Intuitive and Ergonomic Gesture-Based Drone Controller

ECE445 Design Document Spring 2019

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1 Introduction

1.1 Objective

Recreational drones are more popular than ever before with roughly 1.4 million UAVs (Unmanned Aerial Vehicles) operated in the United States in 2018 [1]. Though the Federal Aviation Administration (FAA) projects this number will double to 2.4 million by 2021, this forecast is several million fewer than last years prediction. Analysts at the FAA suggest that "market saturation and shifting consumer tastes" are negatively impacting growth. Accordingly, entering this market can be difficult for new products and older products can be easily overlooked.

Our project aims to provide a means of distinction for numerous commercially available recreational drones[1]. We plan to create an ergonomic and intuitive gesture-based controller. Serving as both a novelty and a simpler means of control, compatibility with our device would raise the profile of compatible products. Additionally, the glove stands out on its own as a cool new way to fly. Users would use wrist and hand movements to control the drone's pitch, roll, and yaw by mimicking the desired movement. Thrust would be controlled by a trigger-like mechanism actuated by the user's index finger. Ideally, the entire package would be low-profile and cost effective while allowing for effective control.

1.2 Background

While attempts to make a similar product already exist on the market, they tend to be clunky and only work with one specific drone model [2, 3]. Our product would be slim and have compatibility with a wide variety of devices. This would attract current and new drone owners to purchase our product as an add-on to their drone or collection of drones. The product could also be included with partner companies products. Our product could be especially convenient for users with multiple drones as removes the need for having a separate controller for each drone.

1.3 High-level requirements list

- The glove must be able to measure user hand movements within 0.2 g and user hand orientation within 3°.
- The glove must be able to transmit control signals to the drone within a latency of less than 50 ms.
- The glove must be low profile (less than 1.5 cm above hand) and lightweight (less than 0.2 kg).

[1] See Appendix A for compatible products.

2 Design

2.1 Block Diagram

The design for this controller consists of four subsystems for proper operation: an array of sensors and buttons; a micro-controller, a power supply, and a transmitter. The array of sensors will collect data about the movement of hand when in the glove. The micro-controller will collect the data from the sensor array via I^2C connections and convert it to a transmittable form. The transmitter will then take the output of the micro-controller and transmit the data stream to the drone. The power supply, through a battery and a collection of voltage regulators, will supply $\sim 3.3\,V$ to each component.

