Work-in-Progress: Using Nano Drone and RaspberryPi to Teach Robotics and Programming in Online Undergraduate Course

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***Abstract*—This work-in-progress paper emphasizes the use of two distinct hardware components as educational tools to achieve specific learning objectives in computer programming and aerial robotics. In the UNSY 329 - Uncrewed Systems Computation and Programming course at Embry-Riddle Aeronautical University, the faculty introduced the Raspberry Pi 400 alongside the DJI Tello Edu nano drone. The teaching of programming concepts was facilitated through the use of a Python Integrated Development Environment (IDE) on the Raspberry Pi, providing undergraduate students with a tangible representation of command execution in a script-based programming language. This approach allowed students to gain practical experience in using programming for drone control and navigation. By leveraging these hands-on tools, the course effectively integrated fundamental computer programming concepts with real-world applications of robotics technology, demonstrated through the operation of a compact uncrewed aircraft system. Additionally, this method included instructing students in the development and adaptation of algorithms for managing movement and flight operations.**

***Index Terms*—Nano drone, uncrewed system, robotics, flight operations**

I. Introduction

Online education has witnessed remarkable growth in the past decade. According to a report from the Education Department's National Center for Education Statistics [1], there was a substantial 5.7% increase in the number and proportion of college and university students enrolled in online classes in 2017. This growth persisted even as overall post-secondary enrollments experienced a slight decline of 0.5%. The global COVID-19 pandemic, spanning from 2020 to 2023, propelled the adoption of online education to unprecedented levels. Initially implemented as an emergency measure to address school closures, online modality has since been embraced by numerous higher education institutions due to its inherent advantages [2], [3], which include enhanced flexibility, increased interactivity, and the ability for students to pace their own learning.

The transition to online education necessitates a collaborative and concerted effort from various academic and administrative units. At the core of every well-established online program is the curriculum that must maintain the required academic rigor while address the unique challenges facing both instructors and students in this new learning environment. These challenges include developing "time management skills, being technologically prepared and computer literate, possessing good work ethics, being effective communicators and goal-oriented learners, ensuring academic readiness, and fostering personal commitment, independence, and responsibility" [2].

Embry-Riddle Aeronautical University Worldwide (ERAU-WW) is one of the leading online universities in the country and had been ranked consistently either No. 1 or No. 2 among all institutions, private or public, in the annual U. S. News and World Report from 2016 to 2023. Beginning as a school that offered distance education primarily to active service members and veterans, ERAU-WW was among the first universities to recognize the potential of, and thus shift to online education. Online courses at Embry-Riddle Worldwide may include both asynchronous and synchronous components. Asynchronous learning allows students to access course materials and complete assignments at their own pace, while synchronous activities, such as live lectures or virtual classroom sessions, provide opportunities for real-time interaction and engagement. Students can choose from a variety of aviation and aerospace-oriented academic and professional programs, both at the graduate and undergraduate levels, that teach novel and emerging technologies and trends, such as uncrewed systems, cybersecurity, and sustainability.

The integration of small indoor drones (or uncrewed aircraft systems UAS) into STEM (Science, Technology, Engineering, and Mathematics) education has gained significant attention in recent years. Several studies have shown that such integration can lead to improved learning outcomes. For example, students who participate in drone-related projects tend to perform better in STEM subjects due to the hands-on, experiential learning environment that drones provide [4]. Furthermore, exposure to drones and robotics in schools and universities can prepare students for future careers in technology and engineering fields. Programs that focus on building, tuning, and programming drones help students develop skills that are directly applicable to many high-demand careers [5].

In this work-in-progress paper, we present a case study of how a nano drone and a Raspberry Pi 400 are used as course material in an undergraduate online course (UNSY 329 Uncrewed Systems Computation and Programming) to teach robotics and programming. The implementation and assessment period were in the academic years 2021/2022 and 2022/2203. Though similar efforts have been made to integrate drone education in engineering, natural sciences, and even high school curriculum as summarized in Section II, we believe ours is the first attempt of such course serving non-STEM and online college students.

