BIRD Project Proposal

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Contents

1. Introduction

Our goal is to design a system that allows a user to view accurate, real-time information about the presence of people in rooms that the user is physically near but not inside. The user should be able to "see people through walls" and be alerted to the exact location of where an individual may be, as well as some information about their speed. Through the use of a drone housing a curated selection of sensors and an augmented-reality software program we will design a functioning prototype of this system.

1.a Problem

There are many situations when law enforcement or emergency medical service professionals need to quickly know real-time, useful information about a non-visible location without sending a human to gather this information due to potential or confirmed risks. One of the most important things to know in these situations is if there are people in a room or area, and if so, where they are located and if they are moving. While many of the present solutions in practice by professionals offer a promising effectiveness, they can rarely be operated by one person and take away valuable time and manpower from situations which almost always require great amounts of both. Our solution attempts to address these existing issues, provide a clean and easy-to-use setup and interface, and most importantly, effectively improve the response capabilities of law enforcement or emergency medical professionals.

1.b Our Solution

Our solution to this issue is to use a reconnaissance drone primarily equipped with two mmWave Human detections sensors, a 3x3 ultrasonic receiver/transmitter array module, and a ESP32 microcontroller. This drone will enter a hazardous room and perform a simple 360 maneuver while hovering. If the sensors detect the presence of a human, the drone will send a notice along with relevant position information directly to the AR software over 2.4G Wi-Fi using the ESP microcontroller. This received information will then be used by a user's device running our custom written augmented-reality viewing program. This program will calculate the distance and angle at which the person is to the user's device. Then the program will display an icon and a distance value overlaid on the device's front camera feed to provide the user with instant and accurate position information of humans present in the adjacent room. The user can then take the appropriate actions or assist other responders present to ensure that they along with the detected human presence are able to continue navigating the situation as safely as possible.

1.c Visual Representation

User with
Viewing
Device
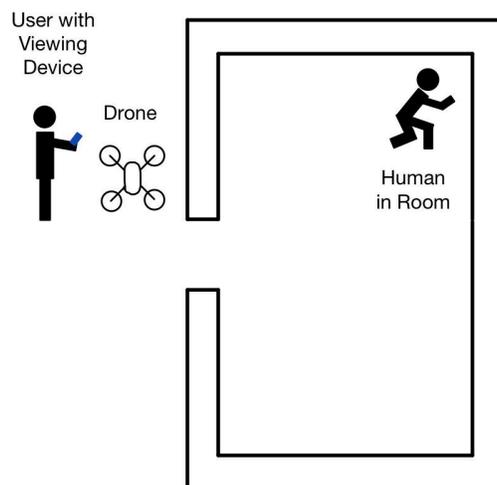
Drone

Human
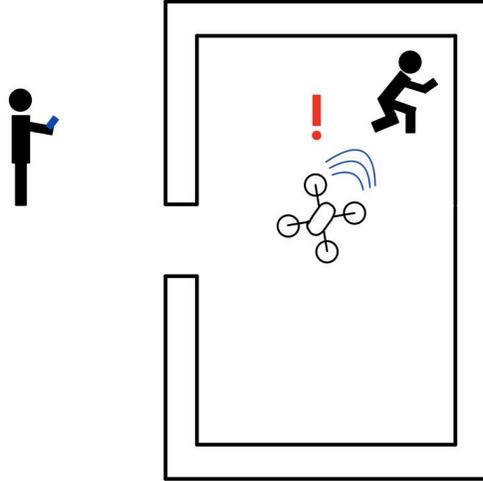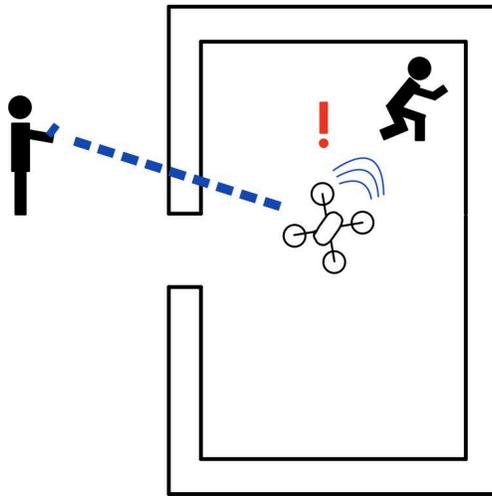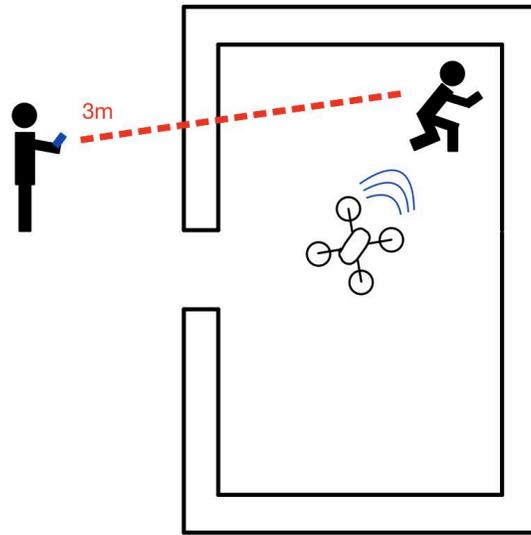in Room

