ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

FPV Drone

Team #64

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Abstract

This project develops a custom First-Person View (FPV) drone for the University of Illinois Center for Autonomy, tailored to navigate efficiently within the constraints of the lab's compact drone arena. The design utilizes the Crazyflie drone platform, augmented with subsystems that include a camera for real-time video transmission to a head-mounted display, and infrared LEDs integrated for precise positioning with Vicon motion capture technology. The subsystems are controlled via custom printed circuit boards (PCBs) that ensure seamless communication and integration. The project aims to provide a platform for comparing flight paths and strategies, enhancing research in autonomous drone navigation while also promoting drone racing as an engaging sport. Through meticulous design and testing, the drone is expected to meet specific requirements, such as maintaining stable flight dynamics, streaming video with minimal latency, and providing accurate and continuous motion tracking. This project not only advances the technical capabilities of FPV drones but also contributes to the educational and research initiatives at the university by merging the thrill of drone racing with the precision of engineering research.

Contents

1 Introduction

1.1 Problem

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

1.2 Solution

To meet the specific needs of the University of Illinois Center for Autonomy, the solution involved developing a custom FPV drone based on the Crazyflie drone platform. This specialized drone was equipped with an ESP32-CAM for transmitting real-time video over WiFi to a receiver board, which hosts a web server. The video feed from this server is then displayed on a Fat Shark Dominator HD2 FPV headset via an HDMI connection from a laptop. Custom PCBs were developed to integrate all necessary electronic components, ensuring smooth coordination between the transmitting and receiving units. Additionally, the solution leveraged the Vicon motion capture system to evaluate the performance of infrared LEDs used in the system.

1.3 High-Level Requirements

There were three primary requirements that this design needed to fulfill to be considered successful:

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 video to the FPV headset with zero perceptible interruptions, maintaining a latency of at least 30 Hz to ensure an immersive real-time experience.

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

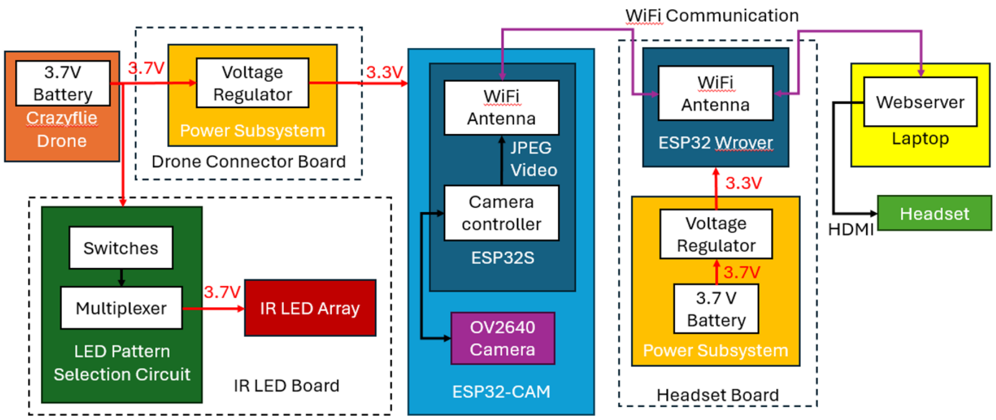

Figure 1: Functional Block Diagram for FPV Drone

2.2 Subsystem Overview

2.2.1 Infrared LED and Vicon Subsystem

This subsystem is dedicated to ensuring accurate tracking within the Vicon motion capture environment. It consists of infrared LEDs that emit light captured by the Vicon system's cameras. The Vicon enables the accurate tracking of the drone, allowing users to 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. The subsystem is designed to be low-power yet effective, ensuring minimal impact on the drone's overall battery life. The specific pattern of the LEDs should be selectable so that several drones equipped with identical boards can be illuminated in different patterns and tracked by the Vicon system simultaneously.

The Vicon system requires three points to track an object, so the design necessitated a board that illuminates three of the four LEDs at a time, allowing the user to select which LED is off.

The board includes a pair of switches that the user can flip to set the wires to 3.7 V or ground, acting as a 2-bit number. The output of these switches is connected to the first two bits of the CD74HCT138E demultiplexer, whose four active low outputs are connected to the LEDs. Depending on the binary bit input, one of the four LEDs is turned off, allowing the user to cycle through using the switches. Originally the plan was to have a button that drives a 2-bit incrementer instead of 2 switches, but the switches were selected as they allowed the user to select the specific pattern they wished instead of cycling through all the options using a button

The use of infrared LEDs with the Vicon was untested, and John Hart, the director of the Center for Autonomy Labs, tasked us with determining if they would work. We determined that the specific LEDs were too dim to be used with the Vicon system given the 3.7 V drone battery voltage. We were able to replace them with passive motion capture retro-reflector balls and track the drone successfully.

In Figures 2, 3, and 4, the schematic, PCB layout, and different illumination configurations of the circuit can be seen, as viewed through a camera that is unshielded to IR light.

