ECE 445 Team 64 Design Review

First-Person View Drone

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Contents

1 Introduction

1.1 Problem

The University of Illinois Center for Autonomy Lab is faced with the challenge of developing a replicable FPV drone that can partake in in-lab races while being precisely tracked using Vicon motion capture technology. Traditional FPV racing drones tend to be quite large and are therefore not compatible with the small space of the drone arena. The objective is to create a system that allows for the comparison of flight paths and the collection of motion data to determine the most efficient navigational strategies. This endeavor will not only contribute to research in drone autonomy but also enhance the lab's engagement with drone technology through the excitement of competitive racing.

1.2 Solution

To address the unique requirements of the University of Illinois Center for Autonomy, the proposed solution involves the development of a custom-designed FPV drone, built upon the Crazyflie drone platform. This enhanced drone will be equipped with a camera subsystem, capable of transmitting a real-time visual feed to a head-mounted display. Additionally, it will display accelerometer and altitude data, offering the pilot an immersive navigational experience. To support this, custom PCBs will be fabricated to integrate the necessary electronic components, ensuring seamless operation between the transmitter, receiver, and the headset. Moreover, the solution incorporates the utilization of the Vicon motion capture system, enhanced by infrared LEDs, to facilitate accurate tracking of the drones during flight. This system will enable the analysis of flight efficiency and path optimization and increase the accessibility and interest in drone technology through the exhilarating arena of drone racing.

1.3 Visual Aid

The visual schematic for the FPV drone system features the compact Crazyflie drone, equipped with a high-definition camera capable of capturing and transmitting vivid aerial footage. Adjacent to the drone is the FPV headset, a critical component for the immersive piloting experience, showcasing the 'Fat Shark' goggles renowned for their clarity and responsiveness. Essential to the system's functionality are the antennas, depicted to highlight their role in maintaining a strong and stable connection between the drone and the headset. This visual aid underscores the interconnectivity and synergy of the components, which together form the backbone of a state-of-the-art FPV drone racing setup.

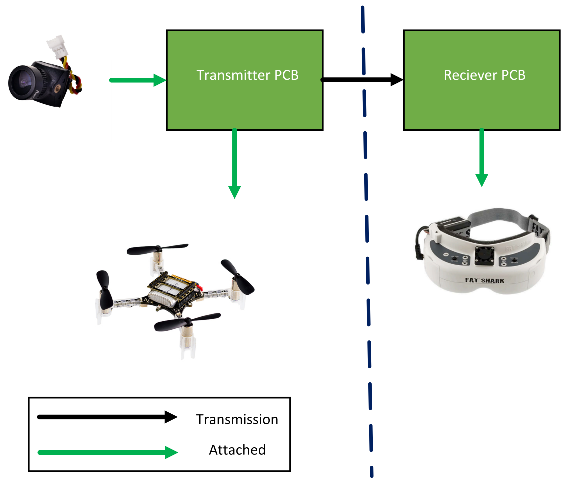

Figure 1: Visual Aid for the FPV Drone

1.4 High Level Requirements

1. The drone shall maintain stable flight dynamics when equipped with additional hardware, ensuring controllability with a maximum deviation of 5% from expected flight paths under standard test conditions. This will require the total additional weight added to the drone to be balanced and less than 15g. This can be measured by flying the drone in one direction, and measuring the unwanted deviation in other directions.

2. The camera system shall stream high-definition video to the FPV headset with zero perceptible interruptions, maintaining a latency of at least 30 Hz to ensure an immersive real-time experience. The video display shall overlay sensor data from the drone, including from the altimeter and the accelerometer.

3. The Vicon motion capture system shall be leveraged to enhance drone tracking capabilities, using either infrared LEDs or motion capture reflector balls ensuring continuous and accurate positioning data within the flight area.

