Project Proposal: Smart Glove Controller and Custom FPV Drone

ECE 445 Senior Design

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Introduction

Problem

High-performance First Person View (FPV) drones are capable of incredible speed and complex acrobatic maneuvers (freestyle flying). However, piloting these aircraft requires mastering traditional dual-joystick radio transmitters. This control scheme has a notoriously steep learning curve, requiring dozens of hours in simulators before a beginner can safely hover, let alone perform acrobatics. The unintuitive nature of mapping thumb movements to the 3D spatial orientation of a quadcopter creates a significant barrier to entry for new hobbyists and professionals alike.

Solution

We propose replacing the traditional RC transmitter with an intuitive, wearable ”Smart Glove” paired with a custom-designed FPV drone. Inspired by DIY wearable electronics, the smart glove will integrate a low-profile microcontroller (e.g., Arduino LilyPad) and a 3-axis accelerometer directly onto a sports glove. It will track the pilot’s hand orientation (pitch and roll) and translate these physical gestures into continuous, proportional flight commands via a low-latency 2.4GHz RF link.

The receiving end is a custom-built 5-inch quadcopter utilizing a Mark 4 frame, featuring an off-the-shelf JHEMCU F722 Flight Controller stack and a custom-designed Power Distribution Board (PDB). To handle the extreme electrical noise generated by the 55A 4-in-1 Electronic Speed Controller (ESC) and 2207 brushless motors, our custom PCB employs a robust, cascaded power architecture. It steps down a Bosli-po 6S 22.2V 1400mAh 150C LiPo battery using a TPS54360 buck converter to 12V, an SY8205 buck converter to 5V, and an AMS1117 LDO to 3.3V, alongside a REF3033 precision reference. This ensures the onboard microcontrollers and RF receiver obtain clean power and the REF3033 precision reference enable high-frequency PID loop calculations for exceptionally stable, gesture-driven freestyle flight.

High-level Requirements List

- The Smart Glove Subsystem must accurately sample continuous analog orientation data from the accelerometer and successfully transmit control packets to the drone’s receiver at a minimum frequency of 50 Hz, ensuring end-to-end control latency remains below 50 ms.
- The custom Power Distribution Subsystem must output a stable 5V logic rail capable of sustaining a 2A continuous load with less than 50 mV peak-to-peak voltage ripple, ensuring the F722 flight controller does not experience brownouts during rapid motor acceleration.

- The Drone Flight Control Subsystem (STM32) must execute its sensor fusion and PID stabilization loop at a minimum frequency of 1 kHz (1 ms loop time) to guarantee stable aerodynamic responses to the glove's continuous input commands.

