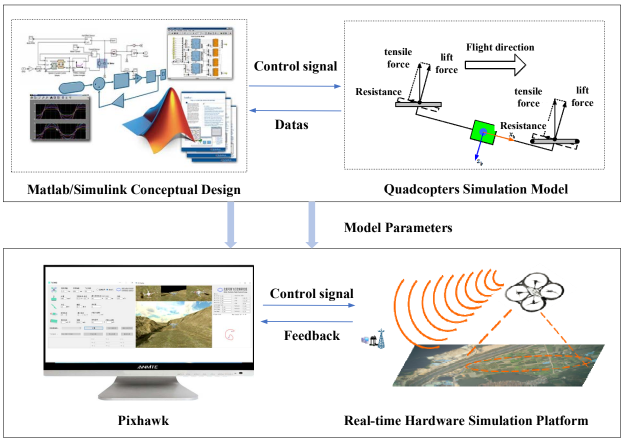

Fig.4. Conceptual Design and Simulation

C. Flight Validation

Then, in the flight validation stage, the sub-models (data acquisition, signal transmission, real-time processing, dynamic system control, and automatic navigation) should be deliberately considered and efficiently combined to realize the automatic control and autonomous visual navigation, as the steps below:

1. Before quadcopters take off, it is necessary to check the system status, including GPS signal, vision computer and flight control system communication.

2. Once the quadcopters rise to the right height, the object search state begins.

3. Once the object is detected, quadcopters start to calculate the state information of the object, such as the distance between the object and itself, the height and yaw angle, and the position of the object.

4. According to the calculated object state information, determine whether the target is within the traceable range.

5. The calculated relative position information of the object is sent as the input of the flight control system to guide the quadcopters to reach the right position and track the desired object.

6、Fine-tune the controller parameters from the ones determined in simulation.

7、Evaluate the performance of the system.

In addition, there might be various emergency situations that may occur during flight validation. For instance, the quadcopters hit something, or the image is motion blurred, or the quadcopters cannot find the right objects. Every time the students encounter problems like that, they may rethink the conceptual design and simulation of their system. It trained their ability to solve engineering problems by the comprehensive application of the knowledge they have learned

IV. IMPLEMENTATION

Besides the multidisciplinary simulation platform and methodology described above, Project Oriented Design Based Learning [8] is also introduced to the comprehensive experimental class, which provides a framework to combine engineering design education with innovation and creativity. The Project Oriented Design Based Learning approach focuses on student experiences and exploration in innovation and creativity where learning is through design-based activities under seven structured steps for the project: Definition, Brainstorming, Research, Design, Modeling, Testing, Delivery [9].

At the very beginning of the comprehensive experiment, the teacher introduces the multidisciplinary simulation platform and related technologies might be involved here. Then, the students were divided into multidiscipline groups. After getting familiar with the hardware and the knowledge they learned before, they begin their project with the seven steps Project Oriented Design Based Learning. During the whole process, the teacher works closely with the students, acting as a mentor and providing appropriate research advice, feedback and guidance to the students and ensuring that all engaged fully with the assigned tasks.

To assess the effectiveness of the experimental process and evaluate the projects, each group, as well as each students, are required to make a presentation and demonstration in front of all the other students and the teachers. Not only the teacher but also each of the students are umpires in this course. Through questions and answers, the students can learn the different solution and novel ideas from each other, which is also a good way to study by themselves during the class.

The different evaluation methods are also involved into the implementation of the comprehensive experiment, which are designed to evaluate how effective the proposed platform and pedagogical context are. It can also be used to continuing develop the future teaching process and projects contents.

1) Compare how the students understanding of different subjects before and after the comprehensive experiment through a questionnaire;

2) Compare the ability of multidisciplinary of the students who participated in the experiment and those who did not;

3) Invite experts to evaluate the teaching process and student experiment of the course;

4) Invite students to evaluate the teaching process and contents of the experiments.

More specifically, the implementation and evaluation of PBL project is provided details in [10], in which give some examples on how to design the questionnaire and survey to the students.

The comprehensive experiments are designed for the senior undergraduate students majoring in Aircraft control and information engineering. In the first one or two years, the students have already learned some basic subjects and professional foundation courses, such as Math, Computer Science, Signal Processing, Image processing, and Control theory. This comprehensive experiments provide an opportunity for students to understand the different disciplines in a systematic project. Through design, simulate, and intelligent control with UAVs under specific tasks, the students can not only have a good review of the previous related courses, learn what they can do with UAVs in aerospace engineering, it can also increase their interests in their professions and extend their ability in specific fields. The proposed comprehensive experiments teaching process can also easily extended to graduate students as a more in-depth research project. For graduate students, they can try to figure out more challenging tasks with the flexible platform, as well as improve their ability to innovate and problem-solving.

V. CONCLUSION

The rapid developments of Artificial Intelligence, the high-speed computing module, and the novel new type of automation equipment are influencing Aerospace Engineering to a great extent and research. Under this situation, how to design the curriculum content to penetrate multi-disciplinary into aerospace engineering education, while attracting students' interest in independent exploration is the problem in the teaching process.

This paper proposes a UVN comprehensive experiment, through a multidisciplinary simulation platform, three steps of curriculum design, and Project Oriented Design Based Learning, which enables students to work on real-world aerospace engineering problems with the multidisciplinary environment. The design and content of the experiment may greatly stimulate the students' curiosity and interest in independent exploration, improve their professional ability and enhance their exploration competence in aerospace areas.

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