Bird Simulator

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Contents

1. Introduction

1.1 Problem

This project addresses the limitations of current FPV drone systems, which can create an immersive visual experiment, but lacks the ability to allow for physical control through the human body through motion cues or body orientation. This results in an experience with a realism factor for people who want an even more exhilarating experience.

Beyond entertainment, FPV drones are very useful in situations where it is not feasible to place humans directly in the environment, such as search-and-rescue operations, disaster response, or other hazardous settings. In these high-risk scenarios, rapid situational awareness is critical. Human reflexes naturally respond to perceived threats by instinctively moving their head or body to shift attention, for example, ducking when approaching an obstacle, or turning your head when there is movement in your peripheral vision. These reflexive movements are much faster than the conscious decision to move your hands to control the sticks to reorient the drone to face the threat. Combined with traditional stick control, human reflexes can be leveraged to create a more responsive tool valuable for applications where quick response time is essential.

1.2 Solution

To address this problem, we will design and implement a bird-inspired FPV drone system that allows the pilot to control flight using full-body motion rather than relying on a traditional controller. Human movements such as arm motion, head orientation, and torso tilt will be captured through multiple IMUs attached to a suit. A microcontroller will then read the data from the IMUs to convert them to instructions transmitted by a 2.4GHz transceiver that the drone receives and uses to maneuver in its environment. The pilot will be able to see what the drone camera sees through FPV goggles, which will receive analog video transmitted over 5.8GHz radio. A traditional drone controller will be made to override suit inputs and take over control in case the drone starts behaving erratically, which will also transmit signals with the 2.4GHz transceiver.

To allow development of the drone, suit, and video transmission in parallel, we will also build a drone simulator using JavaScript that can be run on a web browser. This simulator will provide a safe testing environment for validating controls and other algorithms without the risks of real-world flight, lowering the risk of injury and damage to hardware during development, and allowing more iterations for trial and error.

1.3 Visual Aid

Figure 1: Visual aid for bird simulator

1.1 High Level Requirements

- The bird suit must measure values from a set of IMUs, and transmit data over 2.4GHz to the drone, allowing for control similar to what can be done with a controller.
- The drone must receive 2.4GHz data from the bird suit or controller, and fly through the air with assisted control using the onboard IMU.
- The drone must use a camera to generate and transmit 5.8GHz FM video signals, to be received by either an off-the-shelf or custom FPV headset or screen.