Design

Block Diagram

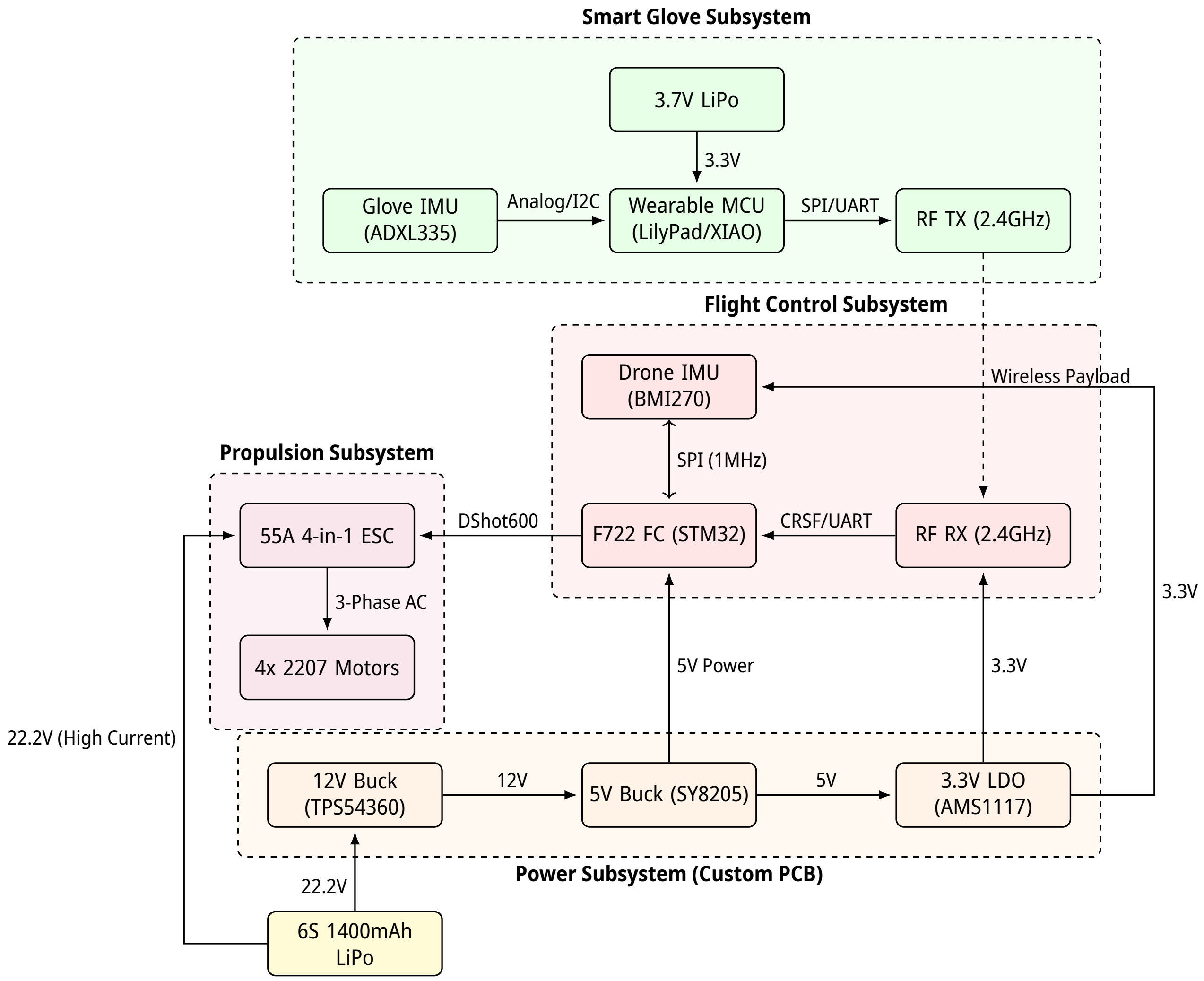

Figure 1: System Block Diagram showing power routing and data interfaces between the Smart Glove and the Quadcopter.

Subsystem Overview

Smart Glove Subsystem: Inspired by wearable DIY electronics, this subsystem is built upon a flexible sports glove, completely replacing the traditional dual-joystick RC remote. We will integrate a low-profile wearable microcontroller (such as an Arduino LilyPad or Seeed Studio XIAO) and a 3-axis accelerometer (e.g., ADXL335 or MPU6000) directly onto the fabric. The MCU continuously reads the analog spatial orientation of the pilot's hand, processes these gestures into continuous proportional flight control channels (pitch, roll, yaw), and wirelessly transmits them via a 2.4GHz RF TX module. This provides an intuitive, physical interface for drone freestyle flying.

Power Subsystem (Custom PCB): Drawing power from a high-voltage Bosli-po 6S (22.2V, 1400mAh, 150C) LiPo battery, this subsystem provides all necessary voltage rails for the custom components. As designed in our schematics, it utilizes a cascaded step-down topology: the battery feeds a TPS54360 buck converter to generate a 12V rail. This 12V rail feeds the SY8205FCC buck converter to generate a high-current 5V rail. Finally, the 5V rail feeds an AMS1117 LDO to supply 3.3V logic to the microcontrollers and sensors. This cascading isolates sensitive logic from the massive voltage spikes generated by the ESCs.

Flight Control Subsystem: The brain of the quadcopter utilizes a JHEMCU F722 Flight Controller (STM32F722 MCU) paired with a BMI270 IMU. It receives the pilot's continuous control setpoints from the RF Receiver over a fast UART interface (e.g., CRSF protocol). The STM32 runs an embedded PID control loop, comparing the drone's actual orientation (from the BMI270) against the setpoints generated by the smart glove, and calculates the necessary motor speeds.

Propulsion Subsystem: Comprises a JHEMCU 55A 4-in-1 Electronic Speed Controller (ESC) and four 2207 brushless motors. The ESC receives digital DShot600 signals from the F722 FC and switches high currents from the LiPo battery to drive the motors, generating the thrust required for flight.

Subsystem Requirements

Power Subsystem Requirement: The 5V buck converter circuit (SY8205) must be able to supply 2A continuously to the flight controller and RF receiver with a voltage output of 5V ± 0.2V. *Failure condition:* If the voltage drops below 4.5V under load, the STM32 and RF receiver will brown-out and reset, causing an immediate catastrophic crash.

