DART: Drone-Assisted Replication Training

SP24 Capstone: ***Final Design Report***

Team Number SP24-03

Team Members: Aaron Yagudayev, Jinam Modasiya, Keyur Rana, Ryan Meegan, and Sean Maniar

Advisors: Dr. Laleh Najafizadeh (ECE) and Dr. Laurent Burlion (MAE)

***Abstract*—**To simplify and accelerate drone training, we propose a feedback-assisted replication routine that we call DART: drone-assisted replication training. The system will be composed of two transmitters, a computer, PixHawk flight controller, a Raspberry Pi, an Arduino, and a drone; it will feature an instructor—who is a novice drone pilot—and a student who wants to learn. The instructor will fly the drone using their transmitter and the student will copy their flight path on their transmitter via one of three modes: trace, real-time, and independent mode. These modes offer varying degrees of difficulty to meet the student at their level and raise them up a tier.

Keywords*—drones, replication learning, haptic feedback, RF/wireless communication*

I. Introduction

A. Background

The popularity of drones has been increasing rapidly, being used in a diverse set of applications from surveillance, surveying, agriculture, defense, and more. In fact, in 2018, the worldwide industry revenue was $2.9B and is expected to increase to $4.7B in 2028. Depending on the drone's configuration and an individual's familiarity with aircraft in general, learning to pilot a drone can be difficult. Therefore, given the large drone demand, there is an overwhelming need to teach individuals to fly drones in a fast, safe, and cost-effective manner. Today, there are only two common methods to train drones: practical training and VR simulator training. Practical training involves real hands-on piloting of actual drones and is the most effective method; however, it may not necessarily be the safest, especially if the pilot is in an enclosed space. Additionally, depending on how expensive the training drone is, it can be costly to repair it if the student crashes it. On the other hand, in VR simulators, students use a VR controller to pilot a drone in a simulated, virtual space via a computer program. While this method is certainly safer—and could potentially be more cost-effective depending on the VR setup and simulator designed or used—it may not be the most accurate and effective. As can be seen, there is not an optimal training method at the moment, and something should be done to fix this problem.

B. Problem

With the increased demand for competent drone pilots, we hope to offer a cost effective and safer alternative to the already existing VR simulation technology. While VR simulations can provide a realistic visual experience, they lack the physical feedback that real-life drone piloting provides. Oftentimes, pilots rely on sensors such as GPS, obstacle detection to navigate safely. VR simulations may not provide an accurate simulation behavior of these sensors which may lead to a gap in training for real-world scenarios where the sensor data is very important. While VR simulations can offer a cost saving compared to real world training practices, the initial cost of setting up VR equipment and the software licenses can be quite expensive. In addition, access to high-quality VR simulation equipment may be limited particularly for individuals who just want to learn to pilot drones casually or have budget constraints. Hence why the development of a safer and cheaper alternative that is commercially available for anyone is crucial to help match the increased demand.

C. Objective

The goal of this project is to establish an effective and cost-efficient framework for training novice drone pilots under the guidance of experienced instructors. This system will be structured around replication training, complemented by an array of live feedback mechanisms, to optimize the learning process. Students will be trained in two distinct modes of instruction: Trace, where servo mechanisms on joysticks replicate the flight path of the instructor either in real-time or from previously recorded flights, and Comparison, which tasks students with controlling joysticks to emulate the flight trajectory of the instructor as recorded. To address the diverse skill levels of students, the system will provide varying difficulty levels, ensuring a tailored learning experience for each individual. Real-time feedback during flight replication will be facilitated through the integration of audio cues and haptic feedback, furthering the depth of learning and promoting skill development.

D. Approach

We propose a new method that aims to combine the safeness of the simulator with the effectiveness of practical training using a feedback-assisted, replication training scheme. In this system, an instructor will pilot the drone along a desired flight path using their transmitter. This flight path will be recorded via a device that we call the controller module. When the instructor is done, they can flip a switch on their transmitter that puts the system into replay mode, instead of the prior record mode. In replay mode, the student uses their transmitter to mimic the same path the instructor took all the while receiving both auditory and haptic feedback (vibration) depending on their accuracy. Based on the student's skill level, the instructor can opt to put the system in one of three modes: trace, real-time, and independent. Trace mode is the simplest difficulty where the student mimics the recorded flight path on the transmitter without flying the physical drone. The real-time mode is a step-up in difficulty where the student mimics the instructor's flight path in real-time while receiving their directions. Independent mode is the hardest level of difficulty where the student controls the physical drone on their own without any directions from the instructor. If the system is currently in independent mode, the drone will auto-correct itself to prevent itself from crashing if the student goes too far off course. A more detailed description of the various components involved are presented below along with a graphic of the overall system.

