ECE 445 SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Smart Glove Controller and Custom FPV Drone

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1 Introduction

1.1 Problem Statement

High-performance First Person View (FPV) drones are capable of incredible speed and complex acrobatic maneuvers. 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.

1.2 Solution Overview & Visual Aid

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 (an STM32 Minimum System Board) and a 3-axis accelerometer/gyroscope 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 GF30-F722 Flight Controller stack and a custom-designed Power Distribution Board (PDB). The custom PCB handles the extreme electrical noise generated by the 55A 4-in-1 Electronic Speed Controller (ESC) and 2207 brushless motors, ensuring the onboard microcontrollers and RF receiver obtain clean power for exceptionally stable, gesture-driven freestyle flight. To ensure safe development and isolate hardware variables, initial flight testing and PID tuning will be conducted using a Radiomaster Pocket (ELRS 2.4G) commercial off-the-shelf (COTS) RC transmitter before fully transitioning to the Smart Glove control.

大疆手势操作过时了，来看看手套控制系统

穹了个妹 · 2018-10-31

Figure 1: Visual Aid of the Smart Glove System in operation.

1.3 High-Level Requirements List

- **Control Latency & Frequency:** The Smart Glove Subsystem must accurately sample continuous analog orientation data from the IMU 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.
- **Power Stability:** 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.
- **Flight Control Execution:** 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.

2 Design

2.1 Block Diagram

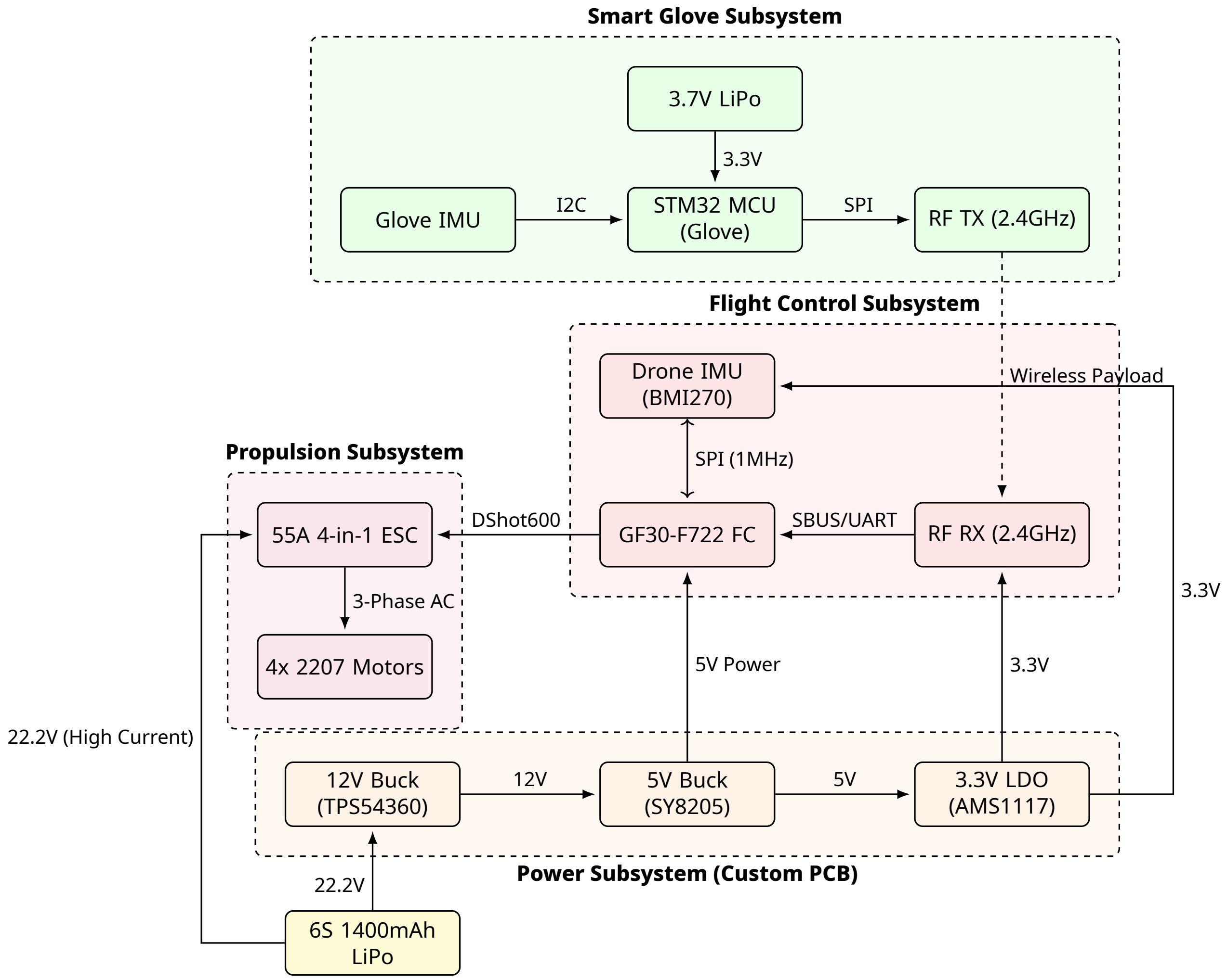

Figure 2: System Block Diagram showing power routing and data interfaces.