2 Design

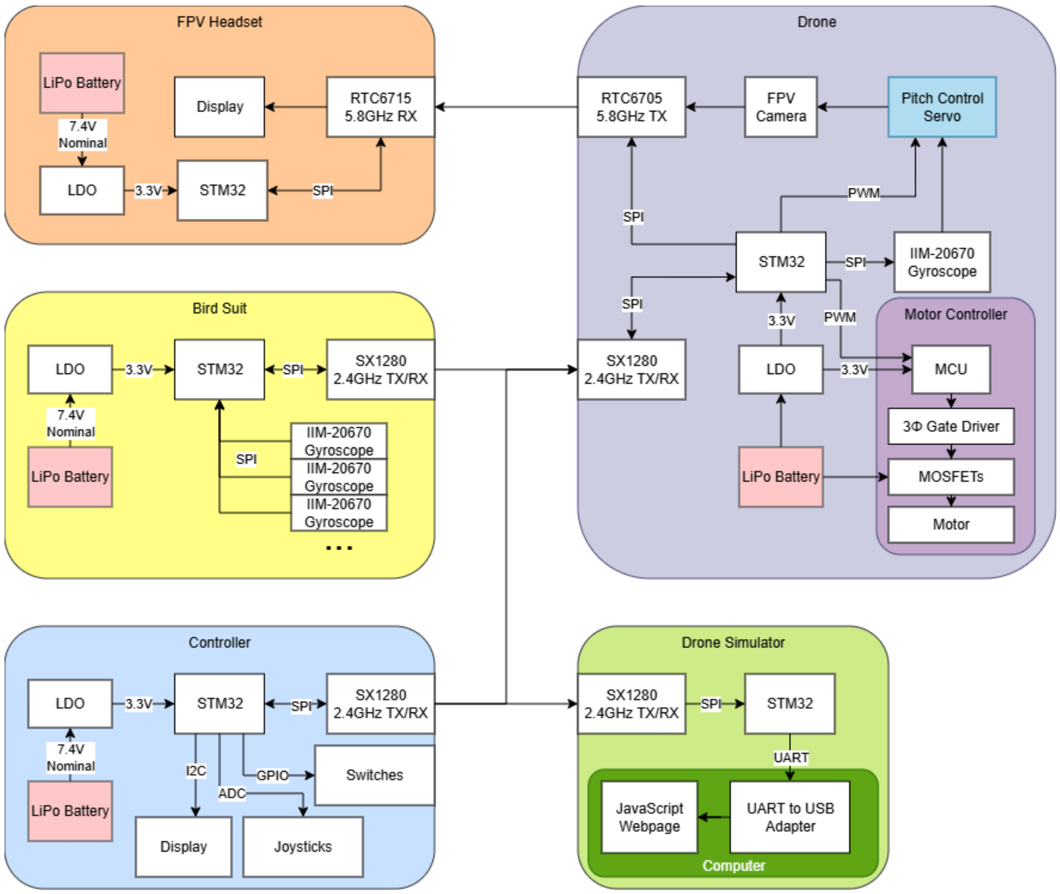

Figure 2: Block diagram for bird simulator

2.1 Subsystem 1: Drone

2.1.1 Flight Controller

The control of the drone will center around an STM32 microcontroller, which will communicate with the SX1280 to receive control signals from either the bird suit or the controller [3]. These signals will contain the raw inputs for the throttle, pitch, yaw, and roll of the drone. The STM32 will then use these signals, as well as the signals from the onboard IMU, to generate four PWM signals for the four motor controller boards. The STM32 will also generate a PWM signal for the pitch control servo for the camera, allowing for the camera to stay level.

2.1.2 Motor Controller

The propulsion system on the drone consists of a motor controller MCU, 3-phase gate drivers, MOSFET half bridge stages, and the BLDC motors itself. Each motor is driven using PWM signals from the flight controller. The gate driver converts PWM signals into gate voltages for the MOSFETs, enabling the switching of motor phases. The BLDC motors generate lift and thrust required for flight.

2.1.3 Video

We will use 5.8 GHz radio to transmit video data from the drone to FPV goggles using the RTC6705 transmitter module. This RF module handles amplifying, mixing, and modulating/demodulating signals and will be configured and programmed by the microcontroller through SPI. The camera outputs analog video to be transmitted by the RTC6705.

2.1.4 Autoleveling

The drone will be equipped with an on board gyro (IIM-20670) to determine its orientation during flight. This orientation information is used to generate motor commands that correct movements that may cause the drone to lose control. The autoleveling control will be implemented using a PID control loop on the microcontroller, which will calculate an error signal between the desired orientation and the current orientation, and generates corrective adjustments to the motor PWM signals.

2.1.4 Power Management

The drone is powered by a LiPo battery. The power subsystem includes a LDO/buck converter for 3.3V logic regulation and a voltage regulator. The power system must support transient current spikes during maneuvers while maintaining voltage stability for the rest of the subsystem.

2.2 Subsystem 2: Bird Suit

There will be 4 IIM-20670 modules embedded in a wearable suit that will collect data to be combined and used to determine the motion and orientation of the user: one on each arm, one on the back of the head, and one on the back (in between the shoulder blades). The IIM-20670 modules can capture gyroscope and accelerometer information, which is communicated to the microcontroller through SPI [7]. Movements such as head rotation, wing flapping, body orientation will be translated to stick inputs on a drone controller. This information will be organized into a series of bytes, sent to the 2.4GHz transceiver chip (SX1280), and transmitted over radio to the drone. The byte order will be discussed in a later section (2.5 Subsystem 5: Controller). This subsystem is powered with a LiPo battery with a 7.4V nominal voltage, which will be stepped down to 3.3V by a LDO.