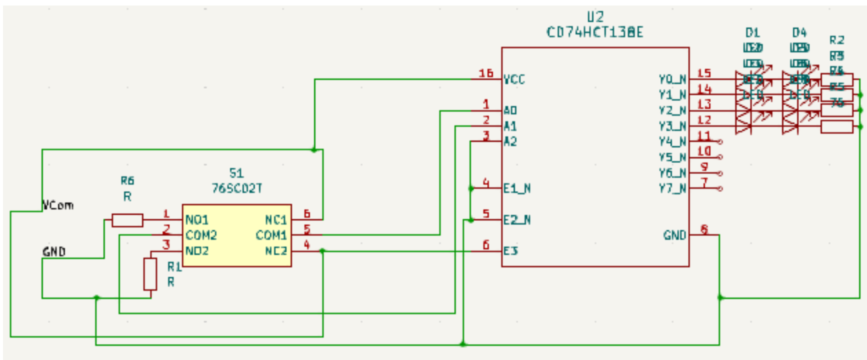

Figure 2: Schematic of the LED Board

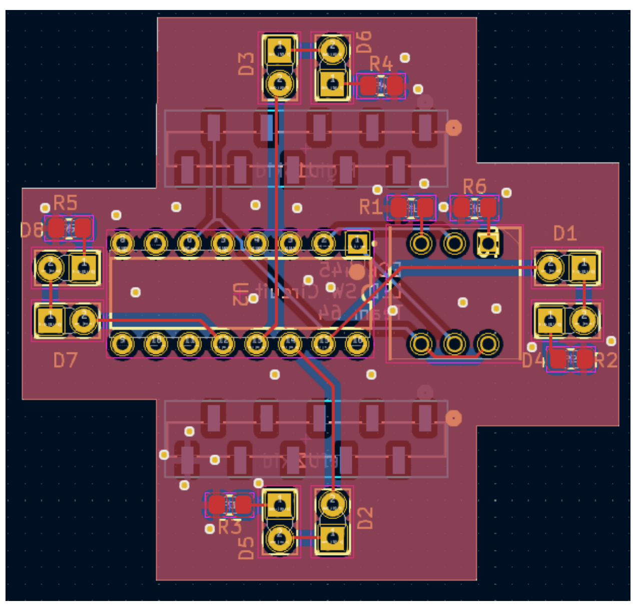

Figure 3: PCB Layout of LED Board

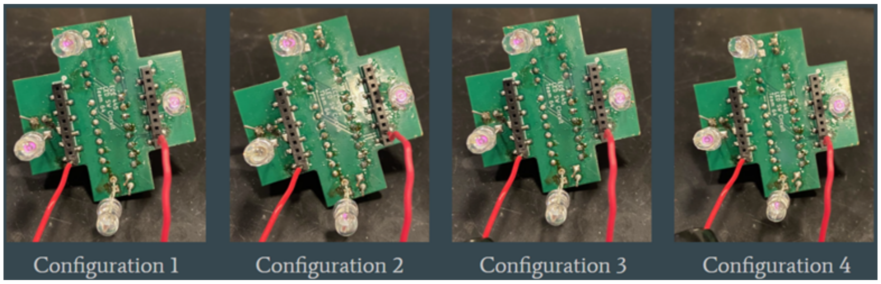

Figure 4: Different configurations of the LED array

2.2.2 Drone Transmitter Subsystem

This subsystem is critical for integrating the ESP32-CAM with the Crazyflie drone and ensuring stable operation during flights. The subsystem has several key responsibilities and features:

1. Securely mounting the ESP32-CAM to the Crazyflie Drone.
2. Providing a stable electrical connection that includes a common ground and V_{com} between the Crazyflie and the ESP32-CAM.
3. Regulating the noisy 3.7 V supply from the Crazyflie to a constant 3.3 V suitable for the ESP32-CAM.
4. Utilizing the onboard camera of the ESP32-CAM for capturing video.
5. Employing the ESP32's WiFi module to transmit video data wirelessly.

Adapter Board Design An adapter PCB was specifically designed to fulfill these functions. It features connectors to accept the pins from the ESP32-CAM on one side and the Crazyflie pins on the other side. The Crazyflie side also includes a Low Dropout (LDO) circuit to ensure clean power delivery to the ESP32-CAM. The schematic of this adapter board is illustrated in Figure 5, and the PCB layout is shown in Figure 6.

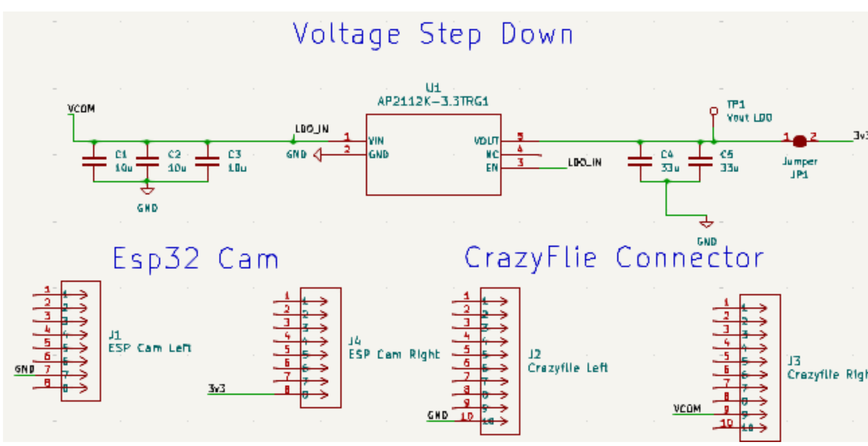

Figure 5: Schematic of the Adapter Board

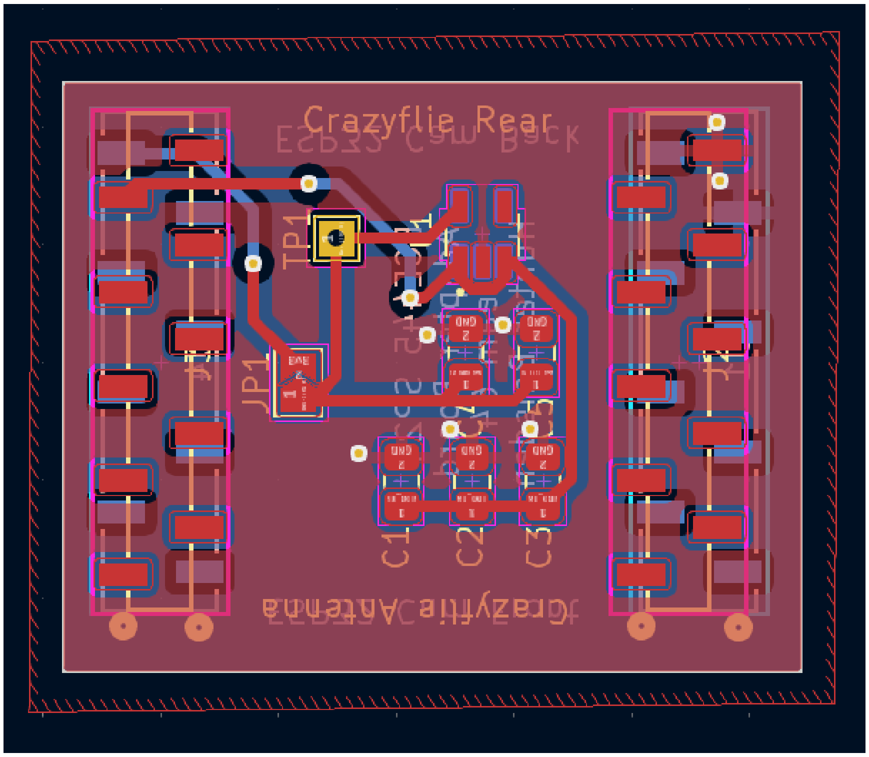

Figure 6: PCB Layout of Adapter Board

3D Model of the Adapter Board The 3D model of the adapter board, providing a top and bottom view, is displayed in Figures 7 and 8 respectively.