2.2 Power Subsystem (Custom PCB)

The custom Power Distribution Board (PDB) acts as the foundation of the drone, safely routing high-current electricity to the propulsion system while providing ultra-stable, isolated low-voltage logic rails for the flight controller and RF receiver. Drawing power from a high-voltage Bosli-po 6S (22.2V, 1400mAh, 150C) LiPo battery through an XT60 PW-F connector, the circuit first utilizes an SMBJ28A Transient Voltage Suppressor (TVS) diode. This critical component protects the entire board from destructive inductive voltage spikes (up to 30V+) that commonly occur when plugging in the battery or during aggressive motor braking.

From the raw battery voltage, the PCB utilizes a cascaded step-down architecture:

- **12V Rail:** A TPS54360 buck converter steps down the 22.2V input to a stable 12V rail. This isolates the downstream components from the massive voltage sags caused by the 55A ESCs.
- **5V Rail:** An SY8205FCC buck converter steps down the 12V rail to a high-current 5V rail. This rail powers the flight controller and the 2.4GHz RF receiver. It utilizes a 10μH inductor

and a large 330μF solid capacitor to minimize switching ripple.

- **3.3V Logic & Reference Rails:** The 5V rail feeds two separate linear regulators. An AMS1117-3.3 LDO provides general 3.3V logic power, while a dedicated REF3033 precision voltage reference IC provides an ultra-clean 3.3V baseline for any analog-to-digital conversions required by auxiliary sensors.

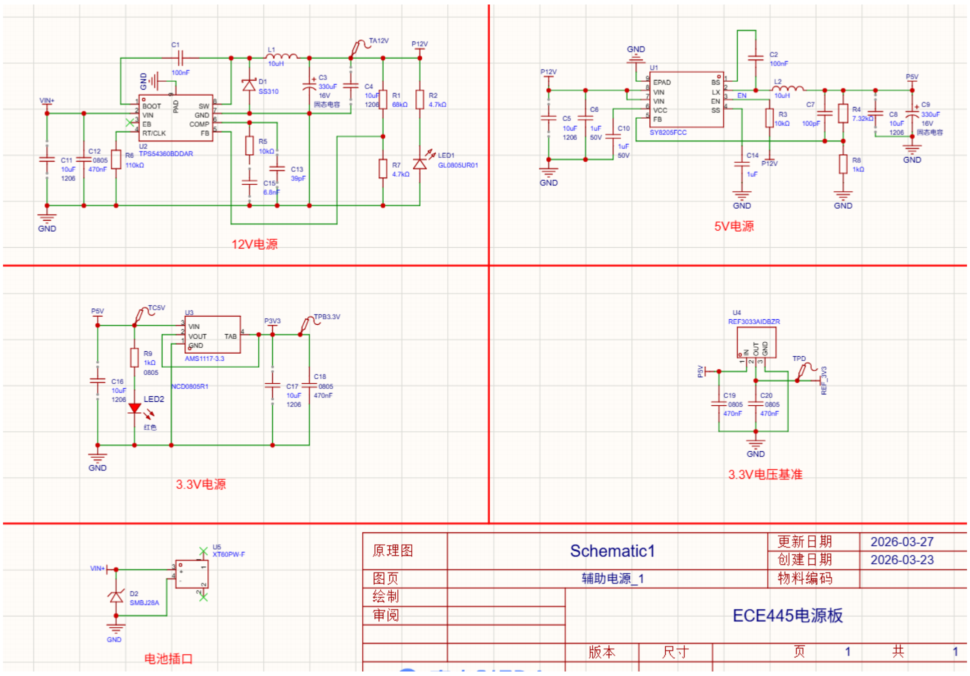

Figure 3: Schematic of the Custom Power Distribution Board.