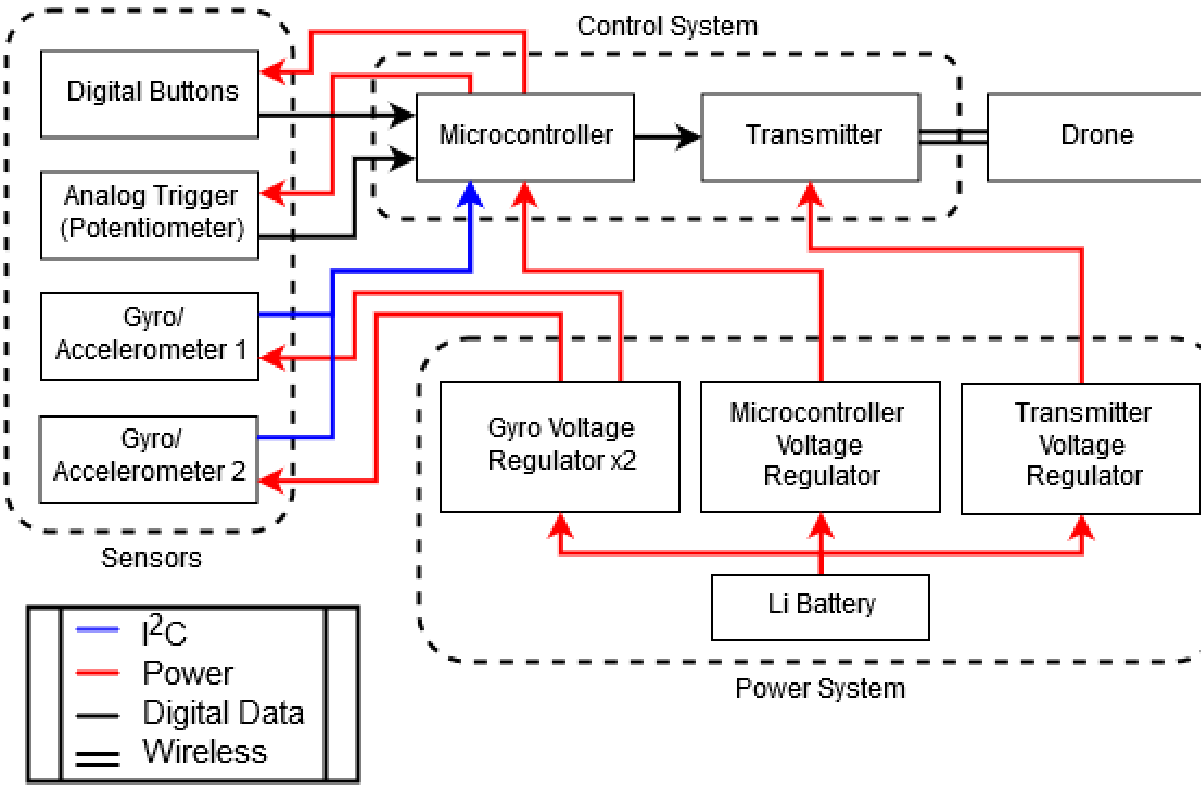

Figure 1: Block Diagram

2.2 Physical Design

Figures 2 and 3 below is a qualitative sketch of the glove with approximate positions where the sensors, battery, and micro-controller will be placed. The top of the hand will hold a PCB containing the sensors, controller, and transmitter. The palm will have a trigger for thrust control. The battery will be placed on the underside of the wrist.

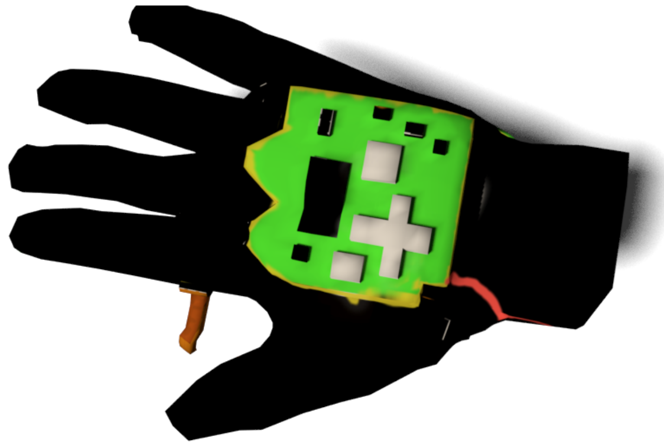

Figure 2: Basic Concept Design Back of Hand

Figure 3: Basic Concept Design Palm Side of Hand

2.3 Functional Overview

The various sensors in the palm and on the back of the hand will relay information to the micro-controller which will in turn translates those signals into control commands for the drone. The control commands will then be sent to the drone via a 2.4 GHz transmitter. The combined electronics will be powered by a rechargeable Lithium-Ion battery.

2.3.1 Sensors

The sensor system of the glove is meant to collect all necessary control inputs from the user. The digital buttons and analog trigger will be powered by the micro-controller and the gyroscopes/accelerometers will have individual voltage regulators.

2.3.1.1 Digital Buttons

The digital buttons will be used to signal different modes and features of the drone. They will be mapped almost directly to the existing controller buttons. See Figure 8 for schematic.

Requirement	Verification
Each button should register exactly one input per press (debouncing).	1. Attach USB adapter and power on device. 2. Load and run *buttonCheck.ino*. 3. Press the button and observe the on-screen data. The counter should only increment by one. 4. Repeat step 3 five times. 5. Repeat steps 2-4 for all buttons.

Table 1: Digital Button Requirements

2.3.2 Battery Pack

The battery pack will power the microprocessor which in turn powers the sensors and transmitter.

2.3.2.1 Analog Trigger

The analog trigger will control the thrust level of the drone through a voltage divider with a potentiometer. See Figure 8 for schematic.