(Figure 1 Hypothetical Use Case)
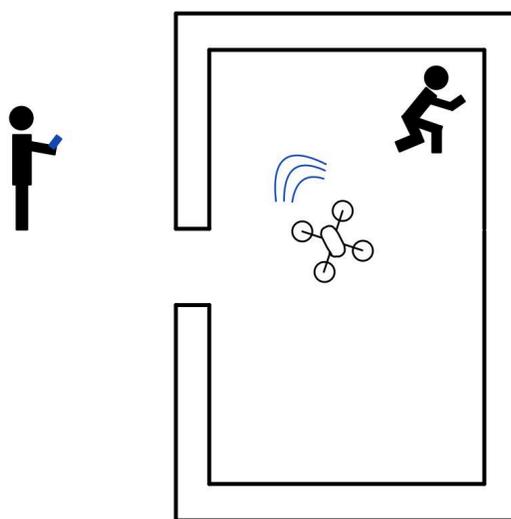
(Figure 2 Drone Sent into Room)

(Figure 3 Drone Detects Human)

(Figure 4 Drone Alerts Exterior Device)

(Figure 5 Outside Device Alerts User)

(Figure 6 Hypothetical View From AR app)

1.d High Level Requirements

Our system will have 3 main criteria for success:

- We have a semi-autonomous vehicle that can provide our sensors with a vantage point
- Our onboard sensors are able to detect a human with a range of 8 meters.
- Transmit, calculate, and display the relevant human presence data onto an alternate reality camera feed as demonstrated by *figure 6* above.