The rest of the paper is organized as follows. Section II reviews the latest exemplary nano drone education in both universities and open online platforms. Section III introduces the two hardware platforms upon which UNSY 329 is developed. Section IV discusses the learning activities in UNSY 329 that are built upon the nano drone, Raspberry Pi, and Python IDE. We conclude the paper by providing a summary of lessons learned in Section V and offering a preview of the next phase of assessment in Section VI.

II. State of Nano Drone Education

One significant challenge identified in the literature is the need for adequate teacher training and curriculum development. Many educators may not have the technical background required to effectively teach drone-based lessons. As such, professional development programs and detailed curriculum guides are essential to equipping teachers with the necessary skills. This section explores the benefits, challenges, and educational outcomes associated with using drones in teaching STEM subjects, drawing from recent published studies and articles.

Ioannou and Makridou [6] highlighted that robotics activities, through programming and problem-solving tasks, provide a hands-on approach that enhances students' ability to think computationally. They emphasize that computational thinking (CT) development in robotics extends beyond mere coding to include evaluating and iterating solutions, which are critical components of CT. Berland and Wilensky [7] noted that physical robotics can sometimes increase cognitive load and distract students from core STEM learning. This complexity necessitates careful instructional design to ensure robotics activities support rather than hinder learning outcomes. The success of robotics in education heavily depends on the instructional strategies employed. Studies have shown that when robotics is integrated with well-designed instructional interventions, such as pre-programming activities and strategic pauses for reflection, students are better able to develop and apply computational thinking skills. The framework proposed by Romero et al. [8] suggests that educational robotics should involve activities that precede programming to build foundational knowledge, which is often overlooked in practice. Robotics also plays a significant role in fostering collaboration among students. According to Kerimbayev et al [9], collaborative robotics activities not only enhance computational thinking but also promote social learning and teamwork. These activities allow students to engage in problem-solving together, which can lead to a deeper understanding of complex concepts and improve learning outcomes in computer science education.

In [5], incorporating drones into the classroom has been shown to significantly enhance student engagement and motivation. Drones offer a hands-on learning experience that can make abstract STEM concepts more tangible and interesting. For instance, students can learn about aerodynamics, physics, and coding through direct interaction with drones, which helps in sustaining their interest in STEM subjects. Drones and robotics, as well as small computer systems such as the Raspberry Pi 400, provide a platform for students to apply theoretical knowledge in practical settings [10]. This is crucial for understanding complex STEM concepts. By building and programming drones, students can explore principles of physics, mathematics, and engineering in a real-world context, enhancing their problem-solving skills and critical thinking. Researchers at UW-Platteville highlighted the benefits of integrating programmable drones into STEM curricula [5]. The study found that drones helped bridge the gap between visual and gamified learning, increasing student engagement and making complex concepts more accessible. A similar course to UNSY 329 offered to engineering students in several universities is introduced in [11]. It is a full course for autonomous aerial robotics inside the RoboticsAcademy framework and focuses on drone programming through practical learning. In [12], exemplary student projects conducted with the use of DJI Tello such as "TelloBird" (QR trajectory generator) and "Sentry drone" for detecting and tracking any humans entering a given area, are presented. The paper also discusses the general application of low-cost, ready-to-use, compact-size flying robots as an experimental platform along with their hardware and software architecture, mathematical model with parametrization, as well as proposed new state machine. A thematic UAS platform that systematically exposed students to the principles underlying robotic systems and the scientific method is introduced in [13]. A survey for the most recent educational robotics is developed in [14], while the authors also propose a set of six learning outcomes that can offer a starting point for a viable model for the design of robotic activities. Five readily accessible "departure points", namely: timed racing trials; precision flight obstacle courses; computer coding; videography; and domain-specific knowledge of drone operation laws and ethics, are proposed in [10] to include drones in contemporary STEM and vocational technology school classrooms that help teachers address common curricular goals. In [15], a UAS education module and laboratory exercise for natural resource science students is developed where students were taught the steps of UAS data acquisition and processing through lectures and UAS simulation videos. A drone and Scratch programming designed on STEM coding framework for kids to learn coding is discussed in [5], where utilizing drone in STEM-coding has shown to transform abstract concepts into concrete learning, deliver an entertaining and motivating learning environment, combine STEM theory with practice, and provide a hand-on skill which is dynamic and attractive. Similar findings are also reported in [16] where a study of a set of drone technologies designed based on the theory of significant learning through the use of active methodologies is carried out with 30 high school students.