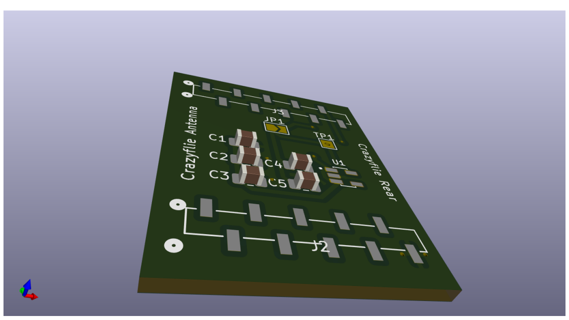

Figure 7: Top view of the adapter board.

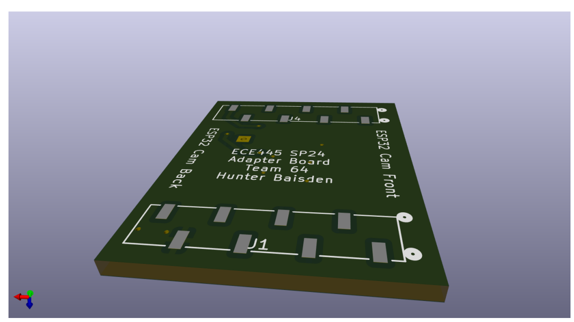

Figure 8: Bottom view of the adapter board.

ES32-CAM Implementation The ESP32-CAM is an off-the-shelf module chosen for its compact design and integrated features including a camera and WiFi module for video streaming. This integration can be seen mounted on the drone in Figure 10.

Figure 9: The ESP32-CAM used in the system.

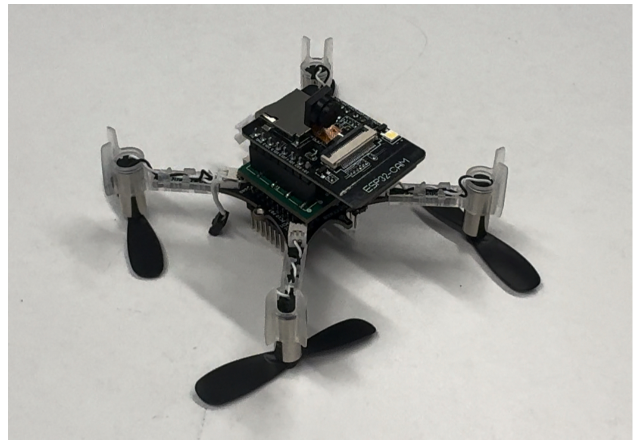

Figure 10: The entire system mounted on the drone, upside down to emphasize the transmission system.

Combining all these components on the drone after flashing the ESP32-CAM with the correct firmware, achieves the intended operational goals, providing reliable and effective power management and wireless video transmission capabilities.

2.2.3 Headset Receiver Subsystem

The headset subsystem is centered around the Fat Shark FSV1074 Dominator HD21 goggles[1], 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 receiver system was intended to decode the incoming video signal and convert it to RCA composite video with minimal latency. A 3-to-1 cable was used to connect 11 on the board to 12 on the headset.

Figure 11: The CSV Connector on the headset board

Figure 12: The AV Connector used by the headset

Board Design The basic design of the board was based on the 445 example board.[2] To convert the digital video feed to the analog CSV, the ESP32-WROVER-E chip was selected since the more modern ESP32-S3-WROOMs do not feature an on-chip DAC. This meant some GPIO_STRAPPING pins were different and required different basic peripheries circuits.