2.a Block Diagram
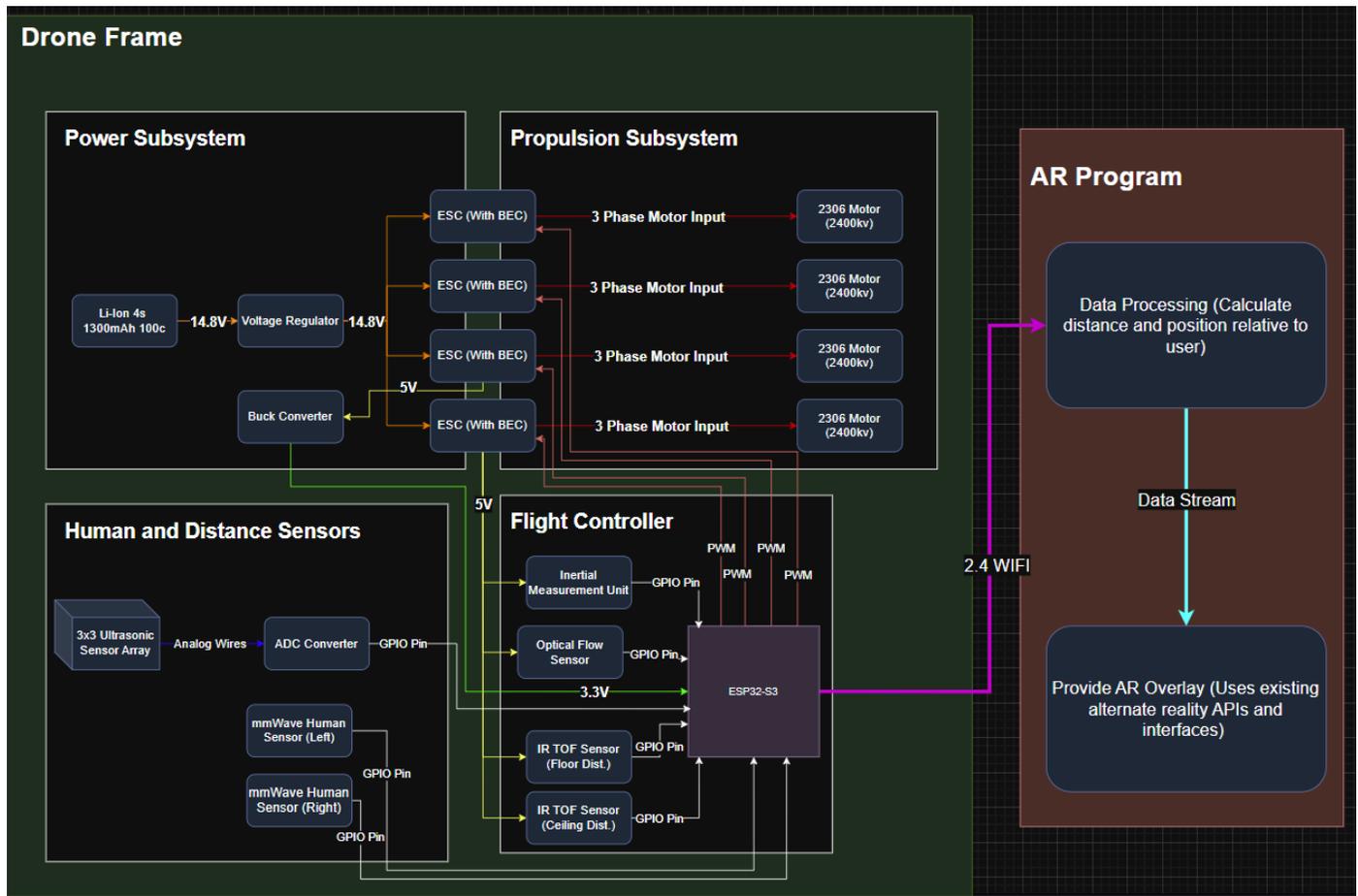
(Figure 7 Block Diagram)

2b. Subsystem Overview

description of purpose of subsystems and their components, including interaction with other subsystems. A brief description of the function of each subsystem in the block diagram and explain how it connects with the other subsystems. Every subsystem in the block diagram should have its own paragraph.

The Power Subsystem is responsible for the distribution of power from the 4S LiPo battery to the *Propulsion* and *Flight Controller* subsystems. Outside of the LiPo battery - this system contains the necessary components for the safe allocation of power; such that the ESC converts the LiPo's direct current (DC) to alternating current (AC) as required by the four motors. Each ESC comes with a battery eliminator circuit (BEC) which supplies 5V at 4A. We will be using these ESC's to provide power for the *Human and Distance Sensor* and *Flight Controller* subsystems. The ESCs and buck converter aim to safely convert the LiPo's 14V down to 5V and further to 3.3V.

The Propulsion Subsystem is used to allow our device to fly. It consists of four electronic speed controllers (ESC) and four corresponding 2306 motors. The motors' stator is 23mm wide and 6mm tall, as indicated by their name. Each motor completes 2400 rotations per minute for each volt applied to the motor up to 22 volts. Given that we are running the system at 14.8 volts, each motor will complete 362,600 rotations per minute. The *Flight Controller* subsystem provides pulse width modulation signals which are converted by the ESCs into alternating current (AC) signals to control the speed of the motors. This subsystem takes in 14.8V from the *Power Subsystem*.