Requirement	Verification
Full actuation of the trigger mechanism should have a range of (1.5 ± 0.1) V.	1. Power on the device. 2. Attach a multi-meter to the potentiometer output and ground. 3. Actuate the trigger from full extension to full retraction noting the voltages at the extremes. 4. The difference between the maximum voltage and the minimum voltage should match the requirement. $\left(\left|1.5 - (V_{max} - V_{min})\right| \leq 0.1\right)$

Table 2: Analog Trigger Requirements

2.3.2.2 Inertial Measurement Units

These IMUs will create sensor data along 6-axis from movement of the hand. These movements will control the roll, pitch, and yaw of the drone. They will also take into account lateral movements in the form of an accelerometer. See Figure 7 for schematic.

Requirement	Verification
The accelerometer must be able to measure user hand movements within 0.2 g.	1. Attach USB adapter and power on device. 2. Load and run *imuCheck.ino*. 3. Drop the glove approximately 0.3 m from one hand to another. Verify the acceleration display on the computer reads (1.0 ± 0.2) g. 4. Repeat step 3 five times.
The gyroscope must be able to measure user hand orientation within 3°.	1. Attach USB adapter and power on device. 2. Load and run *imuCheck.ino*. 3. Using a protractor or digital leveling tool, position the device at 20°. Verify the angle displayed on the computer matches the requirement and positioning. 4. Repeat step 3 for 40° and 60°.

Table 3: IMU Requirements

2.3.3 Micro-controller

This micro-controller will be a ATmega328 boot-loaded with Arduino compatibility so it can be programmed with Arduino. It will collect sensor data, organize it, and transmit it to the drone through the transmitter. See Figure 4 for schematic.

Requirement	Verification
Must be able to preform the Kalman filtering algorithm on the IMU data in less than 6 ms.	1. Attach USB adapter and power on device. 2. Load and run *softwareCheck.ino*. 3. Slowly rotate device from $-90°$ to $90°$ along the pitch axis. Verify that the times displayed on the computer match the requirement. 4. Repeat step 3 for roll and yaw axes. 5. Repeat steps 3-4 for quick rotations.

Table 4: Microcontroller Requirements

2.3.4 Transmitter

The transmitter will be an NRF24L01+ Wireless Module. Its role is to communicate the sensor data from the glove to the drone. We are using this module as neither of us have significant experience in antenna design. As the part is pre-bought the only requirement is that it is configured correctly for communication. See Figure 5 for schematic.

Requirement	Verification
The transmitter must be able to communicate with the drone.	1. Attach USB adapter and power on device. 2. Power on drone. 3. Load and run *transmitCheck.ino*. 4. Perform connection maneuver. Verify the computer displayed "Connected". 5. Power off and repeat step 1-4 three times.