To extract meaningful body movement and orientation from the raw gyroscope and accelerometer data collected by the IIM-20670 modules, several mathematical processing steps are required. At a high level, we will need to use linear algebra to manipulate coordinate planes and transformations, filtering to combine information from multiple sources of information, and other scaling and mapping techniques to achieve a realistic response. We will assign drone input controls to human movement as follows:

1. Throttle: frequency and amplitude of wing flapping determines amount of throttle applied
2. Pitch: angular displacement of the torso in the sagittal plane from the neutral position determines the angle of the drone’s pitch
3. Yaw: angular displacement of the head in the transverse plane from the neutral position determines the rate of yaw
4. Roll: angular displacement of the arms in their extended position in the coronal plane from the neutral position determines the angle of roll

5. Camera pitch: angular displacement of the head in the sagittal plane from the neutral position determines the angle of camera pitch

2.3 Subsystem 3: FPV Headset

In the initial development phase, we will use off-the-shelf FPV goggles to receive the analog video transmitted by the drone's 5.8GHz transmitter. The RTC6705 uses standard 5.8GHz analog FM modulation [4], which is the same protocol that is used by many existing FPV goggles. If time permits, we will design our own FPV goggles, which involve the RTC6715 5.8GHz receiver [5], and either a composite-to-HDMI converter, and a small HDMI compatible LCD screen, or a composite video compatible LCD screen to reduce latency.

2.4 Subsystem 4: Drone Simulator

This subsystem is a continuation of the Flight MP from CS418, which involved using JavaScript and WebGL to randomly generate terrain and take user input from the keyboard to move a camera around the terrain to simulate flight. To make the movement feel more drone-like, the controls will be remapped to a drone controller's sticks, and physics will be added to mimic real-world flight. Further development of the simulator will include a 2.4GHz receiver that can either receive information from the suit or controller which will be read by the computer running the simulation through a UART to USB adapter, and improved graphics by using existing 3D models rendered using Three.js. With the ability to easily modify the backend of this simulator, it is a better tool for the development of the bird simulator than a closed-source off-the-shelf flight simulator.

2.5 Subsystem 5: Controller

The traditional drone controller consists of two switches, two joysticks, a display, and button/joystick, and is powered by a LiPo battery with a 7.4V nominal voltage, which will be stepped down to 3.3V by a LDO. The microcontroller reads the joystick values with an ADC to be converted to throttle, pitch, roll, and yaw values, which sends the data to the RF transceiver (SX1280) to transmit over 2.4GHz radio. One of the switches will arm the drone, and the other switch will cause the controller input to override suit input. The drone will not take any input from the suit unless the controller's arm switch is toggled, so that the drone has a backup control ready at all times. When override is toggled, the suit's transceiver will receive this signal and stop transmitting. The information is sent continuously in packets, which organize the data in this order, with each element being represented by one byte:

[Arm][Override][Throttle][Yaw][Pitch][Roll][empty][empty]

The controller is equipped with a LCD screen (DOGM204-A 4x20) that interfaces with the microcontroller over I2C that displays a cursor which can be controlled by the small button/joystick [8]. This can be used to adjust controls, parameters, etc. without having to reprogram the drone's flight controller.

2.5 Tolerance Analysis

The most significant risk to successful completion of the project is the latency and accuracy of the IMU data processing. The microcontroller must be able to obtain data from each of the four gyroscope modules, process and translate the inputs, and transmit the data fast enough so that the drone receives enough information to maintain stable flight. This risk can be mathematically analyzed to demonstrate that it is feasible.

A drone feels responsive to a traditional joystick controller when data packets are transmitted with a frequency of greater than 50 Hz, or one packet every 20 ms. This means that for the drone to feel responsive and stable, the suit must transmit its data at this frequency or faster.