Flight Control Subsystem Requirement: The STM32 must interface with the BMI270 IMU over SPI at a minimum clock speed of 1 MHz and fetch gyroscope/accelerometer data in under 200 μs. The entire PID calculation loop must complete in under 1 ms. *Failure condition:* If the loop time exceeds 2 ms, the phase delay in the control system will cause unrecoverable high-frequency oscillations (flyaway).

Smart Glove Subsystem Requirement: The glove's wearable microcontroller must map the physical analog pitch and roll of the user's hand from $-60°$ to $+60°$ linearly to continuous channel values (1000 to 2000 μs format) with an angular accuracy of $\pm 2°$. *Failure condition:* If the mapping is limited to binary (on/off) logic or is highly noisy, the drone will drift unpredictably and the pilot will be unable to hold a steady hover.

Tolerance Analysis

A critical risk in our design is ensuring the logic-level 5V power rail remains clean and stable despite the electrically noisy environment of a freestyle drone. We analyze the theoretical output voltage ripple (ΔV_{out}) of our chosen 5V buck converter (SY8205FCC) operating under a continuous 2A load.

The output voltage ripple is primarily determined by the inductor ripple current (ΔI_L), the switching frequency (f_{sw}), the output capacitance (C_{out}), and its Equivalent Series Resistance (ESR). The formula for output voltage ripple is:

$$\Delta V_{out} \approx \Delta I_L \times \left(ESR + \frac{1}{8 \times f_{sw} \times C_{out}} \right) \tag{1}$$

According to our schematic, we are using an inductor $L = 10\mu$H, an output capacitance comprised of two 10μF ceramic capacitors and one 330μF solid capacitor (total $C_{out} \approx 350\mu$F). The SY8205 operates at a typical $f_{sw} = 500$ kHz. Input voltage is $V_{in} = 12$V (cascaded from the TPS54360) and $V_{out} = 5$V.

First, we calculate the inductor ripple current:

$$\Delta I_L = \frac{V_{out} \times (V_{in} - V_{out})}{V_{in} \times f_{sw} \times L} = \frac{5 \times (12 - 5)}{12 \times 500,000 \times 10^{-5}} = \frac{35}{60} \approx 0.583 \text{ A} \tag{2}$$

Assuming a worst-case ESR of 20 mΩ for the combined capacitor bank:

$$\Delta V_{out} \approx 0.583 \times \left(0.020 + \frac{1}{8 \times 500,000 \times 350 \times 10^{-6}}\right) \tag{3}$$

$$\Delta V_{out} \approx 0.583 \times (0.020 + 0.0007) \approx 0.583 \times 0.0207 \approx 0.012 \text{ V} = 12 \text{ mV} \tag{4}$$

Our analysis demonstrates that the expected voltage ripple is approximately 12 mV, which is well below our high-level requirement threshold of 50 mV. This confirms that our cascaded power schematic design, particularly the generous 330μF solid output capacitor, is highly tolerant to load fluctuations and will successfully provide a clean rail for the flight controller logic.

Ethics and Safety

Developing an FPV quadcopter involves fast-spinning propellers and LiPo batteries, which can be dangerous if not handled properly. In this project, we follow basic engineering ethics by always putting safety first during design and testing.

Safety Mitigations: During development and indoor testing, the drone will be fixed in place, and the propellers will be removed when uploading code or tuning PID parameters. This prevents accidental injuries.

During flight testing, we will install propeller guards to reduce the risk of injury. In addition, if the STM32 flight controller does not receive control signals from the smart glove for more than 200 ms, it will immediately stop all motors. This helps prevent the drone from flying out of control.

Regulatory Compliance: All test flights will be conducted outdoors in open areas and within visual line of sight. We will avoid flying near people and follow basic drone safety rules.

Distribution of Work

- **Zhenbo Chen (EE):** Power Subsystem design. Responsible for the custom PCB schematic and layout of the high-efficiency cascaded buck converter architecture (TPS54360 and SY8205) and power distribution to the ESCs.
- **Zhengyu Zhu (EE):** Flight Control Subsystem integration. Responsible for the JHEMCU F722 integration with the custom power PCB, IMU sensor fusion calibration, and modifying the embedded PID flight control firmware to accept smart glove inputs.
- **Renang Chen (ECE):** Hardware Assembly and Systems Integration. Responsible for the Mark 4 5-inch mechanical frame build, 2207 motor and 55A 4-in-1 ESC wiring, Bosli-po 6S battery mounting, and ensuring vibration isolation for the FC stack.
- **Jintu Guo (ECE):** Smart Glove Control Subsystem design and implementation. Responsible for integrating the wearable MCU (e.g., LilyPad) and accelerometer onto the sports glove, and establishing the low-latency 2.4GHz RF communication protocol to the drone.