Table 5: Transmitter Requirements

3 Schematics

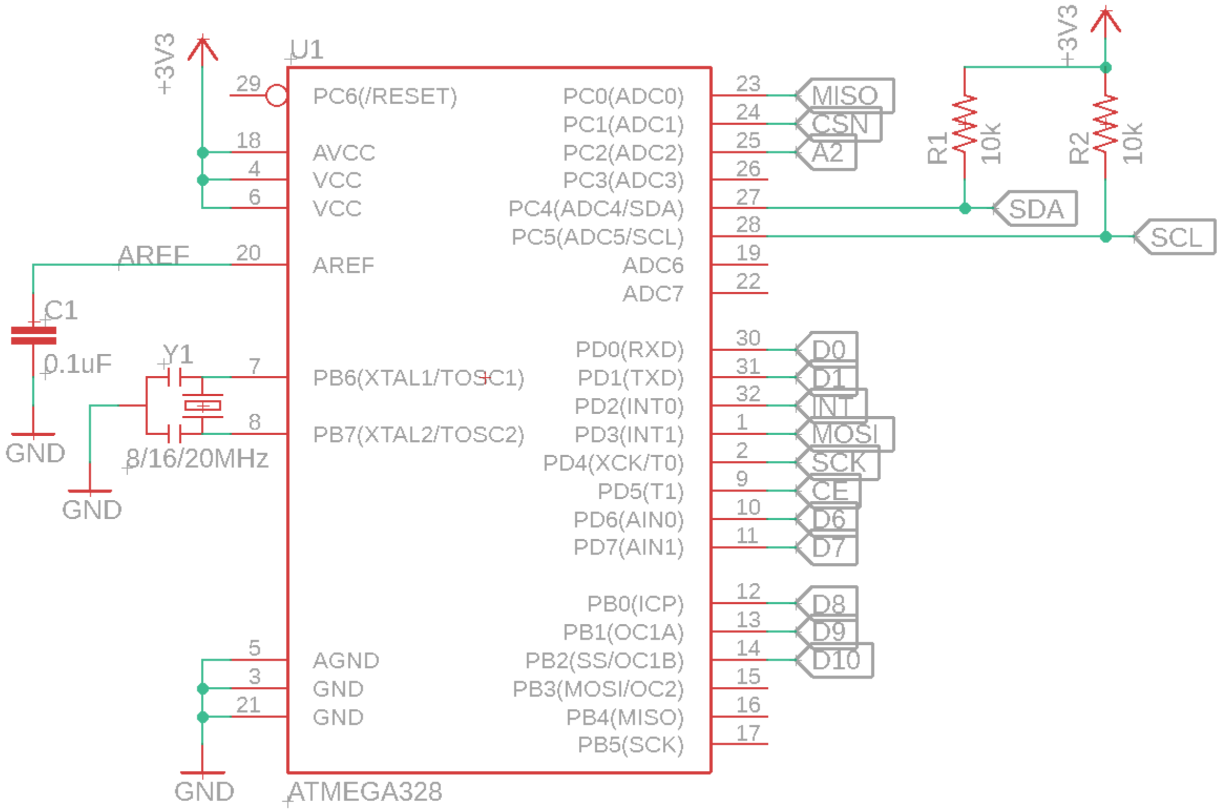

Figure 4: Microcontroller Schematic

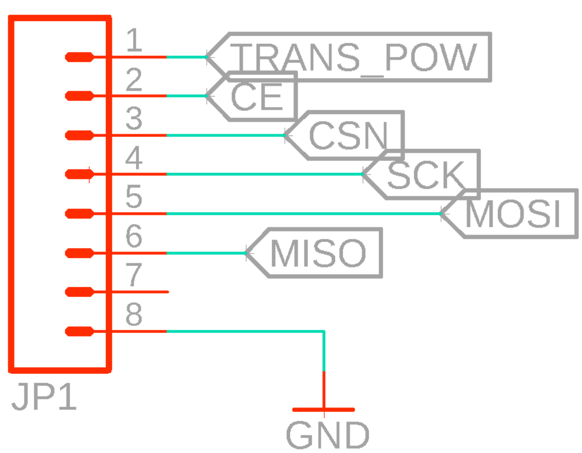

Figure 5: Transmitter Schematic

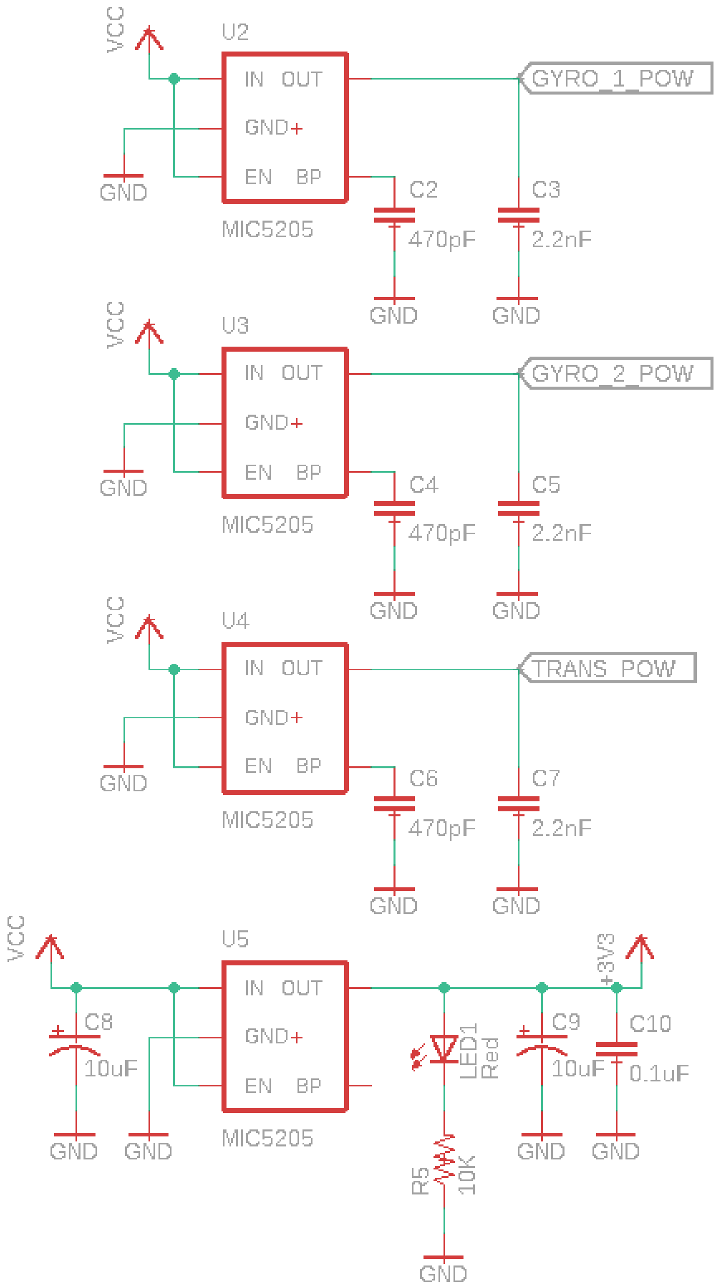

Figure 6: Power Subsystem Schematic

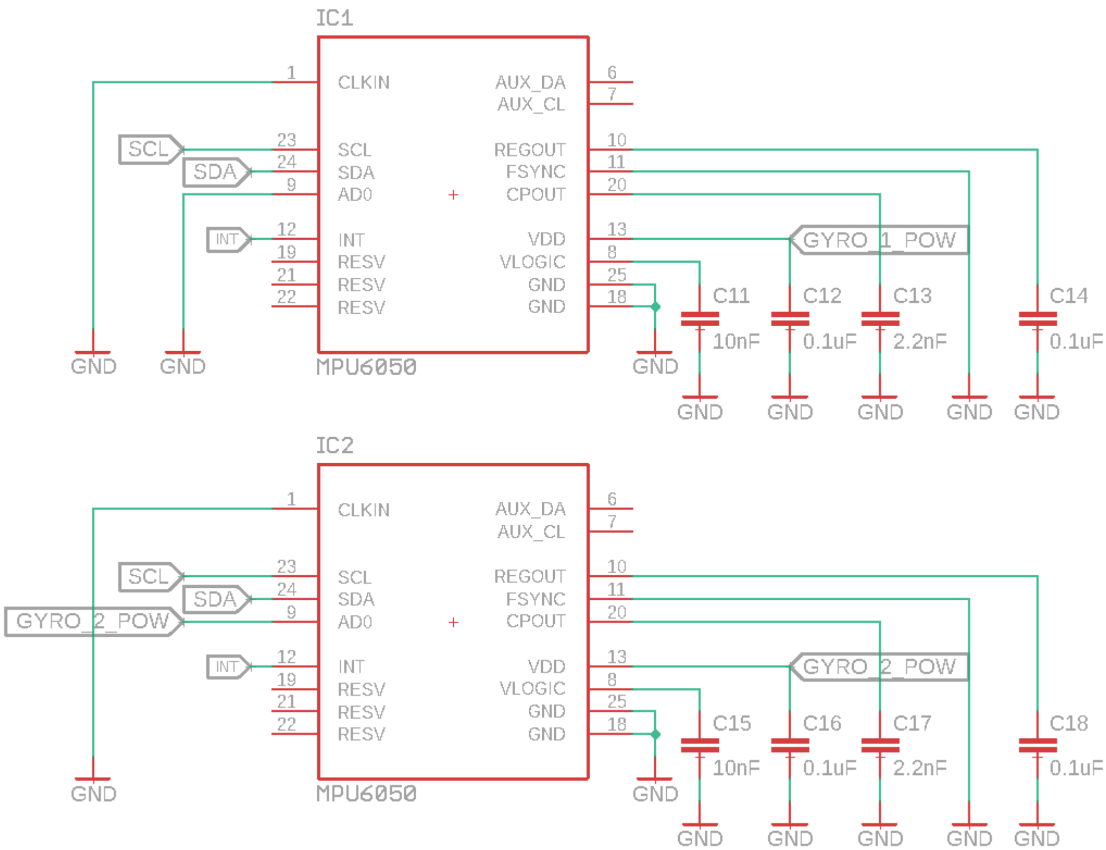

Figure 7: IMU Schematic

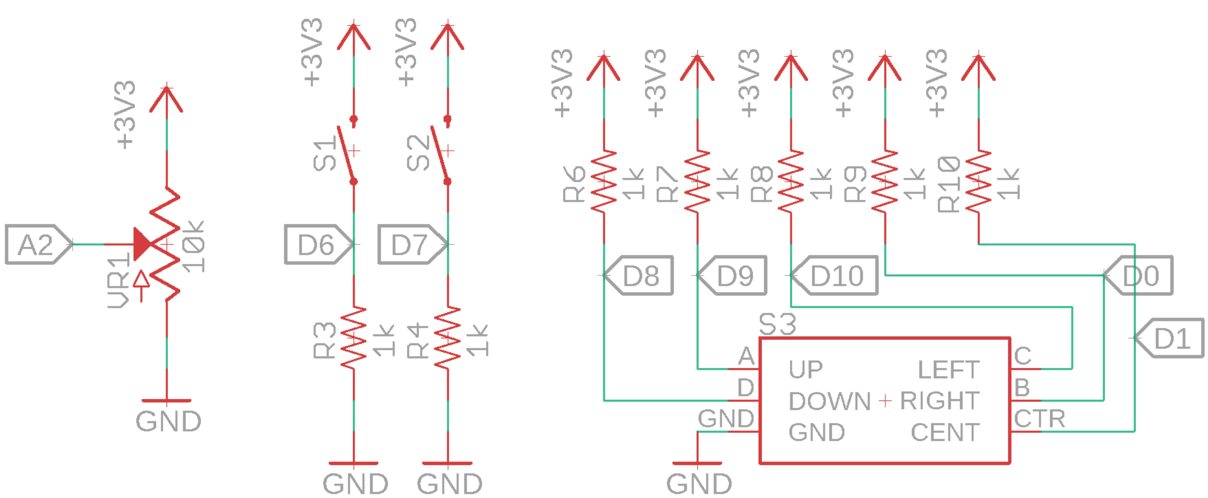

Figure 8: Buttons and Trigger Schematic

3.1 Software Diagram

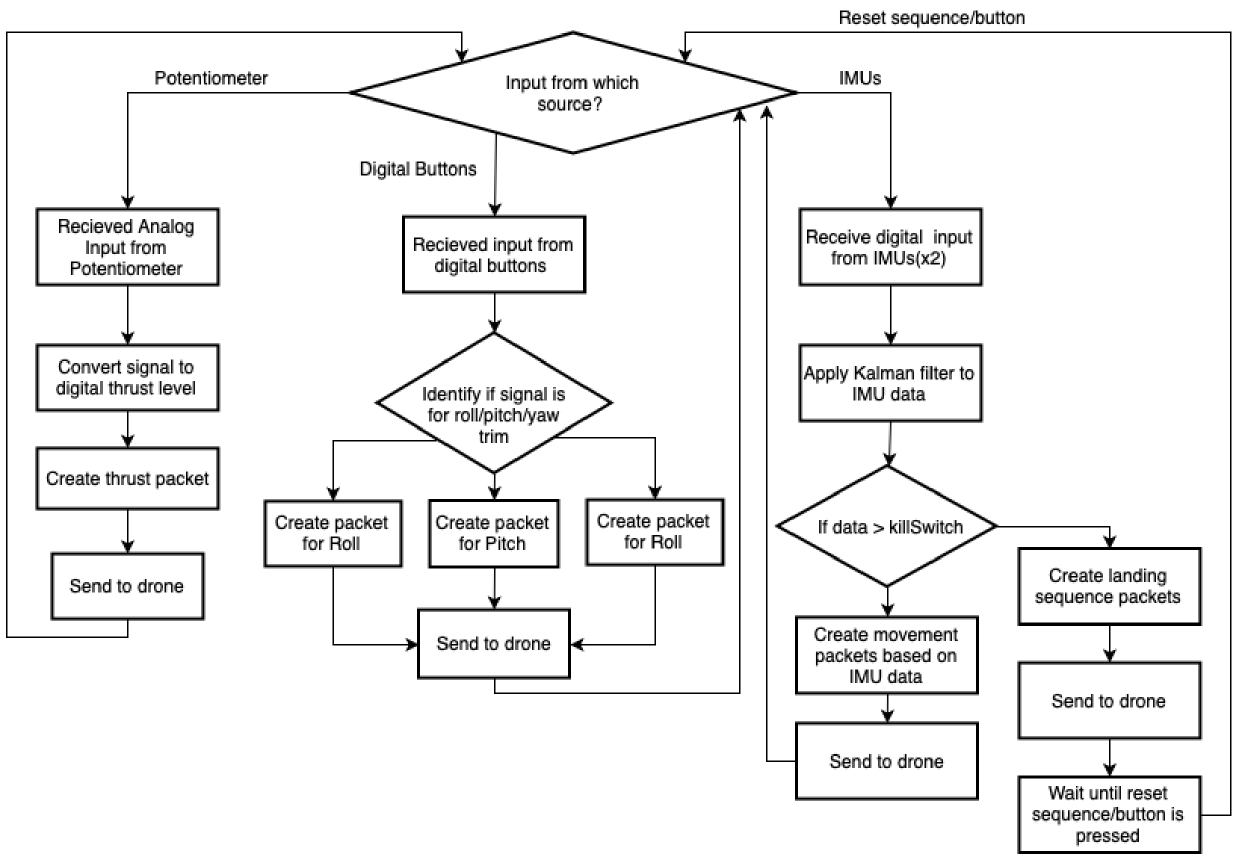

Figure 9: High level overview of software algorithm to be programmed

4 Tolerance Analysis