Since each gyro module provides 12 bytes of raw data, the microcontroller receives 48 bytes of data per polling. Assuming a SPI clock with a frequency of 10 MHz, the time to read 48 bytes is:

$$T_{poll} = \frac{1\ second}{10*10^{6}\ bits} \cdot \frac{8\ bits}{1\ byte} \cdot 48 = 28.8\ \mu s$$

which, compared to the time constraint of 20 ms, is negligible.

After polling the gyros, the raw data needs to be processed and translated to drone inputs. The processing consists mainly of filtering and manipulation of matrices and vectors, which can be executed very efficiently using optimized C libraries. The total processing time can be estimated to be on the order of microseconds, which again, compared to the time constraint of 10 ms, is negligible.

Finally, data will be transmitted by the RF module using LoRa modulation, which can transmit 8 bytes of data in 10 ms. The total time from polling the gyros, processing the data, and transmitting over radio is less than 20 ms, which means the drone will be able to receive input frequently enough to maintain responsive and stable flight.

3. Ethics, Safety, and Societal Impact

3.1 Legal Issues

This project poses three potential legal issues; transmission on the 2.4GHz band, 5.8GHz band, as well as operating a flying object in public, outdoor airspace. While the SX1280 is FCC Part 15 certified, our use in a custom board without FCC testing and certification will require an amateur radio license [2]. Similarly, both of the 5.8GHz chips we are using for video are not FCC certified. To work around this, Emily will obtain a Technician Class Amateur Radio License (HAM License) under FCC part 97. This allows for legal use of custom radio boards without FCC certification [2].

Recreational flight in public airspace requires an FAA remote pilot license, which Eli currently possesses. This allows for flight of any object below 250 grams, without any FAA registration [6]. We expect to stay below 250 grams, but should we end up above this weight, registration of the drone is still relatively simple, inexpensive, and well within our ability. During any flight of the drone, Eli will be in control of either the bird suit or the controller, allowing him to take control of the drone at any point, should the flight pose any hazard.

3.2 Ethical and Safety Issues

In accordance with the IEEE Code of Ethics, our primary focus is keeping our project safe, both for us, as well as people in the areas where our drone would be flown. Our project involves high-speed propellers, which could pose a safety hazard. The primary safety risk is a loss of control of the drone in flight. To uphold IEEE Code of Ethics I.1 [1], we will implement an ‘override’ system, where a traditional controller can take control instead of the bird suit’s inputs. This allows for a certified remote pilot to take control of the drone, and allow it to land safely.

Operating on 2.4GHz and 5.8GHz without FCC certification poses an ethical risk of interfering with other communications. We are mitigating this by requiring a Technician Class Amateur Radio License (HAM License) under FCC Part 97 [2], ensuring we operate legally, within any power or frequency band limitations.

To minimize physical risk while designing the drone, we are utilizing a drone simulator. This allows for us to validate the signals generated by the bird suit in a virtual environment, preventing hardware damage or injury from the drone flying erratically.

The use of LiPo batteries in multiple parts of our system also poses safety risks. We will adhere to standard charging and storage protocols to prevent thermal runaway or fire hazards. This will be done by storing the batteries in battery storage containers when not in use, charging them only in open air under active supervision, and regularly monitoring the voltage of the batteries to prevent over- and under-voltage.

3.1 Societal Impact

This project is broad in its applications and potential to impact society. In this iteration, the bird simulator is purely for entertainment purposes, giving FPV pilots a new, more immersive way to explore environments using a drone. Beyond entertainment, this project explores how leveraging natural body movement and reflexes for control can lead to more intuitive and responsive ways for humans to operate remote systems. This enhanced-human machine interaction can have benefits from a safety perspective, reducing risk to humans in hazardous situations. Applications such as search-and-rescue, disaster response, and inspection of dangerous environments could benefit from faster, reflex-driven control that mimics natural human instincts, potentially reducing risk of damage and injury when reaction times matter.

4. References

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