2 Design

2.1 Block Diagram

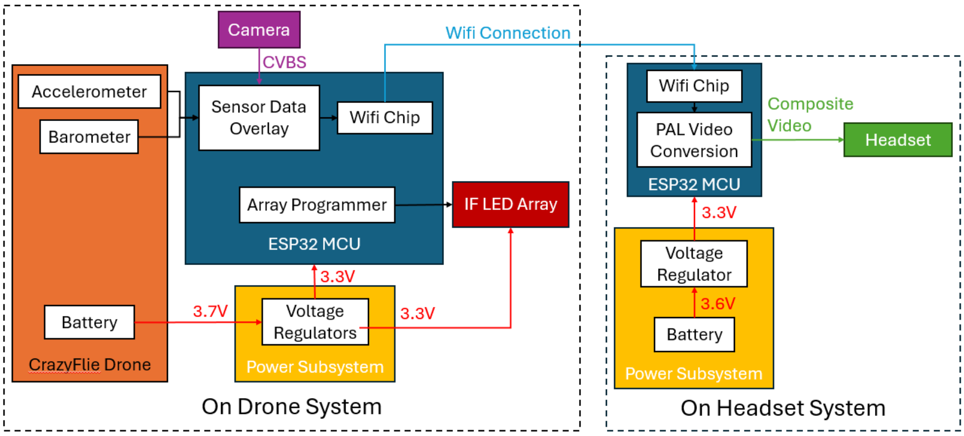

Figure 2: Block Diagram for FPV Drone

2.2 Subsystem Overview

2.2.1 Infared LED and Vicon Subsystem

This subsystem is dedicated to ensuring accurate tracking within the Vicon motion capture environment. It consists of high-intensity infrared LEDs that emit light captured by the Vicon system's cameras. The Vicon enables the accurate tracking of the drone, allowing the user to do things like find the best path through the course. The LEDs are strategically positioned on the drone to provide a 360-degree visibility profile, crucial for precise localization during flight. Each LED is driven by a current-regulated driver circuit, allowing for consistent output levels that are crucial for reliable tracking. The subsystem is designed to be low-power yet effective, ensuring minimal impact on the drone's overall battery life. The LED array will be programmable so that a distinct pattern can be cycled through with a button and thus a drone can be distinguished by the Vicon system, potentially allowing for the tracking of multiple drones. The use of infrared LEDs with the Vicon is untested, and if the system is unable to pick up the LEDs we will replace them with passive motion capture balls.

Table 1: Infared LED and Vicon Subsystem – Requirements & Verification

Requirements	**Verification**
• The LEDS will be controllable allowing different patterns	• The designed PCB will have red LEDs wired with each of the Infrared LEDs • The pattern of illuminated LEDs changes as part of a cycle as the button is pressed.
• The placement of the infrared markers allows the Vicon system to distinguish and track the drone with 99% accuracy	• The drone will be held at a known position on one side of the flight arena • The drone will be moved (not flown) to the other side of the room, to a second known position that has been manually measured • The offset between the measured location and the reported location from the Vicon will be divided by the distance travelled

2.2.2 Drone Transmitter Subsystem

This subsystem's 3 primary roles are read the camera data, integrate the drone's accelerometer and barometer data into an overlay on the video feed, and transmit the feed to the FPV headset via WiFi communication. This subsystem includes a Caddx Ant FPV Camera, integration with the Crazyflie drone, and an ESP32 microcontroller. The ESP32's DACs will be used to read the camera data, the CPU will be used to construct the video overlay, and the WiFi chip and built in antenna will be used to transmit the video feed.

Table 2: Drone Transmitter Subsystem – Requirements & Verification

Requirements	Verification
• The transmitter subsystem must be able to read the video from the camera with low latency.	• A test protocol will be written to output the camera's video feed to a data file on an connected external computer. This data will then be verified. • This will verify that the camera data can be read by the ESP32 with no loss of information and low latency.
• The transmitter subsystem must be able to read the data from the drone's sensors.	• A test protocol will be written to output the drone's sensor data to a data file on an connected external computer. This data will then be verified. • This will verify that the drone's sensor data can be read by the ESP32 with no loss of information and low latency.
• The transmitter subsystem must be able to overlay the data from the sensors onto the video stream with low latency.	• A test protocol will be written to overlay test data onto a test video stream. • This will verify that the overlay program works with low latency.
• The transmitter subsystem must be able to transmit the video feed to the receiver subsystem.	• A test protocol will be written to ensure that a stream of test data can be transmitted between the two ESP32 chips. • Verifying this test protocol will ensure a strong Wi-Fi connection for sending video.

2.2.3 Headset Receiver Subsystem

The headset subsystem is centered around the Fat Shark FSV1074 Dominator HD21 goggles, which are equipped with a high-resolution display to render the video feed from the drone's camera with clarity and depth. These goggles are selected because they are what the Center for Autonomy has to offer. The onboard receiver decodes the incoming video signal and converts it to RCA composite video with minimal latency.

Table 3: Headset Subsystem – Requirements & Verification

Requirements	**Verification**
• The receiver ESP32 need to be connected via Wi-Fi to the transmitting ESP32, establishing a strong wireless connection	• A test protocol will be written to ensure that a stream of test data can be transmitted between the two ESP32 chips. • Verifying this test protocol will ensure a strong Wi-Fi connection for sending video.
• DACs on the receiver microcontroller will take the digital signal from the Wi-Fi and convert it to RCA	• The DAC needs to be programmed to output a RCA signal using a proper sampling. This will be independently tested to ensure the DAC is converting to RCA • The DAC will then be connected to the drone video feed to verfiy that the wireless video is decoded and sent to the headset

Figure 3: The AV protocol used by the headset

2.2.4 Drone Power Subsystem

The Drone power subsystem is responsible for supplying power to all of our added components on the drone. The power source will be the 3.7V battery used by the drone, and the system needs to output a consistent 3.3V for the microcontroller, camera, and LED array.