Several online commercial platforms offer programs to use drones to facilitate interdisciplinary learning by combining elements of computer science, engineering, and technology. DroneBlocks [17] is an integrated platform that provides a block-based programming interface via web-browser or app to develop movement algorithms for small indoor drones. Using the Tello drone, this program offers cloud-based lessons that teach students coding, physics, and teamwork, demonstrating how drones can enhance traditional STEM education methods. Another existing best-practice example for STEM education with small drones is the DroneMasters Academy, founded in Germany [18]. The project has effectively integrated small indoor drones and robotics into STEM education through a comprehensive and innovative approach. It offers a variety of courses that cater to different age groups and interests and cover fundamental topics like drone flying, construction, and programming, which are essential for understanding modern technologies.

III. Materials and Hardware

In this section, we provide an overview of the two distinct material platforms for the project.

A. Raspberry Pi

The Raspberry Pi is a small, affordable, and versatile single-board computer developed by the Raspberry Pi Foundation. There are several generations of Raspberry Pi available with different settings and learning environments. Fig. 1 visualises a Raspberry Pi 4 Model B with detailed overview of all ports and connectors.

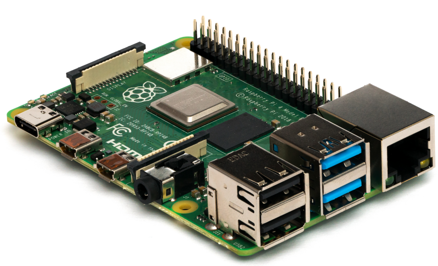

Fig. 1. Raspberry Pi 4 Model B. Source: Michael H. (Laserlicht)/Wikimedia Commons/CC BY-SA 4.0

For the purpose of UNSY 329 Uncrewed Systems Computation and Programming, a variant of the Raspberry Pi was chosen. The Raspberry Pi 400, a compact computer built into a keyboard, offers a versatile platform for learning coding, electronics, and robotics. When paired with a nano indoor drone, it creates a dynamic and engaging STEM teaching tool. Fig. 2 visualizes the respective hardware resources of Raspberry Pi 400.

Fig. 2. RaspberryPi 400. Source: SimonWaldherr/Wikimedia Commons/CC BY-SA 4.0

Fig. 3. Ryze Robotics Tello Edu variant. Source: SimonWaldherr/Wikimedia Commons/CC BY-SA 4.0

B. Nano Drones

For the purpose of this paper, nano drones are defined as very small and lightweight robotic aerial vehicles, with a weight of less than 250 grams and designed for indoor flights. They can be operated remotely piloted by a control unit, like a handheld radio control (RC) or pre-programmed in connection with a computer device. Data links for command and control and telemetry are standard free-license frequencies for consumer device RC. When connected to a computer device, a nano-drone mostly uses Wi-Fi or Bluetooth for standard consumer device interfaces.

We do not favor any particular nano-drone and adopt vendor-neutral, non-exhaustive examples that fit the performance parameters and needs for the course project. Fig. 3 shows Ryze Robotics Tello Edu variant, a typical nano-indoor drone for educational purposes, which we adopt in the underlying course example.