Requirements	**Verifications**
1. The TVS Diode (SMBJ28A) must clamp voltage spikes to below 30V when connecting a fully charged 6S LiPo (25.2V).	1. Connect an oscilloscope to the VIN test point. Rapidly plug in the XT60 connector 10 times. Verify the peak transient voltage never exceeds 30V on the scope trace.
2. The 12V Buck Converter (TPS54360) must output 12V $\pm\ 0.5$V under a 1A load.	2. Connect an electronic load to the 12V test point, set to draw 1A continuously. Measure the voltage using a digital multimeter (DMM) to ensure it stays between 11.5V and 12.5V.
3. The 5V Buck Converter (SY8205) must supply 2A continuously with a peak-to-peak voltage ripple ≤ 50 mV.	3. Apply a 2A load to the 5V rail. Use an oscilloscope with AC coupling to measure the 5V test point. Verify the peak-to-peak ripple does not exceed 50 mV.

Table 1: Requirements and Verifications for the Power Subsystem

2.3 Smart Glove Subsystem

This wearable subsystem replaces the traditional dual-joystick RC remote. By pivoting to an STM32-based architecture, we utilize an STM32 micro-controller board (e.g., STM32F103 series) embedded into a sports glove. Paired with an MPU6050 6-axis IMU and an NRF24L01+ 2.4GHz RF transceiver module, the subsystem continuously reads spatial data. The STM32 utilizes its hardware I2C interface to fetch the IMU's raw data and computes precise Euler angles via sensor fusion. The MCU maps the pilot's physical hand pitch ($-60°$ to $+60°$) and roll to standard RC PWM values (1000 μs to 2000 μs) and wirelessly transmits this payload packet via the NRF24L01+ using the hardware SPI bus.

Requirements	**Verifications**
1. The STM32 must fetch and process pitch and roll angle data via I2C with a steady-state error of $\leq \pm 2°$.	1. Secure the MPU6050 to a calibrated digital angle gauge. Tilt it to precisely $+30°$ and $-30°$. Read the STM32 UART debug output to verify the software angle matches within the $2°$ tolerance.
2. The NRF24L01+ RF transmitter must successfully send control packets via the STM32 SPI peripheral at a minimum rate of 50 Hz.	2. Instrument the receiver module's RX interrupt pin with an oscilloscope. Measure the time interval between incoming packet pulses to ensure $\Delta t \leq 20$ ms.

Table 2: Requirements and Verifications for the Smart Glove Subsystem

2.4 Flight Control Subsystem

The brain of the quadcopter utilizes a high-performance GF30-F722 Flight Controller powered by an STM32F722 MCU, paired with an onboard Bosch BMI270 IMU. The BMI270 is chosen for its superior resistance to high-frequency motor vibrations common in FPV applications. An onboard NRF24L01+ receiver module catches the data packets from the smart glove and feeds them into the STM32 via a standard UART port (using the SBUS or CRSF protocol format). The STM32 executes an embedded PID (Proportional-Integral-Derivative) control loop in Betaflight, constantly comparing the drone's actual orientation from the BMI270 against the setpoints commanded by the glove to stabilize the aircraft.

Requirements	**Verifications**
1. The flight controller must successfully parse incoming UART control packets from the RF receiver without dropping more than 1% of frames.	1. Connect the FC to the Betaflight Configurator. Monitor the "Receiver" tab for 5 minutes of continuous operation and verify that the channel bars do not freeze or jitter due to packet loss.
2. The STM32 PID loop time (calculating sensor fusion and motor mixing) must consistently execute in under 1 ms (≥ 1000 Hz).	2. Access the Betaflight CLI (Command Line Interface) and run the 'tasks' command. Verify that the 'PID' task rate is consistently maintained at or above 1000 Hz.

Table 3: Requirements and Verifications for the Flight Control Subsystem

2.5 Propulsion Subsystem

This subsystem translates electrical commands into physical thrust. It comprises a 55A 4-in-1 Electronic Speed Controller (ESC) stack and four 2207 high-KV brushless motors. The ESC receives digital DShot600 signals directly from the GF30-F722 FC. Based on these signals, the ESC rapidly switches high-current PWM pulses from the 6S LiPo battery to drive the 3-phase AC motors, generating the dynamic thrust required for acrobatics and altitude holds.

Requirements	Verifications
1. The 55A 4-in-1 ESC must safely sustain a 40A continuous current draw per motor for 10 seconds without experiencing thermal shutdown or voltage sags below 18V.	1. Mount a single 2207 motor to a thrust stand. Connect an inline ammeter and voltmeter. Ramp throttle until the ammeter reads 40A. Hold for 10 seconds and verify the ESC remains functional and voltage remains ≥ 18V.

Table 4: Requirements and Verifications for the Propulsion Subsystem

2.6 Tolerance Analysis

A critical risk in our design is ensuring the logic-level 5V power rail on our custom PCB 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. Excessive ripple could cause the STM32 flight controller or the RF receiver to brown-out, resulting in catastrophic drone failure mid-air.