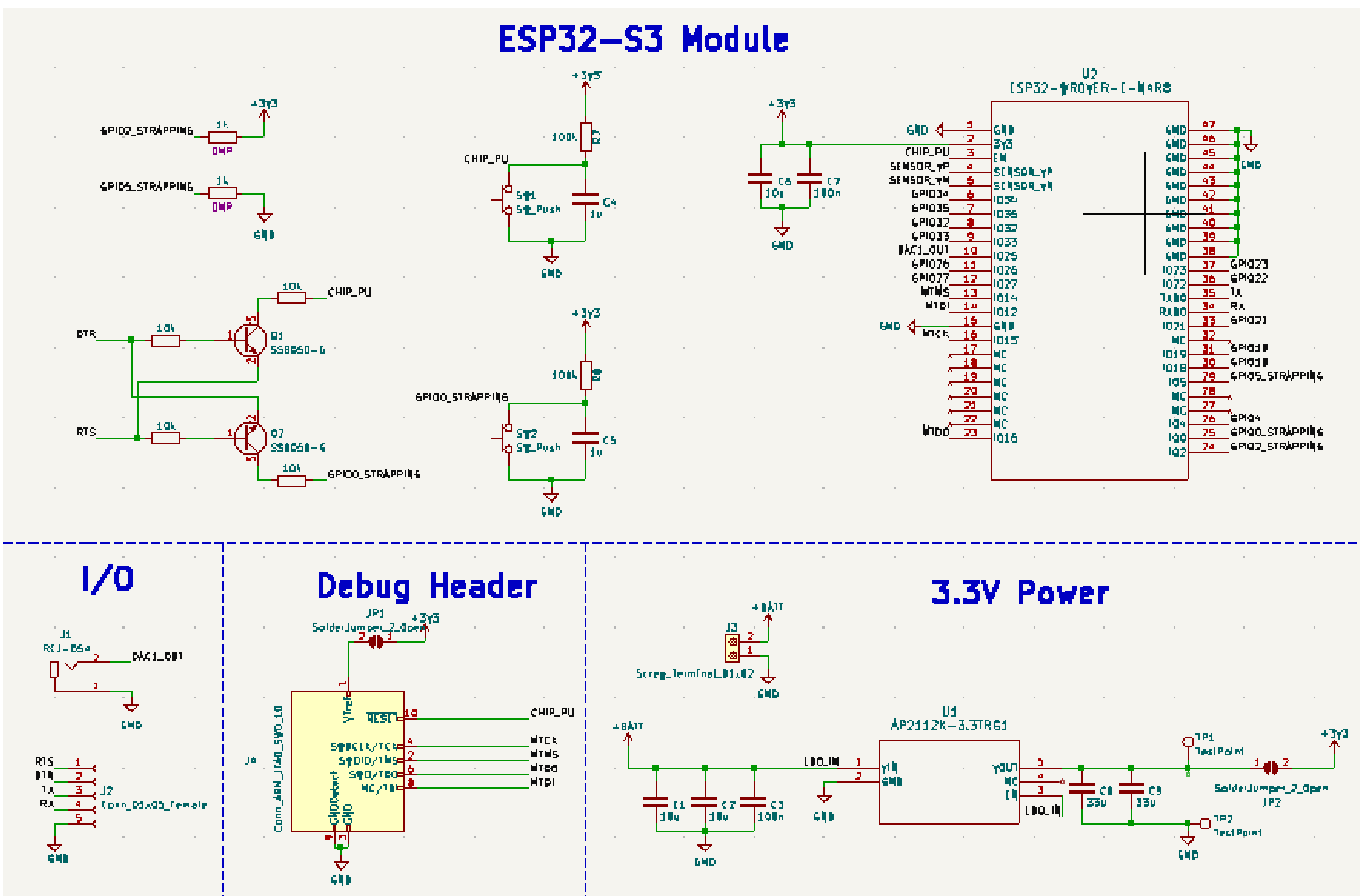

Figure 13: The Headset Board Schematic

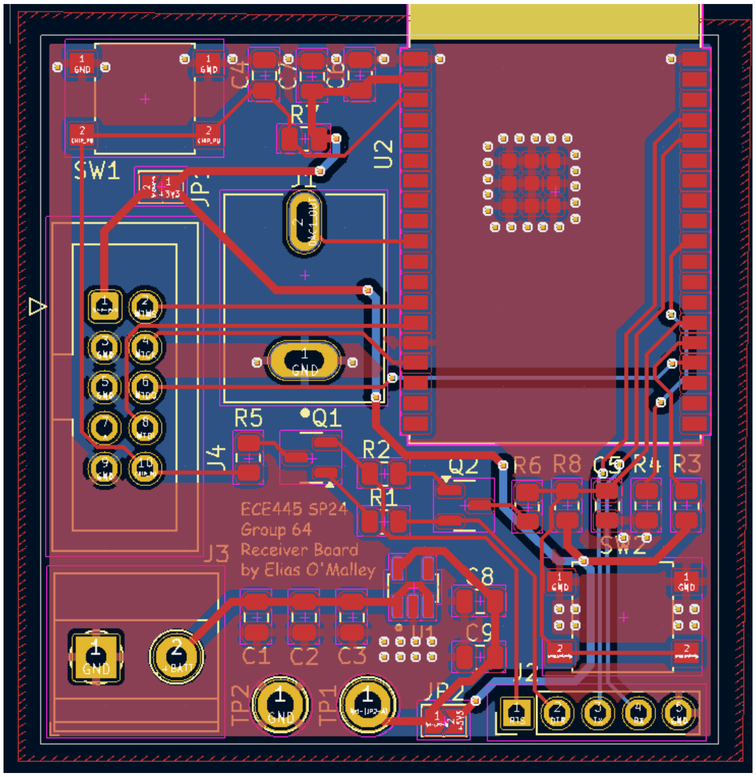

Figure 14: The Headset Board Layout

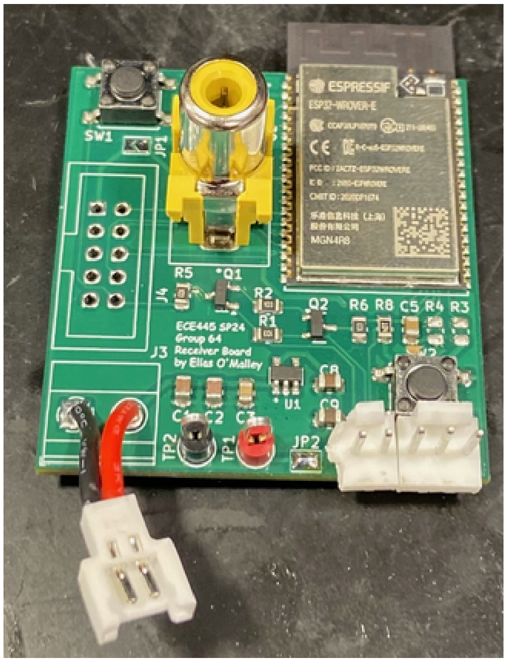

Figure 15: View of the Finished Headset Board

CSV Conversion Software To utilize the DACs, we used the esp32_composite_video_lib repo to convert the video.[3] This library initializes and optimizes the DACs for CSV video output. It comes with an example code repository that was used to demonstrate the hardware's functionality with a preloaded video.[4]

Video Webserver This was used as an intermediary to convert the video to an HDMI signal using a laptop. The laptop connects to the WiFi server and sends HTTP GET requests to the drone board which sends the JPEG frames back to be displayed in a webpage. These HTTP messages are sent through the drone board which acts as the handler of the video communication.

Finally, the headset can be treated as a second display for the laptop, sending the video on the webserver to the headset for the pilot to view.

2.2.4 Drone and Receiver Power Subsystems

The Drone and Receiver Power Subsystems utilize the AP2112K-3.3TRG1 Linear Dropout Regulator (LDO), chosen for its ability to support up to 600mA of output current and its ability to achieve a low dropout voltage of approximately 0.4 volts, making it ideal for the power needs of both the drone and the receiver headset boards.[5]

Circuit Overview The circuit employs the AP2112K LDO to regulate a 3.7V input down to a stable 3.3V output, essential for powering the critical components on both boards, including the ESP32-CAM on the drone, and the ESP32-WROVER on the headset board. The arrangement features several capacitors (C1, C2, C3 at the input and C4, and C5 at the output) to stabilize the voltage and filter out noise, ensuring clean and reliable power delivery. These capacitors help manage any voltage fluctuations and maintain consistent power during varying load conditions. The circuit can be seen in detail in Figure 16.