The most critical portion of our project is the IMU array and translating those digital signals into usable packets for the drone to read so the the glove will function as a legitimate controller. If this subsystem is inaccurate to the movement of the user's hand the drone will not function properly and could lead to frustration of the user and possible danger to the flight area.

The IMUs are the MPU-6050 which we chose for its easy compatibility with the arduino library, interface over I^2C, and that it is both a gyroscope and accelerometer thus decreasing the overall number of components on the glove. According to the datasheet the full scale range of the device is from $\pm 250\,°/s$ to $\pm 2000\,°/s$ with a cross-axis sensitivity of $\pm 2\,\%$ [4]. For this project, we will program the controller for $\pm 250\,°/s$ since that will give the most accurate reading for hand movements over a 180° range.

Part of the tolerance is figuring out what hand movements will correspond to what drone movements. Using a digital level placed on the top of the hand we measured what different angles of hand movement looked like. Throughout testing we noticed that a 10° movement in any axis was not significant enough to see a visual change. Also since humans normally cannot keep their hands perfectly still a deadband is needed. The 0° mark is the vertical axis and has a 10° deadband on all axes. After the 10° mark each direction has incremented power levels centered around 20°, 40°, 60°, and 80° each with a width of 20°. See Figure 10 for a visualization of this dead band and incremented power levels. This accounts for shaking of the user's hand an inaccuracies from the IMUs. To further account for variation in signals, the Kalman algorithm will be implemented as a signal filter to remove outliers from the data stream before being processed.