II. Methods/Results/Approach

A. Conceptual Design

The main deliverables in the project are the control module, main transmitter, and training transmitter. The interaction between them is pictured in the block diagram below.

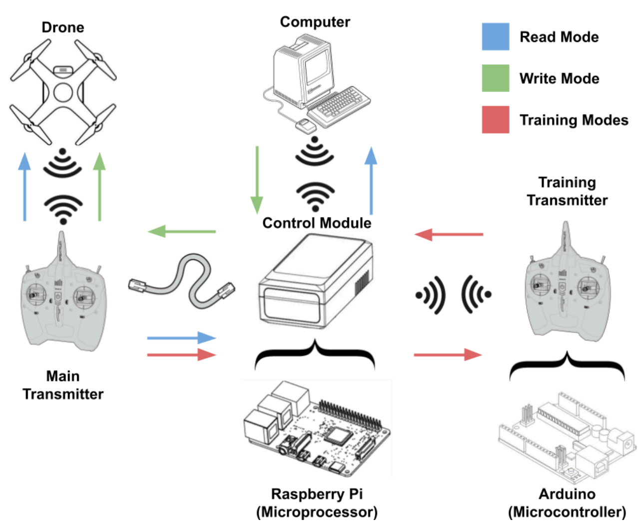

Fig. 1 Component Block Diagram

B. Detailed Design

1) Control Module

The control module is a small, portable embedded device that attaches to the back of the instructor's transmitter. When the system is in record mode, It will parse the four voltage values from the instructor's transmitter—throttle, yaw, pitch, and roll—through the use of an analog-to-digital converter (ADC). An onboard Python program, using the CircuitPython library, will then generate the flight path control system. The Python program generates a comma-separated values file (.csv) where each column represents the four voltage values and the rows represent the change in time. When the system is in replay mode, the device will output the control system via a digital-to-analog converter (DAC) to the student's transmitter. Thus, the pipeline is essentially as follows: take the analog input from the main transmitter and route it through the ADC into the Pi, the python program saves a .csv file for the four voltage values, and finally route the output through the DAC to convert it from digital back to analog so it can be used in the training transmitter. The value ranges between the DAC and ADC differ so a conversion factor had to be utilized. For the purposes of this project, the embedded device will be a Raspberry Pi 5.

2) Main Transmitter

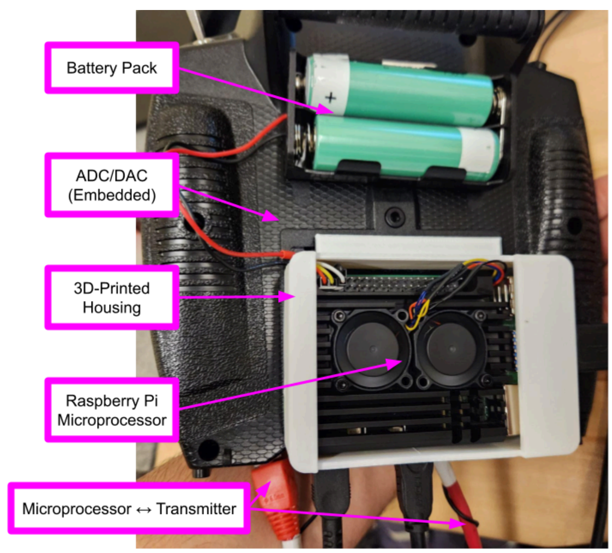

Fig. 2 Control Module mounted on Main Transmitter

The main transmitter is a modified Spektrum DXe that has an extra switch to toggle between the record as well as replay mode. Flipping the switch in the upright position puts the system in the record mode, which generates a control system based upon the voltage values derived from the transmitter, while flipping the switch puts the system in the replay mode, which sends the control system to the training transmitter to handle the feedback.