Nano drones do not have Global Navigation Satellite Systems (GNSS) guidance, so their exact relative or absolute positioning must be determined by onboard proprioceptive sensors or other external means. Those internal sensors are mostly Microelectromechanical Systems (MEMS) units, which are miniature devices that integrate mechanical and electrical components on a microscopic scale.

- Accelerometers measure the drone's linear acceleration along the three axes (X, Y, Z). By integrating acceleration over time, they provide information about the drone's velocity and displacement. Accelerometers help drones detect changes in speed and direction, enabling them to maintain stability and control.

- Gyroscopes measure the drone's angular velocity or rate of rotation around its axes. They provide feedback to stabilize the drone's orientation and prevent it from spinning or tilting uncontrollably. Gyroscopes are essential for maintaining flight stability, especially in response to external disturbances.
- Barometers measure atmospheric pressure, which varies with altitude. By monitoring changes in pressure, barometers can estimate the drone's vertical position and altitude relative to a reference point. Barometers are useful for altitude control and maintaining a consistent flight level indoors, where GNSS signals are unavailable.
- The opposite of proprioceptive sensors used in the positioning of indoor nano-drones are exteroceptive sensors. While proprioceptive sensors provide information about the drone's internal state and motion, such as its position, orientation, and velocity, exteroceptive sensors gather information about the external environment in which the drone operates. Exteroceptive sensors help drones perceive and interact with their surroundings, enabling tasks such as obstacle detection and avoidance
- Optical flow sensors use cameras to track visual features on the ground and estimate the drone's horizontal motion relative to its surroundings. By analyzing changes in image position over time, optical flow sensors provide feedback for position and velocity control, especially in environments with texture-rich surfaces. Time of Flight (ToF) sensors emit infrared light pulses and measure the time it takes for the pulses to reflect off objects and return to the sensor. By calculating the round-trip time, ToF sensors can estimate distances to nearby obstacles and help drones avoid collisions during indoor flight.

Internal Measurement Units (IMU) combine accelerometers and gyroscopes to provide comprehensive motion sensing capabilities. By integrating data from both sensors, IMUs can accurately determine the drone's position, orientation, and velocity in three-dimensional space. Several operational scenarios provide real-time feedback, allowing students to observe the immediate effects of their control or programming decisions. This iterative process promotes a deeper understanding of cause-and-effect relationships in programming and robotics.

IV. Course Activities using Hardware Components

Connecting the nano drone and the Raspberry Pi 400 via data link, such as Bluetooth or Wi-Fi enables the student to utilize programming interfaces to operate the aerial robotic vehicle. Fig. 4 shows an example of an instructor introducing the nano drone in an online class setting. Several assignments and activities introduce the general concept of the Raspberry Pi and the nano drones as platforms and concepts.

Fig. 4. UNSY 319 Instructor Demonstrating Nano Drones in Online Video

In the following module activities students learn programming languages using the Python Integrated Development Environment (IDE) on the Raspberry Pi.

- Core Concepts: Basics of Python Programming
- Lab Activity: Blink an LED Using General Purpose Input Output (GPIO)
- Lab Activity: Using Objects to Control an Unmanned System
- Lab Activity: Obstacle Course

Students learn to use script languages such as Python to control both the Raspberry Pi and the drone. They can write code to interface with GPIO pins on the Rasperry Pi for sensor integration and control external components. Additionally, students use Python or other programming languages to send commands to the drone, controlling its flight path, maneuvers, and interaction with external sensors. Also, the Raspberry Pi 400 can be used as a central hub for integrating various sensors, such as cameras, ultrasonic sensors, or environmental sensors. Students learn how to interface these sensors with the Raspberry Pi and use the data collected to make decisions for controlling the drone. For example, student can program the drone to detect and avoid obstacles using ultrasonic sensors or to perform tasks based on environmental conditions sensed by environmental sensors.