The Human and Distance Sensors Subsystem, as the name implies, provides the sensing element of the drone system. The two mmWave Human Presence Sensors are aligned such that their beam angles have a cross-section, which allows for more precise distance measurement and detection location - with both sending their individual readings to the *Flight Control's* ESP32 via GPIO pins. These mmWave sensors provide the system with data on human presence, human velocity, and scalar distance to the drone. The ultrasonic sensors are shaped in an array pattern in order to be used in a phased array beam-forming approach with 8 transmitters and 1 receiver or through a more traditional sonar approach using 8 receivers and 1 transmitter - either will have much greater precision/resolution than just using a single transceiver and receiver pair for general 1D distance measurements. In either configuration, the transmitter(s) will be driven with square wave pulses via ESP32 GPIO pins, and the weak pulses that are reflected will be amplified through a low-noise op-amp, and processed either through a simple envelope detector or a full ADC to obtain usable inputs from the reflection data for another GPIO pin to monitor.

The Flight Controller Subsystem is used to both ensure stable flight and process incoming data from sensors. The heart of this system is the ESP32-S3. This is our microcontroller which takes in the data from the *Human and Distance subsystem* and the IR TOF sensors and transmits it over WIFI to the *AR subsystem* through the use of an external antenna connected to the ESP32. In addition, the ESP32 takes in data from the inertial measurement unit (IMU) which provides attitude, acceleration, and orientation data. It also takes in data from the optical flow sensor which provides position information. Once all the flight data is processed the

ESP32 sends out PWM signals to the *Propulsion Subsystem* to adjust the drone's direction, position, rotation, and attitude.

The AR Program Subsystem will be running on a separate device outside the room the drone is analyzing. It will likely be running on an Android device. This subsystem is responsible for receiving information from the drone and processing the data to determine where a person is with respect to the device that the AR program is running on. This will be done through simple trigonometric calculations. The program will then call upon Android AR APIs to provide an alternate reality overlay for the user to see.

2c. Subsystem Requirements

Power Subsystem Requirements:
- The battery is properly discharged through the circuitry and speed controllers to ensure both the safety and longevity of all components and operations.

Propulsion Subsystem Requirements:
- Motors and ESC's are safely tested and properly driven by PWM signals for safe and controlled operation of intended maneuvers.
- The motors never reach maximum capacity, such that they are never operating past 14.8V & 40A = 592 W.

Human and Distance Sensor Requirements:
- The human presence sensors are correctly driven and proper position data is read for transmitting over Wi-Fi.
- The ultrasonic sensor array utilizes a phased array approach to drive transmitters in a beam-forming manner to build a simple sonar depth map over the area surrounding a human's rough location.
- The IMU is driven properly and mounted to the vehicle frame such that unwanted vibrations do not cause noisy sensor data which can disrupt PID-based autonomous telemetry and guidance algorithms.
- The optical flow sensor is driven properly and effectively prevents accumulated sensor error and other physical issues from contributing to swaying and instability while hovering.
- The infrared time-of-flight sensors are properly driven and used to monitor the distances to the floor and ceiling at all times, allowing for proper guidance and useful data for AR perspectives.
- All sensor data is combined to get an accurate distance and therefore relative position for the location of humans within the functional range of the sensor array.

Flight Controller Requirements:
- The flight controller effectively and properly communicates with and drives all sensors and speed controllers to ensure all intended functionalities.
- The vehicle can sustain stable hovered flight at a variable distance from the floor.
- The vehicle can perform a slow 360 degree scanning yaw rotation about its central axis.
- The vehicle can navigate from a doorway to a central location before stabilizing to a hover and executing a scanning maneuver.

AR Program Requirements:
- The MCU onboard the vehicle can effectively communicate all useful data either to a host server or directly to the AR software app through Wi-Fi with a usable latency.
- The AR program properly uses Android or Apple APIs to utilize the device's camera and internal IMU data and combine it with received data for use in the AR overlay algorithm.
- The position of humans within the same room as the hovering drone are overlaid on a live preview of the front-facing camera of the device to achieve the intended AR functionality.