3) Training Transmitter

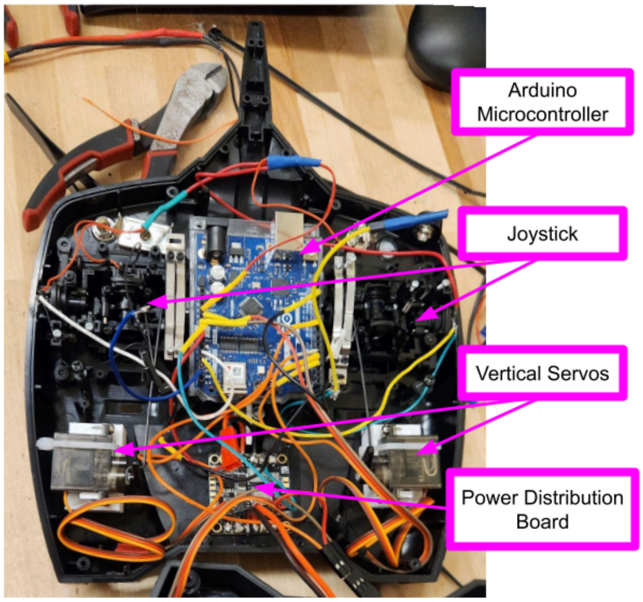

Fig. 3 Inside of Training Transmitter

The training transmitter is a modified Spektrum DXs equipped with haptic feedback and servo-controlled control sticks. It connects directly to the instructor's transmitter via an Arduino to enable replay of the instructor's inputs in real-time or from a previously generated flight path. The training transmitter has three operational modes. In the first mode, the servos that are placed inside the transmitter dictate joystick movements, replicating the exact maneuvers corresponding to the replayed flight. Here, learners can trace the joysticks, understanding the flight path's nuances. In the second mode, the user controls the transmitter, attempting to mimic the replayed flight independently. Accurate joystick movements won't trigger any response, but deviations will activate the haptic feedback. The intensity of this feedback escalates as the user's movements deviate further, guiding them to mirror the correct flight path. This system can also be employed in real-time, allowing learners to emulate the trainer's joystick movements as they pilot the drone. In the third mode, we have enhanced the haptic training controller's connectivity so that it can directly link to the main transmitter and replicate its outputs as the instructor operates the drone.

C. Use of Standards

1) Standard Network Technologies

The Raspberry Pi and Arduino use an MQTT server to communicate with each other and a computer. The Arduino also uses bluetooth low energy (BLE) to communicate with a phone app.

2) Standard Software Development Tools

MATLAB and Python are being used to program the control systems and to interface between a computer and the control module. The Arduino Integrated Development Environment (IDE) is used to program the Arduino microcontroller used in the training transmitter. Ardupilot Mission Planner and QGroundControl are used to control the flight controller, simulate drone flight, and determine flight diagnostics.

3) Open Source Standards

The Linux distribution Ubuntu is used as the operating system for the Raspberry Pi microprocessor, allowing for easy use of Python and its libraries.

III. Cost and Sustainability Analysis

A. Economic Cost

The total cost of the purchased materials used for the project is broken down in Table 1. The most significant cost can be attributed to the Raspberry Pi. The total cost of the materials owned by our advisor is broken down in Table 2.

1) TABLE 1. Purchased Materials List

Item	Cost
Raspberry Pi 5 (1)	$80
Linear Servo (4)	$32
Control Rod (1)	$7
Brushed Motor ESC (1)	$15
Power Distribution Board (1)	$12
9g Plastic Servo (4)	$8
Haptic Motor (2)	$8
4-Channel DAC (1)	$13
4-Channel ADC (1)	$13
9g Metal Servos(8)	$24
Linkage Stoppers	$9
TOTAL	$221

2) TABLE 2. Advisor Materials List

Item	Cost
Drone	$150
PixHawk Flight Controller	$200
Spektrum DXs	$115
Spektrum DXe	$115
Arduino Uno R3	$28
TOTAL	$608

The Raspberry Pi serves as the microprocessor, facilitating communication between the controller module and the main computer, as well as the instructor transmitter. Four linear servos, control rods, and linkage stoppers collectively enable movement of the two joysticks within the training controller, allowing for new user training on joystick manipulation. The brushed motor electronic speed controller (ESC) manages all servos within the project, while the power distribution board supplies power to each component. Nine gram servos monitor joystick movements within the instructor controller. Haptic motors deliver tactile feedback in the training controller. The 4-Channel Digital to Analog Converter (DAC) and Analog to Digital Converter (ADC) respectively handle write and read operations within the instructor controller. Nine gram metal servos provide additional reinforcement for joystick control. Costs for the last three items are approximate, as they were previously acquired by our advisor. The drone serves as the object of control for the controllers. The Spectrum DXe/DXs Controllers serve as the instructor and training controllers, respectively. The Pixhawk Flight Controller receives input from the controllers and simulates flight to facilitate testing.