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 (Figure 3), we are using an inductor $L = 10\mu$H, and an output capacitance comprised of one 10μF ceramic capacitor and one 330μF solid capacitor (total $C_{out} \approx 340\mu$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:

$$\Delta V_{out} \approx 0.583 \times \left(0.020 + \frac{1}{8 \times 500,000 \times 340 \times 10^{-6}} \right) \tag{3}$$

$$\Delta V_{out} \approx 0.583 \times (0.020 + 0.000735) \approx 0.583 \times 0.0207 \approx 0.012 \text{ V} = 12 \text{ mV} \tag{4}$$

Our mathematical analysis demonstrates that the expected theoretical 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 inclusion of the generous 330μF solid output capacitor, is highly tolerant to load fluctuations and will successfully provide a clean rail for the logic components.

3 Cost

Part	**Quantity**	**Unit Cost (RMB)**	**Total Cost (RMB)**
Bosli-po 6S 1400mAh 150C LiPo	2	168.0	336.0
GF30-F722 Flight Controller Stack	1	200.0	200.0
Radiomaster Pocket (ELRS 2.4G) RC	1	369.0	369.0
Mark 4 5-inch Frame	1	65.8	65.8
2207 Brushless Motors	4	65.8	263.2
Custom PCB Manufacturing & Components	2	100.0	200.0
HOTA T6 battery charger	1	169.15	169.15
STM32 Core Board (e.g., F103C8T6)	1	25.0	25.0
MPU6050 IMU Module (Glove)	1	15.0	15.0
NRF24L01+ RF Modules (TX & RX)	2	20.0	40.0
Total Cost			**1683.15**

Table 5: Estimated Parts Cost

4 Schedule

Week	**Zhenbo Chen (EE)**	**Zhengyu Zhu (EE)**	**Renang Chen (ECE)**	**Jintu Guo (ECE)**
3/31	Order Custom PCB and source components.	Setup STM32 development environment for GF30-F722.	Assemble Mark 4 frame and mount motors.	Setup STM32 HAL library project for glove circuit.
4/7	Solder PCB components.	Flash FC and establish base PID tuning profiles.	Wire 55A ESC to motors and test basic spinning directions.	Write C code (HAL_I2C) to read raw data from MPU6050.
4/14	Test 5V and 12V rails with electronic loads for ripple verification.	Integrate Radiomaster Pocket RC and tune base flight characteristics.	Integrate Power PCB into the drone frame.	Write SPI code to send pitch/roll data via NRF24L01.
4/21	Address any PCB thermal issues and finalize power delivery.	Swap Radiomaster RC for NRF24L01 and map RF packets to Betaflight.	Mount LiPo battery and finalize center of gravity.	Integrate STM32 circuits onto the wearable sports glove fabric.
4/28	Conduct full system power stress test with motors active.	Conduct tethered flight tests and tune PID loop for glove inputs.	Prepare safety netting and documentation for demo.	Fine-tune gesture deadbands and finalize TX latency.

Table 6: Project Schedule and Division of Labor

5 Ethics and Safety

5.1 Ethics

Our engineering process will strictly adhere to the IEEE Code of Ethics. In accordance with Canon 1, which states the obligation ”to hold paramount the safety, health, and welfare of the public,” we recognize the inherent dangers of creating a high-speed projectile system. We are committed to transparency regarding our system’s capabilities and limitations, adhering to Canon 3 to ”be honest and realistic in stating claims or estimates based on available data.” Furthermore, we ensure that our remote gesture control data collection remains strictly local to the device, respecting user privacy.

5.2 Safety

Developing an FPV quadcopter involves high-speed spinning propellers and high-energy-density lithium-polymer (LiPo) batteries, posing severe laceration and fire risks.

- **Physical Mitigations:** During all development and indoor testing phases, the drone will be tethered to a weighted test bench. Propellers will be strictly removed during firmware flashing, PCB debugging, and PID tuning. When untethered flight testing begins, we will equip the drone with physical propeller guards.

- **Software Failsafes:** The STM32 flight controller will be programmed with a strict Failsafe protocol. If the drone detects a loss of RF telemetry from the Smart Glove for more than 200 ms, it will immediately cut all motor throttle to 0%, forcing the drone to safely drop to the ground to prevent a flyaway scenario.

- **Regulatory Compliance:** We will comply with Federal Aviation Administration (FAA) Part 107 regulations for small unmanned aircraft. Since our 5-inch drone will exceed the 250-gram weight limit, it will be properly registered. Test flights will be strictly conducted outdoors within Visual Line of Sight (VLOS) in designated, unpopulated AMA (Academy of Model Aeronautics) fields.

- **Battery Safety:** To mitigate fire risks, the 6S 150C LiPo batteries will be charged using balance chargers set to a safe 1C charge rate and stored in fireproof LiPo safe bags to contain potential thermal runaway incidents.