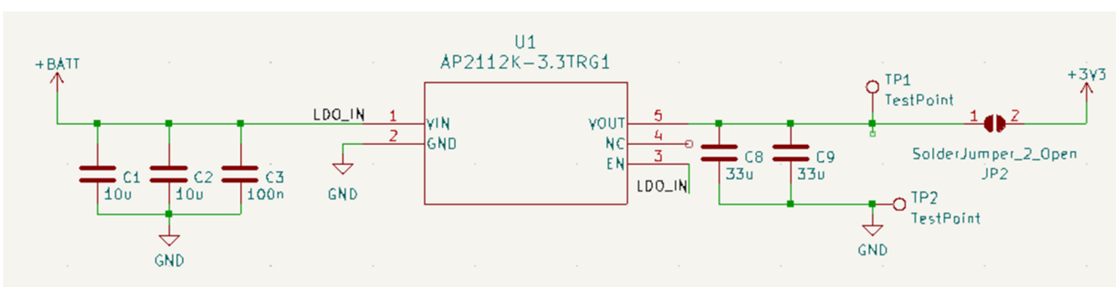

Figure 16: Schematic of the LDO

Efficiency and Performance The LDO's low dropout voltage allows effective regulation even when the battery voltage is close to the output voltage, which is critical during the lower end of battery life. This ensures that the drone and receiver can operate effectively without power interruption, even under low battery conditions.

2.3 Tolerance Analysis

2.3.1 Power Consumption on the Drone

One important area of tolerance the project was designed around is power consumption on the drone. We used the built-in battery on the Crazyflie drone with a capacity of 350mAh that outputs at 3.7V, with a maximum sustained output of 5.25A. The drone consumes 100mA while stationary and 7W when flying unburdened at 27 grams. The ESP32-CAM weighs 5 grams, and the ESP32-CAM and Adapter Board together weigh about 12.5 grams. We calculated that power consumption grows quadratically with the weight. This meant simply carrying the components to consume around 15W, which at 3.7V is 4.05A.

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

$$27g + 12.5g = 39.5g$$

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

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

The camera consumes 120mA when streaming, and about 600mA for a brief moment when setting up a WiFi server. This was found empirically and in the documentation [6].

The total power consumption was calculated by adding the operational current of the ESP32-CAM during streaming and its peak current during WiFi setup to the current calculated for the drone's flight with added components.

$$\begin{aligned}\text{Total Current Consumption (during streaming)} &= 4.05A + 120mA + 600mA \\ &= 4.05A + 0.12A + 0.60A \\ &= 4.77A\end{aligned}$$

The drone's battery has a maximum sustained output capacity of 5.25A, so the current consumption during the most intense operational phase was within the safe operational limits of the battery.

To further analyze the system's performance, we calculated the battery life during continuous operation. The total battery capacity is given as 350mAh, which converts to 1260 coulombs of charge (350mAh * 3600s).

$$\begin{aligned}\text{Battery Life} &= \frac{\text{Total Charge}}{\text{Total Current Consumption}} \\ &= \frac{1260 \text{ coulombs}}{4.77A} \\ &= 264.15 \text{ seconds}\end{aligned}$$

This provides a battery life of approximately 4.4 minutes, which is almost identical to our tested camera run time without heavy motor usage. We determined that heavy motor usage causes the output voltage to drop on a lower charge, and within a minute of flight putting the motor to full throttle can cause the camera to brown out, while still allowing flight.

3 Design Verification

3.1 LED Board and Vicon Subsystem Verification

The verification of the LED board is focused on three primary factors. First, is the board designed and built correctly, do the LEDs light up in the proper sequence? Second, is the Vicon Motion Capture system able to follow the LED points of light (This is what we were tasked with determining by John Hart). Third, is the drone able to be tracked by the Vicon System?

3.1.1 Board Operation Check

To verify the LEDs are illuminated three at a time, with the pattern being selected by the switches, a board with green LEDs in series with the infrared LEDs was soldered. It was confirmed that three LEDs illuminate at a time, and the unlit LED is selected by the switches. In addition, modern cameras do not completely filter out LED light, and when the final board is viewed through a camera the infrared light is visible as a pink glow, confirming once again that three LEDs illuminate at a time, and the unlit LED is selected by the switches.

3.1.2 Vicon Integration Check

At the beginning of the project, it was unclear whether the Vicon system could even track the infrared LEDs, and John Hart tasked us with figuring it out. We initialized the Vicon system, prepared the room, and placed the LED board inside. We determined that the system did not pick up the LEDs. We then brought in the reflector balls and confirmed the system was operational as it was able to pick them up. This tells us that the infrared LEDs are too dim to be picked up by the Vicon at voltages provided by the drone.

3.1.3 Vicon Tracking Check

While the Vicon was unable to track the infrared LEDs, we were still able to track the retro-reflector balls on the drone. We were able to confirm it was being tracked accurately by placing the drone on the ground, recording its location, moving it several meters away, and recording its new location while also measuring the distance.

Using a ruler, the drone was moved 11.0m across the room. We attempted to ensure the drone was only moved along the y-axis of the room according to the Vicon layout. The drone was measured to have moved 11.08m in the y direction, with an imperceptible difference in the x direction. This demonstrated a Vicon measurement of 0.7%, meaning it is substantially more accurate than our 99% requirement. This is summarized in an RV table in Appendix A, Table 3.

3.2 Drone Transmitter Verification

The verification of the drone transmitter was structured around testing for three primary performance criteria: frame rate at 30 FPS, minimal interruptions in the video feed, and low latency. The methodology adopted for verification is detailed below:

3.2.1 Frame Rate Verification

To verify that the drone's video stream maintained a frame rate of 30 FPS, a high-definition video was recorded from the live feed. The drone was moved back and forth to create noticeable changes in the video feed. Adobe Premiere Pro was then used to perform a frame-by-frame analysis of the recording. This analysis confirmed that the video updated consistently at a rate of 30 frames per second, thereby meeting the frame rate requirement.