B. *Environmental Impact*

DART offers a potential reduction in emissions compared to traditional drone training methods, especially if it replaces in-person training sessions or multiple trial-and-error flights. By enabling students to learn efficiently and effectively, it minimizes unnecessary flights, thus reducing fuel consumption and emissions associated with drone operations. The production and operation of the DART system could potentially increase demand for certain electronic components, which may put pressure on natural resources used in their manufacturing, such as rare earth metals for circuitry or lithium for batteries. However, compared to other industries like automotive or aviation, the overall impact is likely to be minimal due to the smaller scale of drone technology. The use of drones is subject to regulations regarding emissions, noise pollution, and flight restrictions, among other factors. As such, the DART system would need to comply with these regulations to ensure its environmental impact remains within acceptable limits. Additionally, adherence to recycling and disposal regulations for electronic waste generated by the system's components would be necessary to mitigate environmental harm.

C. *Social Impact*

The modified main transmitter can enhance the learning experience for drone pilots, allowing for better training and skill development. It can also potentially improve safety by enabling instructors to review and analyze flight data with students, reducing the risk of accidents and improving overall competency. The product addresses the need for effective drone pilot training and skill development. It caters to both individuals seeking to become proficient drone operators and communities or industries requiring well-trained drone pilots for various applications such as aerial photography, surveying, and emergency response. While the product itself may not directly change consumption patterns, it could indirectly contribute to increased adoption of drones for professional and recreational purposes due to improved training capabilities. An impact on employment stemming from modified drone transmitters could be the creation of specialized drone training and education programs. As the demand for skilled drone pilots increases across various industries, there will likely be a corresponding need for qualified instructors to teach drone operation, safety protocols, and advanced flight techniques. The advancement of drone technology often creates new job opportunities in various sectors such as aerial cinematography, mapping, agriculture, and infrastructure inspection. The modified drone transmitters could contribute to this trend by fostering better-trained pilots who can fulfill these roles effectively. Safety is a significant consideration in drone operation, and the ability to review flight data and simulate scenarios with the modified transmitters can contribute to safer drone operations. However, there may be concerns related to potential misuse or accidents during training sessions, emphasizing the need for proper guidelines and supervision. Regulations governing drone operation already exist to address social and environmental concerns such as privacy, airspace safety, and environmental impact. The modified drone transmitters would need to comply with these regulations, ensuring that their use does not pose additional risks or liabilities.

IV. Conclusion

A. *Results Summary*

Overall, our project demonstrates the effectiveness of the proposed framework in training novice drone pilots, offering versatile learning experiences and progressive skill development through replication training and live feedback mechanisms. The integration of varying difficulty levels and real-time feedback further enriches the learning process, fostering proficiency among learners. The economic cost analysis of our project reveals that while the Raspberry Pi initiative constitutes a significant portion of our expenses, the investment in the drone itself, priced at $150, serves as a crucial foundation for our project's aerial capabilities. This cost is justified by the drone's versatility and durability, ensuring reliability throughout our experimentation process. Furthermore, the environmental impact assessment underscores both the potential benefits and challenges associated with the DART system. While it holds promise in reducing emissions compared to traditional drone training methods by minimizing unnecessary flights, concerns arise regarding the increased demand for electronic components and its consequent pressure on natural resources. Adherence to regulations governing emissions, noise pollution, and recycling will be essential to mitigate any adverse environmental effects. Additionally, the social impact analysis highlights the transformative potential of the modified main transmitter in enhancing the learning experience for drone pilots. By facilitating better training, improving safety, and addressing the growing demand for skilled drone operators across various industries, the DART system can contribute significantly to the advancement of drone technology and the creation of new job opportunities. However, careful consideration of safety guidelines and compliance with existing regulations is imperative to ensure the responsible and beneficial deployment of the modified transmitters. Thus, our project not only demonstrates the efficacy of our training framework but also acknowledges and addresses various economic, environmental, and social implications.

B. *Further Development*

The main focus of the further development of our project would be commercialization. In order to be commercially viable, a large change would have to be made to the project in reducing it to just the training transmitter. To do this, the system would have to be modified so that it could receive signals from an unmodified main transmitter that the consumer would already possess, which is technically possible but more time intensive. To further cut costs, a custom transmitter could be designed to largely reduce the cost of the off the shelf transmitter purchased to make the prototype. Finally, the Raspberry Pi and Arduino could be replaced with an embedded processor to greatly reduce costs, as these boards were used purely for their ease of use in prototyping.

V. Acknowledgements

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VI. References

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