Fig. 5 shows the course activities using the Python Integrated Development Environment (IDE) on the Raspberry Pi 400 connected to the nano drone.

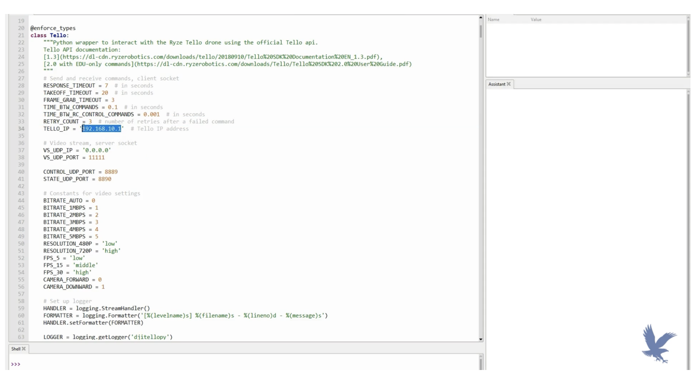

Fig. 5. Python IDE for Programming Drone

V. Lessons Learned from Course Integration

Given the fully online modality of ERAU-WW, the two technical platforms chosen for this course integration project provide several benefits for the academic environment.

- Smaller drone is lightweight and designed for indoor use, making it suitable for classroom environments where safety is a priority. Students can explore drone technology without the need for outdoor space or specialized facilities. Also, for an online campus such as the Embry Riddle Aeronautical University, aspects of availability and accessibility are prime indicators for course hardware options. Students are located all over the globe and will take the online classes from their location. Being able to order and receive shipments from a hardware vendor to all locations is a key aspect for realization of such projects.
- Another aspect to mention is affordability. Miniature drone technology is still in its nascent phase with small numbers of sales worldwide, compared to commercial off the shelf consumer hardware. Whereas the Raspberry Pi 400 was being sold worldwide for around $ 100 in 2023, small classroom drones can easily reach prices over $ 500, depending on the vendor and capabilities. Affordable Ready to Fly kits of nano indoor drones, enable academic institutions to integrate this engaging hardware into course environments. Drones are increasingly used in industries such as agriculture, environmental monitoring, film-making, and disaster response. By learning to program and control drones, students develop skills that are applicable to future careers in these fields.

ERAU-WW regularly conducts student end-of-course surveys to measure course effectiveness and the achievement of learning outcomes. Also, the satisfaction level of students with the learning environment and the course material used is measured in the end-of-course surveys. In the case of UNSY 329, students reported a very high satisfaction with the utilization of the two hardware platforms and the associated activities. Another factor to determine the effectiveness, impact, and suitability for the described course hardware, are the assessments outcomes and grading results of students. Those are a direct indicator for the achievement of course learning outcomes. In the measured period for this case study, student final grade results in the course where A (94.64).

VI. Conclusion

In this work-in-progress paper, we present an online undergraduate course that combines Raspberry Pi and nano drone that serves non technical students who want to pursue career opportunities in uncrewed systems. Engaging in projects like creating autonomous flight missions, building obstacle courses, or designing aerial photography setups fosters creativity and innovation. Working with drones encourages teamwork, communication, and collaboration among students. Students can brainstorm ideas, troubleshoot problems together, and share their discoveries, fostering a collaborative learning environment.

For programs with similar curriculum development aspirations, we recommend the utilization of low-threshold hardware such as a nano drone and Raspberry Pi to teach robotics and programming in an undergraduate academic environment. The effects of hardware platform and course content will be evaluated through quantitative measures on pre- and post-course assessments in the upcoming academic year.

References

[1] S. A. Ginder, J. E. Kelly-Reid, and F. B. Mann, "Enrollment and employees in postsecondary institutions, fall 2017; and financial statistics and academic libraries, fiscal year 2017," U.S. DEPARTMENT OF EDUCATION, Tech. Rep., 2019.