3.2.2 Interruption and Continuity Check

During the frame-by-frame analysis, the video was also examined for any signs of interruptions or loss of frames. The analysis showed no interruptions, confirming that the video feed was smooth and continuous, fulfilling the requirement for minimal interruptions.

3.2.3 Latency Measurement

Latency was measured by calculating the time delay between an action performed with the drone (e.g., a sharp movement) and the corresponding change appearing in the video feed. The procedure was as follows:

- A video was recorded at 60 FPS capturing the live feed as the drone was manually jolted.
- The latency was determined by counting the number of frames from when the drone was moved until the movement was observed in the video feed.
- With the recording at 60 FPS, each frame represents $\frac{1}{60}$ of a second or about 16.67 milliseconds.
- The delay was measured to be 10 frames from the action to the appearance in the video.

Thus, the latency calculation is:

$$\text{Latency} = 10 \text{ frames} \times 16.67 \text{ ms/frame} = 166.7 \text{ ms} \tag{1}$$

This result of 166.7 milliseconds is within an acceptable range for real-time FPV operations. These tests collectively verify that the drone transmitter subsystem meets all set requirements, validating its performance for effective use in FPV drone racing and operations. This is summarized in an RV table in Appendix A, Table 4.

3.3 Headset Receiver Verification

The verification of the Headset Board is focused on two parts of the video pipeline. The first is verifying the ability to setup a WiFi server and sending data from the drone board to the headset board. The second is the conversion to CSV via the DACs.

3.3.1 WiFi Connection Verification

To verify that the WiFi server was setup and the boards were connected, serial messages were printed to confirm the WiFi status of each board.

To verify that the data stream maintained video integrity, the webserver was used for visual verification.

3.3.2 DAC Conversion Verification

To verify the DAC hardware, a preloaded video was used and outputted to a monitor. [4] This uses a CSV to HDMI converter to display the video on a regular computer monitor. The image in 17 shows a portion of that demo video.

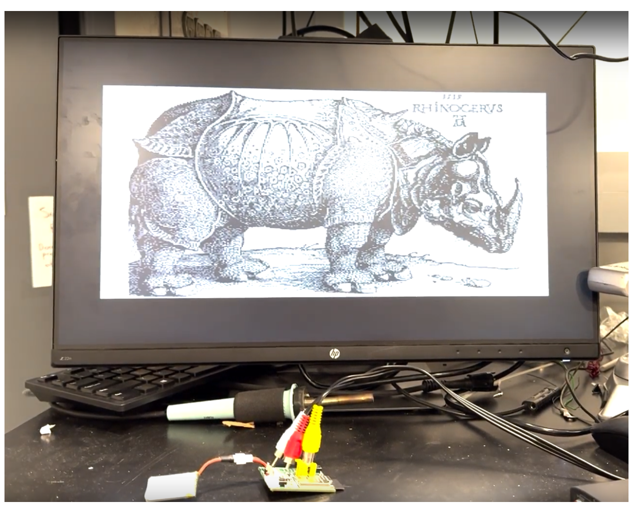

Figure 17: Frame of the Demo Video

To verify the software of the CSV conversion, the video data sent to the board could be sent to the monitor. Unfortunately, we were unable to verify this since the software was never completed. This is summarized in an RV table in Appendix A, Table 5.

3.4 Drone Power System Verification

The verification of the drone power system was conducted to ensure that the power supplied to critical components, particularly the ESP32 camera, remained stable under various operating conditions. The methodology and findings are discussed below:

3.4.1 High Battery Verification

With a fully charged battery, the drone's power system was tested under load conditions by revving the drone to simulate flight stresses. An oscilloscope was used to monitor the voltage supplied to the ESP32 camera during these tests. The results indicated that the voltage remained stable, at 3.3 V, within the required limits for optimal camera operation. This confirmed that the power system effectively regulated and delivered power under typical usage scenarios.

3.4.2 Low Battery Verification

As the battery level decreased, a subsequent test was conducted to evaluate the power system's performance under similar load conditions. During this test, the oscilloscope captured a noticeable dip in the voltage supplied to the ESP32 camera when the drone was revved. The voltage dip was significant enough to cause a temporary loss of power to the camera, known as a "brown out." This brown out condition led to a temporary failure of the camera, indicating that the power system struggles to maintain adequate voltage at lower battery levels.

3.4.3 Brown Out Explanation

A "brown out" condition occurs when the power supply dips below the operational threshold of electronic components, temporarily disrupting their function. This can lead to system resets, loss of operational data, or intermittent hardware failure, which are critical in drone operations as they affect both reliability and safety.

3.4.4 Graphical Analysis of Voltage Stability

The graph shown in Figure 18 illustrates the voltage seen by the ESp32-CAM across different battery voltages. The blue line represents the ESP32-CAM under working conditions, maintaining a stable output around 3.3V, while the orange line shows the output when the system experiences a brown out due to lower battery voltage.

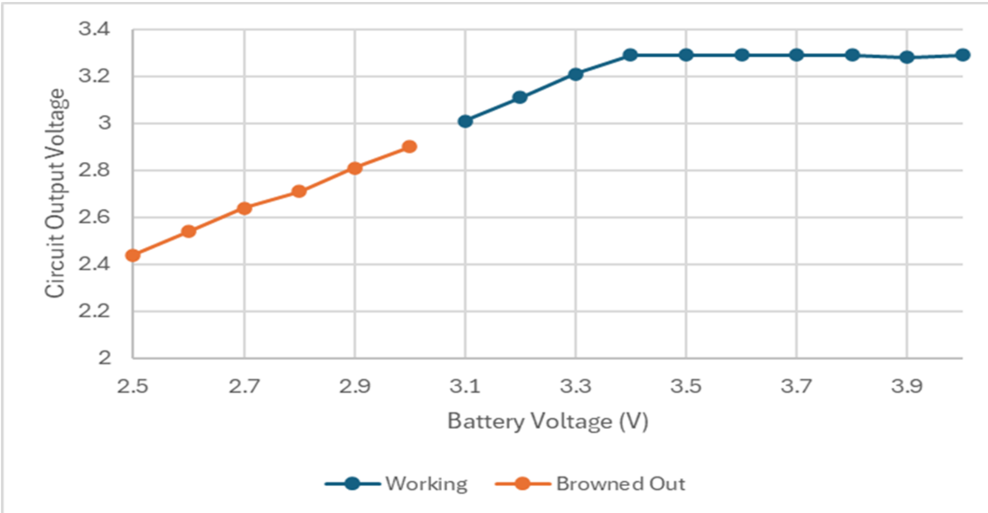

Figure 18: Graph showing the circuit output voltage at various battery levels, highlighting working conditions and brown out occurrences.