2d. Tolerance Analysis of Drone Flight Capability

Total Mass Calculation (estimate):
- Carbon fiber drone frame: ~125 g
- LiPo Battery: 156 g
- Brushless DC motors: 30.2 g x 4 = 120.8 g
- Electronic speed controllers: 44.2 g x 4 = 176.8 g
- Sensor array: 4.8 g x 9 + ~10 g = 53.2 g
- PCB: ~60 g
- Accounting for propellers, wiring, other incidentals: ~50 g
- **Total: ~750 g**
- **Absolute max: 1100 g**

Thrust Calculation:
Each motor has a value of 2400kv. This means that each motor can perform 2400 rotations per minute per volt. We will be running each motor at 4s (~14.8V).
- RPM Per Motor: 2400RPM/V * 14.8V = 35,520RPM
- Propeller Pitch: 4.5in or 0.114m
- Diameter: 5in or 0.127m

Drone Thrust Equation:

$$Thrust = 4.392 * 10^{-8} * RPM * d^{3.5}/\sqrt{pitch} * (4.233 * 10^{-4} * RPM * pitch)$$

$$Thrust = 4.392 * 10^{-8} * 35520 * 5^{3.5}/\sqrt{4.5} * (4.233 * 10^{-4} * 35520 * 4.5)$$

Total Thrust Per Motor = 13.9N

Comparing Metrics:

When comparing our estimated total weight with our calculated total thrust, our thrust to weight ratio appears reasonable for our intended uses and maneuvers.

3. Ethics, Safety, and Societal Impact

For the past two decades, society has been shown a wide-scale adaptation of the use of drones in both military and civilian circumstances. As such, it is prudent to specify that the Building Interior Reconnaissance Drone (BIRD) is intended solely for use in search and rescue and/or police-sanctioned operations. Thus, any use of this drone and related software for unlawful entrance or harassment is strictly forbidden in accordance with IEEE Code of Ethics, Sec. I.1 [1]. While we do not currently intend to commercialize our project; if our stance was to change - we would insure to only sell the BIRD to law enforcement professionals or fire and rescue departments in order to ensure the responsibility of potential users of our project and to eliminate the use of the BIRD in nonprofessional settings in accordance with IEEE Code of Ethics. Sec. I.3 [2] and Sec I.4 [3].

The BIRD contains no devices that are unstable or intentionally harmful towards its users and recipients. Our project utilizes human presence radio sensors that operate at 24 GHz. According to the FCC [4], the 24.05 GHz - 24.25 GHz frequency band is designated for industrial, scientific, and medical equipment and allows for the use of unlicensed devices within this range, therefore we may operate our human presence sensors freely without license. The ultrasonic sensors will be used in the 40 kHz sound frequency, and as such should not affect human hearing in any way, despite potential audible emissions due to the operational design of the array. The major safety concern of our project is the use of a 4S LiPo battery with a discharge rate of 100C and capacity of 1300mAh, operating at 14.8V. For the protection of the battery, motors, and our PCB - we use four ESCs (electronic speed controller) rated at 40A for 2-4S, which also each contain a BEC (battery eliminator circuit) with output of 5V. Thus, each ESC includes power-on protection, over-temperature protection, low-voltage cutoff, and signal-loss protection which aim to protect the ESCs, motors, and circuit components while also acting as voltage regulators to step-down the LiPo voltage to 5V. This 5V output is passed through a buck-converter in order to step down to the required 3.3V needed to supply the ESP32-S3 microcontroller chip.

The BIRD will protect the safety of officers and other government personnel from blindly clearing rooms that may otherwise contain a threat, either in the form of a person or a structural instability. The important distinction between the BIRD and currently available commercial detection drone systems is that the BIRD is safely usable by one individual. In other words,

current drone systems require the user to control the drone through a physical controller - therefore preoccupying them - and thus requiring two people to ensure safety of the drone user. On the contrary, BIRD requires the user to send in the drone initially while having full control of the situation afterwards, be it to avoid falling objects from a collapsing structure or an assailant exiting the selected room during drone operation. In a search and rescue scenario, this allows for a theoretical increase of x2 speed at clearing a residential building - as we may now have twice the number of room clearing operations occurring with the same manpower as before.

References

[1] IEEE, *IEEE Code of Ethics*, sec. I.1. [Online]. Available:
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[3] IEEE, *IEEE Code of Ethics*, sec. I.4. [Online]. Available:
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[4] "Federal Communications Commission," Dec. 2001. Accessed: Feb. 14, 2026. [Online].
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[5] Drone Equation Link
https://www.tytorobotics.com/blogs/articles/how-to-calculate-propeller-thrust?srsltid=AfmBOool
eXPEWdIui0XQD1EwkoKIBElChglpRuKlnJJXuC1sXqsJpkZn