Table 4: Drone Power – Requirements & Verification

Requirements	**Verification**
• Maintains consistent 3.3V	• Attach voltage regulator to a voltage source, multimeter, and potentiometer. • Set the voltage to a maximum 3.7V and step through loads with the potentiometer, and check with the multimeter to ensure the voltage doesn't fall outside 3.3V ±9%, then steadily lower the voltage, still ensuring it stays within bounds.
• Turns off when battery voltage is no longer able to support circuit.	• Attach power circuit output to a resistor and LED • Fly the drone until the battery voltage drops enough to cause the circuit to turn off • Ensure the LED is off while the drone is still able to hover.

2.2.5 Receiver Power Subsystem

The Receiver Power Subsystem is responsible for supplying power to our receiver and composite video output. The power source will be a 3.6V battery, and the system needs to output a consistent 3.3V for the microcontroller.

Table 5: Receiver Power – Requirements & Verification

Requirements	**Verification**
• Maintains consistent 3.3V	• Attach voltage regulator to a voltage source, a multimeter, and a potentiometer. • Set the voltage to a maximum 3.6V and step through loads on the potentiometer, and check with the multimeter to ensure the voltage doesn't fall outside 3.3V ±9%, then steadily lower the voltage, still ensuring it stays within bounds.
• Turns off when battery voltage is no longer able to support circuit.	• Attach voltage regulator to a voltage source, a multimeter, and a potentiometer. • Steadily decrease input voltage, and ensure the load stays within 3.3V ±9%until a .1V range on the load where the output voltage drops to 0V on the circuit

2.3 Tolerance Analysis

One important area of tolerance our project must meet is power consumption on the drone. We plan to use the built in battery on the Crazyflie drone with a capacity of 350mAh that outputs at 3.7V, with maximum sustained output of 5.25A. The drone consumes 100mA while stationary and 7W when flying unburdened at 27 grams. The camera weighs 2.5 grams, and we can assume the ESP32/ PCB combo weighs around 10 grams or less. As a rough approximation if we assume power grows quadratically with weight we would expect simply carrying the components to consume around 15W, which at 3.7V is 4.05A.

$$\frac{7W}{(27g)^2} = .0096$$

$$27g + 2.5g + 10g = 39.5g$$

$$(39.5g)^2 * .0096 = 15W$$

$$\frac{15W}{3.7V} = 4.05A$$

The camera consumes 120mA, and we can assume the ESP32 and LEDs will consume 400mA total. Combining that all together we have a total expected consumption of

4.57A, below the max capacity of 5.25A.

$$120mA + 400mA + 4.05A = 4.57A$$

We would expect it to have a total battery life of 4:35 of flight.

$$350mAh = 1260000mAs = 1260As$$
$$\frac{1260As}{4.57A} = 275s = 4:35$$

3 Cost Analysis

An extremely important factor in any project is the overall cost to the manufacturer to develop and produce the product. Below is a cost estimation to understand what the price of a company developing this drone would cost.

3.1 Component Costs

Table 6: Itemized list of Components and Costs

Description	Manufacturer	Quantity	Unit Price	Total Price	Link
ESP32 Microcontrollers	Mouser	4	3.20	12.8	Link
100 Count IR LED	Chanzon	1	8.99	8.99	Link
Caddx FPV Camera	SoloGood	1	18.90	18.90	Link

3.2 Labor Costs

The labor cost for the project is estimated based on the involvement of three electrical engineers. Below is the labor cost breakdown for three electrical engineers working on the project:

Table 7: Labor Cost for Electrical Engineers

Description	Quantity/Rate	Cost (USD)
Annual Salary per Engineer	\$98,000	
Hourly Rate (based on 2080 annual work hours)	\$47.12	
Total Work Hours (3 months,2-4$\frac{hours}{day}$,5$\frac{days}{week}$)	130-260 hours	
Total Labor Cost for 3 Engineers		\$18,326.40 - \$36,652.80