3.4.5 Oscilloscope Captures

The following figures 19 and 20 show the oscilloscope captures at high and low battery conditions when the motors are suddenly revved, illustrating the voltage stability and the observed brown out, respectively.

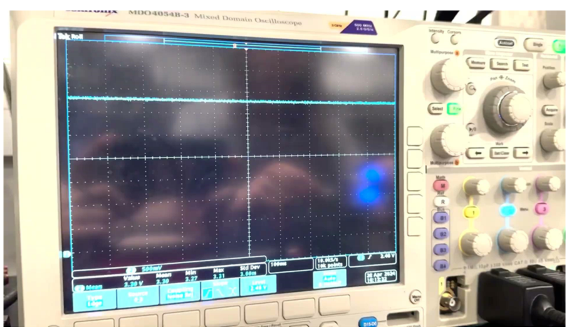

Figure 19: Oscilloscope capture at high battery

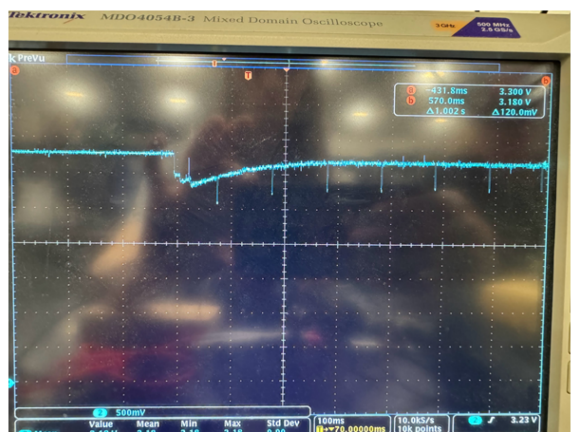

Figure 20: Oscilloscope capture at low battery

These tests collectively highlight the need for careful monitoring of battery levels to ensure smooth camera operation. This is summarized in an RV table in Appendix A, Table 6.

3.5 Receiver Power Verification

The verification of the receiver power subsystem was straightforward and aimed to confirm the stability and reliability of the power supply to the ESP WROVER module on the receiver board. The main focus was to ensure that it consistently received the required 3.3V from the LDO, crucial for its operation.

3.5.1 Verification Method

A multimeter was used to measure the voltage supplied to the ESP WROVER module to verify that it received a steady 3.3V from the Linear Dropout Regulator (LDO). The verification process involved the following steps:

- Connecting the multimeter to the output of the LDO where it connects to the ESP WROVER.
- Monitoring the voltage reading to ensure it maintained a constant 3.3V while the receiver board was operational.

3.5.2 Operational Testing

Further tests were conducted to assess the operational reliability of the receiver board under normal conditions:

- Successfully programming the ESP WROVER module multiple times without any power-related issues.
- Running the module as a WiFi server to check for any disruptions or failures that could indicate power instability.

3.5.3 Results

The ESP WROVER consistently received the correct voltage, and the board performed reliably during programming and while hosting a WiFi server. These outcomes confirmed that the receiver power subsystem was functioning effectively, ensuring stable and dependable power delivery to critical components. This is summarized in an RV table in Appendix A, Table 7.

4 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 price a company choosing to develop this project would have to pay.

4.1 Component Costs

Table 1: Itemized list of Components and Costs

Description	Seller	Quantity	Unit Price	Total Price	Link
Crazyflie 2.1	Bitcraze	1	225.00	225.00	Link
250mAh LiPo battery + charger	Bitcraze	2	10.00	20.00	Link
Crazyradio PA	Bitcraze	1	35.00	35.00	Link
ESP32-WROVER-E-N4R8	Mouser	4	2.75	11.00	Link
100 Count IR LED	Chanzon	1	8.99	8.99	Link
RCA JACK MONO	Digikey	2	1.19	2.38	Link
AP2112K LDO	Digikey	6	0.32	1.92	Link
ESP-CAM Connector	Digikey	4	1.10	4.40	Link
Crazyflie Connector	Digikey	4	1.13	4.52	Link
All three PCBs	PCBWay	30	0.50	15.00	Link
PCB Stencils	PCBWay	3	10.00	30.00	Link
				358 .21	

4.2 Labor Costs

The labor cost for the project was estimated based on the involvement of three electrical engineers with salaries equivalent to the Electrical and Computer Engineering Department average after graduation. Below is the labor cost breakdown for three electrical engineers working on the project:

Table 2: 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

5 Conclusion

5.1 Executive Summary

This project has successfully developed a drone system capable of carrying a streaming camera with onboard video processing capabilities. Our achievements include seamless video streaming to an FPV headset, advanced power management, and programmable LED patterns for drone identification. However, challenges such as limited camera lifespan and weight-related mobility constraints have highlighted areas for future improvement.

5.2 Review of Accomplishments and Challenges

The project met several critical objectives:

- **Drone Functionality:** The drone maintained stable flight while operating the camera, fulfilling its core functional requirement.
- **Video Transmission:** Real-time video streaming was achieved, enhancing the user experience by providing immediate visual feedback.
- **Power Supply Management:** The power systems on both the drone and the adapter board remained stable and reliable throughout operations.
- **LED Control:** The LEDs on the IR LED board lit up in a distinct and selectable pattern
- **RCA Output:** The headset board is capable of decoding a digital video and outputting to a composite video signal
- **Board Modularity**The Drone Connector board, the ESP32-CAM board, and the LED board are all modular and can be swapped in and out onto other Crazyflies with ease. This allows for the easy setup of multiple FPV drones that can be raced against each other. It also opens the possibility for the integration of specific modules from our project into future Center for Autonomy Lab projects.

