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SMCS TEAM: Open Course on Cyber Physical Systems Foundation and Design for Unmanned Aerial Vehicles (UAVs)*

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Abstract— **This abstract describes the project funded by the IEEE SMCS on Transforming Educational Assets and Materials (TEAM) in Systems, Man, and Cybernetics. The project develops an open course on Cyber Physical Systems (CPS) Foundation and Design for Unmanned Aerial Vehicles (UAVs). The course will be available to the public and serve the need of researchers, students and professionals who are interested in conducting UAVs related research. The open course contains integrated modules on control, communication and networking, computing, and artificial intelligence (AI) to provide trainees a comprehensive knowledge needed for UAVs. The course is self-paced and contains quizzes in each module for help students assess the quality of learning and also allow course designers to evaluate the effectiveness of the course materials for continuous improvement. The open course promotes CPS which is a SMCS technical field. It will also attract students and professionals to the SMC community.**

I. Introduction

The purpose of this project is to develop a self-paced open course on Cyber Physical Systems (CPS) Foundation and Design for Unmanned Aerial Vehicles (UAVs). Endorsed by the Cyber-Physical Cloud Systems Technical Committee, the open course will be available to the public and serve the need of researchers, students and professionals who are interested in conducting UAVs related research.

There has been a remarkable surge of interest in UAVs from academia, industry, and federal agencies. The surge is boosted by the broad applications of UAVs in commercial sectors such as transportation, infrastructure monitoring, real estate, filmmaking, and agriculture. According to Statista, the global drone market is projected to reach 41.3 billion by 2026 [1].

UAVs are not simple vehicles. From the CPS perspective, UAVs can be visioned as aerial robots integrated with advanced sensing, computing, communication, and control components. Despite the broad interest of UAVs, this interdisciplinary CPS nature of USVs poses a significant challenge for students and professionals to conduct UAV related research and development. Current UAV training programs, primarily targeted at pilot training, fall short of providing the detailed system design knowledge and skills required for a comprehensive mastery of UAVs.

The challenges identified above motivated us to develop the proposed open course, which provides the foundational learning materials on CPS and its support of the design and development of UAVs. The open course contains integrated modules on control, communication and networking, computing, and artificial intelligence (AI) to provide students a comprehensive knowledge needed for UAVs. The course is self-paced and contains quizzes in each module for help students assess the quality of learning and the course designers to evaluate the effectiveness of course materials. Feedback from the students will be collected for further improvement of the course.

The proposed open course fills the gap on the lack of foundational learning materials on UAVs and will support the growth of community interest in this fast-growing field. Built upon the CPS concepts, the open course also promotes CPS which is a SMCS technical field. In addition, through broad distribution, the course will reach out to students and professionals outside the SMC community and attract them to the community.

II. Methods

The self-paced open course contains the following modules: (1) UAV Platform Design and Regulation where the basics of UAV mechanics and FAA regulations on UAV operations are introduced, (2) UAV Control that ranges from a single UAV control to multi UAVs; 3) UAV Communication and Networking that provides key concepts on wireless channels, and UAV networking techniques, 4) UAV Computing that covers the onboard computing unit design for UAVs and the processing of computation tasks during flight, and 5) UAV AI Applications that focus on various AI techniques, including fundamental learning models and their integration into real-world UAV operations for diverse applications.

Each module is crafted to cultivate the foundational learning of CPS and practical knowledge on UAV technology, ensuring trainees to acquire the essential skills for effective problem-solving and research in UAVs. Each module contains sub-modules of lectures of 10-15 minutes and quizzes in the end. The self-paced course can be paused and resumed any time to facilitate learning. Considering the diverse background of trainees and their specific learning objectives in USVs, they have the option of choosing to complete a subset of the modules instead of going through all modules. A course completion certificate will be issued after the trainee successfully completes the modules with passing quiz scores. The detail of each module is summarized as follows.