[2] P. Paudel, "Online education: Benefits, challenges and strategies during and after covid-19 in higher education." *International Journal on Studies in Education (IJonSE)*, vol. 3, no. 2, 2021.

[3] O. B. Adedoyin and E. Soykan, "Covid-19 pandemic and online learning: the challenges and opportunities," *Interactive learning environments*, vol. 31, no. 2, pp. 863–875, 2023.

[4] L. Smith. (2020, Jun.) Incorporating drones into stem education. Accessed 2024/01/30. [Online]. Available: https://robotlab.com

[5] M. Roopaei and J. Horst, "Stem-coding using drones," in *2021 IEEE integrated STEM education conference (ISEC)*. IEEE, 2021, pp. 140–145.

[6] A. Ioannou and E. Makridou, "Exploring the potentials of educational robotics in the development of computational thinking: A summary of current research and practical proposal for future work," *Education and Information Technologies*, vol. 23, no. 6, pp. 2531–2544, Nov. 2018.

[7] M. Berland and U. Wilensky, "Comparing virtual and physical robotics environments for supporting complex systems and computational thinking," *Journal of Science Education and Technology*, vol. 24, Mar. 2015.

[8] M. Romero, A. Lepage, and B. Lille, "Computational thinking development through creative programming in higher education," *International Journal of Educational Technology in Higher Education*, vol. 14, Dec. 2017.

[9] N. Kerimbayev, N. Nurym, A. Akramova, and S. Abdykarimova, "Educational robotics: Development of computational thinking in collaborative online learning," *Education and Information Technologies*, vol. 28, pp. 1–23, Apr. 2023.

[10] T. F. Slater, "Identifying implementation strategies for integrating drones into stem and career technology education cte programs," *Education Sciences*, vol. 14, no. 1, p. 105, 2024.

[11] J. M. Cañas, D. Martín-Martín, P. Arias, J. Vega, D. Roldán-Álvarez, L. García-Pérez, and J. Fernández-Conde, "Open-source drone programming course for distance engineering education," *Electronics*, vol. 9, no. 12, p. 2163, 2020.

[12] W. Giernacki, J. Rao, S. Sladic, A. Bondyra, M. Retinger, and T. Espinoza-Fraire, "Dji tello quadrotor as a platform for research and education in mobile robotics and control engineering," in *2022 International Conference on Unmanned Aircraft Systems (ICUAS)*. IEEE, 2022, pp. 735–744.

[13] L. C. Félix-Herrán, C. Izaguirre-Espinosa, V. Parra-Vega, A. Sánchez-Orta, V. H. Benitez, and J. d.-J. Lozoya-Santos, "A challenge-based learning intensive course for competency development in undergraduate engineering students: Case study on uavs," *Electronics*, vol. 11, no. 9, p. 1349, 2022.

[14] S. Evripidou, K. Georgiou, L. Doitsidis, A. A. Amanatiadis, Z. Zinonos, and S. A. Chatzichristofis, "Educational robotics: Platforms, competitions and expected learning outcomes," *IEEE access*, vol. 8, pp. 219 534–219 562, 2020.

[15] M. M. Bolick, E. A. Mikhailova, and C. J. Post, "Teaching innovation in stem education using an unmanned aerial vehicle (uav)," *Education Sciences*, vol. 12, no. 3, p. 224, 2022.

[16] I. Yepes, D. A. C. Barone, and C. M. D. Porciuncula, "Use of drones as pedagogical technology in stem disciplines," *Informatics in Education*, vol. 21, no. 1, pp. 201–233, 2022.

[17] Drones in the classroom. Accessed 2024/01/30. [Online]. Available: https://droneblocks.io

[18] DroneMasters Academy. Inspiring for future technologies since 2017. Accessed 2024/01/30. [Online]. Available: https://dronemasters.academy