We also faced significant challenges:

- **Hardware Limitations:** The camera's short operational lifespan and the drone's restricted movement due to its design presented considerable setbacks.
- **System Integration:** The need for an external laptop and HDMI cord for video transmission to the headset indicated a gap in our system's integration capabilities.

5.3 Ethics and Safety

Our project was able to successfully meet the technical requirements, but we also ensured that throughout the development and deployment, we adhered to the highest ethical standards and ensured the safety of all individuals involved, in alignment with Section 1.1 of the IEEE Code of Ethics [7].

5.3.1 User and Bystander Risk

User and Bystander risk is inherently a consideration when flying drones. To ensure that everyone involved was safe, all drone flying for this project was conducted by lab-trained pilots, in a closed drone flight arena designed to keep bystanders safe from drones.

5.3.2 Equipment Safety and Regulation

We ensured that all electronic components, including transmitters, receivers, and batteries, complied with industry safety standards and regulations. Batteries were consistently charged in certified packaging to mitigate fire risks.

5.3.3 Data Processing and Privacy

Although our project did not involve the storage or transmission of personal data, we maintained a strong commitment to privacy, particularly in the collection and processing of environmental data. All team members upheld user privacy by complying with relevant data protection laws and adhering to the ethical guidelines outlined in section 1.6 of the IEEE Code of Ethics [7].

5.4 Broader Impacts

The broader impacts of our drone technology project are multifaceted, contributing significantly to educational, societal, and recreational domains. By providing hands-on experience with drone technology, the project enhances outreach and research opportunities at the University, enabling students to engage directly with drone technologies. Additionally, the project introduces fun and competitive drone racing activities, offering students and hobbyists a thrilling recreational outlet that promotes active participation in technology-driven sports. These diverse impacts underscore the project's contribution to both practical applications and community engagement.

6 Future Work

The experiences and outcomes from this project provide a solid foundation for future developments. Moving forward, there are several areas identified for improvement that are critical to enhancing the overall performance and utility of the drone system.

6.1 Reducing Weight of the Drone Transmission Subsystem

A critical area for improvement in the drone transmission subsystem is the reduction of its weight. Future work could aim to minimize the weight of the adapter PCB and the

ESP32-CAM. Reducing weight is essential for increasing flight duration and maneuverability.

Efforts should be directed towards:

- Designing a more compact and lightweight adapter PCB.
- Evaluating lighter alternatives for the ESP32-CAM that do not compromise on the functionality and quality of video transmission.
- Exploring advanced manufacturing techniques such as half-thickness PCBs

By focusing on these aspects, it would be possible to significantly reduce the weight of the transmission subsystem, thereby enhancing the agility and prolonging the operational capacity of the drone.

6.2 LED Visibility

Enhancing the visibility of the LEDs for Vicon tracking is another priority. This will entail experimenting with LEDs that have higher luminosity or adjusting the voltage driving the LEDs to increase their brightness without compromising power efficiency. Additional work may also explore alternative tracking technologies that could either complement or substitute the Vicon system if LED enhancements alone do not suffice.

6.3 Wireless Video Transmission Software

Improving the wireless video transmission capability remains a crucial objective. Currently, the reliance on auxiliary devices such as laptops and HDMI cables stems primarily from the incomplete development of the JPEG to Composite video conversion code. Completing this code will remove the need for a laptop to display live FPV footage in the headset.

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Appendix A Requirements and Verification Tables

Table 3: Infared LED and Vicon Subsystem – Requirements & Verification

Requirements	Verification	Verification Status
The LEDS will be controllable allowing different patterns	1. The designed PCB will have green LEDs wired with each of the Infrared LEDs 2. The pattern of illuminated LEDs changes as part of a cycle as the button is pressed.	Yes
The placement of the infrared markers allows the Vicon system to distinguish and track the drone with 99% accuracy	1. The drone will be held at a known position on one side of the flight arena 2. The drone will be moved (not flown) to the other side of the room, to a second known position that has been manually measured 3. The offset between the measured location and the reported location from the Vicon will be divided by the distance traveled	Yes

Table 4: Drone Transmitter Subsystem – Requirements & Verification

Requirements	Verification	Verification Status
The transmitter subsystem must maintain a video frame rate of 30 FPS.	Video frame rate verified by Adobe Premiere Pro analysis, confirming 30 FPS.	Yes
The video stream must have minimal interruptions.	Frame-by-frame analysis to ensure no interruptions in the video feed.	Yes
The video stream must exhibit low latency.	Latency measured by the delay in video response using Adobe Premiere Pro at 60 FPS; calculated the time from a physical action to its appearance in the video feed as 10 frames, equating to 166.7 ms.	Yes

Table 5: Headset Subsystem – Requirements & Verification

Requirements	Verification	Verification Status
The receiver ESP32 needs to be connected via Wi-Fi to the transmitting ESP32, establishing a strong wireless connection	Serial messages confirmed the WiFi connection status. Visual verification via webserver to maintain video integrity.	Yes
DACs on the receiver microcontroller will take the digital signal from the Wi-Fi and convert it to RCA	1. A preloaded video was used to verify the DAC's hardware by displaying the video on a monitor using a CSV to HDMI converter. 2. Software completion for CSV conversion was not achieved, and hence could not be verified.	No

Table 6: Drone Power – Requirements & Verification

Requirements	Verification	Verification Status
Maintains consistent 3.3V at high battery	1. Used an oscilloscope to monitor the voltage delivered to the ESP32 camera. 2. At high battery, revved the drone and observed that the voltage remained stable, ensuring consistent power delivery to the camera. 3. At low battery, repeated the test and observed voltage dips on the oscilloscope when the drone was revved, leading to a temporary camera brown out.	Yes

Table 7: Receiver Power – Requirements & Verification

Requirements	Verification	Verification Status
Ensures consistent 3.3V supply to ESP WROVER	1. Multimeter was used to monitor voltage to the ESP WROVER to ensure a stable 3.3V from the LDO. 2. Verified operational stability by programming the module and running it as a WiFi server.	Yes