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Module 1: UAV Platform Design and Regulation: UAV platform allows lifting and mobility. Its design is complicated, involving a variety of components such as power supply, mechanical rotators, microcontroller, e-compass, GPS, autopilots, and diverse sensors (see Figure 2). This module will introduce the functions of each component, their selections, and the assembly of the components into a functional UAV platform. The latest Federal Aviation Administration (FAA) regulations on UAV operations will be discussed and flight-testing procedures will be described.

Module 2: UAV Control: Control is an essential component for UAVs at many levels. At the most basic level, a UAV relies on an autopilot to stay stable in the air, reject disturbances, and move to desired locations through waypoints or commands from a manual remote controller. At a higher level, path planning formulated as control problems allows UAVs to travel in a time-efficient manner under various physical constraints such as limited onboard power. The new applications of networked UAVs also pose challenging control problems with multiple UAVs, such as formation and collision avoidance that require the communication and control co-design [2]. This module will start with the fundamentals of model-based controls and their design procedures for a single UAV control. In addressing the diverse control problems for UAVs, traditional model-based controls are usually not sufficient. Models can be unknown and environmental uncertainties can modulate system dynamics in a complicated fashion. Data-driven control and uncertainty evaluation will be introduced. Last but not the least, we will also highlight advanced controls for networked UAVs including the autonomous directional antenna alignment for robust UAV networks [3].

Module 3: UAV Communication and Networking: Communication and networking for UAV play a crucial role in various applications, particularly when multiple UAV need to share real-time information and coordinate actions. This module prepares trainees for key concepts in communication and networking. This includes topics such as wireless communication channels, source and channel coding techniques, digital modulation, the seven layers of the open systems interconnection model, cellular systems, Wi-Fi networks, and millimeter wave communication [4]. This module will provide trainees with high-level introductions on these concepts. While these concepts often involve technical and mathematical aspects, the module will prioritize conveying the core ideas without getting overly involved in complex technical details.

Module 4: UAV Computing: UAV applications often involve processing large amounts of data, such as videos and images from onboard cameras, which require substantial computational resources. Traditionally, this demand has been met by offloading computation-intensive tasks to ground servers or remote clouds. However, this approach can lead to significant delays or even failures. Recently, advancements in technology have led to the development of powerful, yet lightweight single-board computers, enabling the direct execution of demanding tasks onboard UAVs [5]. This module will start with an introduction to airborne computing, covering the advantages of airborne computing, new applications it enables, and the technical challenges for achieving high-performance airborne computing. The focus next is on the design of the computing unit for individual UAVs and selecting suitable computing devices to enhance the airborne computing performance. It will also delve into virtualization techniques, which promise to improve the flexibility and programmability of the UAVs. The third part will expand the discussion to multiple UAVs and how UAVs can cooperate and share resources to further enhance airborne computing performance.

Module 5: UAV AI Applications: In the rapidly evolving fields of UAVs, AI stands as a cornerstone technology, revolutionizing how UAV operates and interacts with the world. AI in UAV transcends traditional flight control, enabling autonomous decision-making, enhanced data processing, and adaptive responses to dynamic environments. By integrating AI, UAVs can perform complex tasks such as real-time image and pattern recognition, integrated sensing and communications, and efficient route planning, even in challenging conditions. This module aims to equip trainees with both theoretical knowledge and practical skills in applying AI to UAVs. This module will commence with a comprehensive introduction to the role of AI in augmenting the capabilities of UAV, emphasizing its transformative effects in areas such as autonomous navigation, real-time data processing, and complex decision-making. Following this introduction, the module will pivot to the fundamentals of AI and machine learning, covering a spectrum of learning models — from the basic, like linear regression, to the more advanced and current, such as convolutional neural networks and transformer. The advanced concept of federated learning, a cutting-edge paradigm in distributed machine learning will also be introduced [6]. Trainees will be guided through the technical complexities of implementing FL within UAV frameworks, addressing the challenges posed by constrained computing resources and variable network conditions.

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