4 Schedule

Below is a comprehensive schedule for working on this project

Week	Task	Person
Feb 18th - Feb 24th	Write Design Document	Everyone
	Order Major Component Parts	Hunter
Feb 25th - Mar 2nd	Prototype basic video output from ESP32	Eli & Hunter
	Prototype camera-to-ESP32 connection	Griffin
Mar 3rd - Mar 9th	Design On-Headset PCB	Eli & Hunter
	Prototype drone sensors-to-ESP32 connections	Griffin
Mar 10th - Mar 16th	Design On-Drone PCB	Everyone
Mar 17th - Mar 23rd	**PCB Order Round 2**	Hunter
	Order PCB Small Component Parts	Hunter
	3D Print Headset Door	Hunter
	Prototype WiFi Connection between two ESP32s	Eli & Griffin
Mar 24th - Mar 30th	Prototype sensor data video overlay	Everyone
Mar 30th - Apr 6th	Solder On-Drone PCB	Eli
	Solder On-Headset PCB	Hunter
	Build LED array programmer	Griffin
Apr 7th - Apr 13th	Test Power Subsystems	Eli
	Test Receiver Subsystem	Eli & Hunter
	Test Transmitter Subsystem	Hunter & Griffin
	Test IF LED Subsystem	Griffin
Apr 14th - Apr 20th	**Mock Demo**	Everyone
	Fix bugs	Everyone
Apr 21st - Apr 27th	**Final Demo**	Everyone

5 Risk Analysis

For a FPV drone project, risk analysis is crucial to identify potential hazards and implement strategies to mitigate them, ensuring the safety of both operators and bystanders.

5.1 Microcontroller Failure

The primary microcontroller integrated for video streaming plays a pivotal role in managing the real-time video feed from the drone to the operator. While the Crazyflie drone comes equipped with its own microcontroller that handles essential flight control tasks such as throttle management, navigation, and stabilization, our added microcontroller focuses on ensuring seamless video transmission. This distinction is crucial for the project's success, as uninterrupted video streaming is vital for an immersive FPV experience.

Should the video streaming microcontroller encounter issues, it could compromise the quality or continuity of the video feed, potentially affecting the operator's ability to control the drone effectively. Flying the drone within the flight arena will ensure the risk to operators and bystanders is low should this occur.

5.2 Communication Loss

Loss of communication between the drone and the remote control can occur due to interference, range limitations, or component failure. In such cases, its important that the drone be flown within the flight arena so any crashes due to communication loss are contained in a safe environment

5.3 Motor or Propeller Failure

The motors and propellers are critical for the lift and propulsion of the drone. A failure in these components could lead to an immediate loss of altitude and control. Its important to check the integrity of the motors and propellers before takeoff every time to mitigate this risk.

5.4 Battery Failure or Depletion

A sudden loss of power due to battery failure or depletion can result in the drone falling from the sky. Ensuring the drone's battery is at a full charge before takeoff can prevent this. The operator should know the total flight time of the drone before takeoff, and keep this in mind whilst operating the drone.

5.5 Collision and Obstacle Avoidance

Collisions with obstacles or other drones pose a significant risk, especially in crowded environments or when flying at high speeds. Flying inside of the Flight Arena will ensure that the risk for collisions is low, and the obstacles are controllable.

5.6 Environmental Factors

Environmental factors such as wind, rain, and temperature extremes can affect the drone's performance and reliability. The drone therefore will be designed to be used indoors within a proper flight arena to remove these risks.

Figure 4: The University of Illinois Robotics Lab Flight Arena

6 Ethics and Safety

6.1 User and Bystander Risk

Our project's mission is to harness advanced drone technology to enhance the educational and research capabilities of the University of Illinois Center for Autonomy. We are committed to upholding the highest ethical standards and ensuring the safety of all involved, aligning with Section 1.1 of both the ACM and IEEE Ethical Codes.

6.2 Equipment Saftey and Regulation

All electronic components, including transmitters, receivers, and batteries, adhere to industry safety standards and regulations. The battery systems, in particular, are designed with multiple layers of protection against overcharging, short-circuiting, and thermal runaway. All batteries will be charged in certified packaging to reduce fire risk. We also ensure that the ESP32 Wi-Fi transmission power complies with FCC regulations to avoid interference with other devices and communication systems.

6.3 Data Processing and Privacy

While our project does not currently involve the storage or transmission of personal data, we recognize the importance of privacy in systems that collect and process environmental data. All team members are required to respect user privacy, complying with relevant data protection laws and the ethical guidelines outlined in section 1.6 of the ACM Code of Ethics

6.4 Personal Responsibility

Each team member is responsible for upholding ethical practices throughout the project's life cycle. This includes a commitment to transparency, accurate reporting of data, and a refusal to manipulate test results or compromise on the quality and safety of our work. Our conduct is guided by the principles of honesty, integrity, and accountability, which are essential for maintaining the trust and credibility of our project.