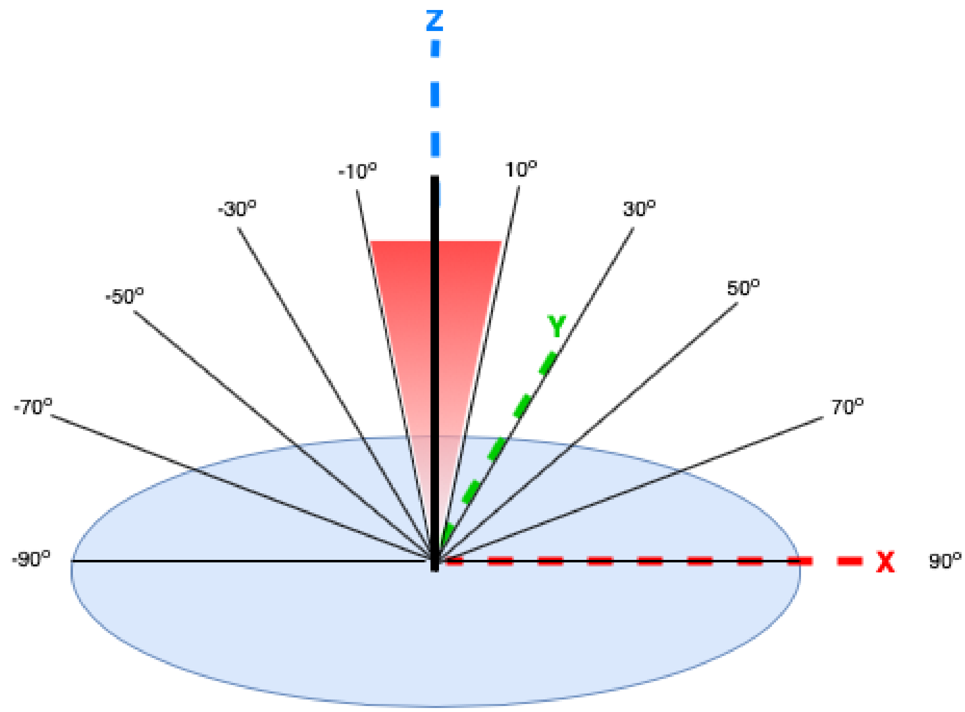

Figure 10: Visualization of deadband. The blue oval represents a flat hand.

The other critical feature of the IMU is the accelerometer based Kill Switch which stops the drone in case of sudden movement. This prevents erroneous flight paths of the drone. As part of the use of this device the user will have to hold their hand out in front of them, so we classified a sudden movement of the hand as moving their hand in any direction with an acceleration greater than 80% freefall drop of the hand (0.8 g). This threshold will be defined in software and before any further calculations are preformed on the IMU data the data will be compared to this threshold to ensure it has not bee passed. Should the data be greater, the drone will simply fall to the ground and won't be able to be controlled by the glove again until the user replaces their hand and issues a reset signal.

5 Cost and Schedule

Part	Cost	Number Needed	Total
MPU-6050	$8.31	2	$16.62
ATMega328	$2.14	1	$2.14
NRF24L01+	$2.55	1	$2.55
Resistors	$0.10	10	$1.00
Capacitors	$0.30	18	$5.40
Custom PCB	$5.00	1	$5.00
Battery	$9.95	1	$9.95
Physical Glove	$5.00	1	$5.00
Poteniometer	$0.95	1	$0.95
3D Printed Trigger	$2.00	1	$2.00
Parts Subtotal			$50.61
Labor	$40/hr	180 hrs	$7,200.00
Total			$7,250.61

Table 6: Costs for Parts and Labor

Dates	Targets
Week 1: Feb. 18 - 24	Elaine: Test available parts for verification. Adam: Test arduino library works with drone.
Week 2: Feb. 25 - Mar. 3	Elaine: Prototype IMU circuitry. Adam: Prototype thrust circuitry.
Week 3: Mar. 4 - Mar. 10	Elaine: Design trigger housing for thrust, and buy glove Adam: Design PCB off of current schematics and adjustments made from prototyping.
Week 4: Mar. 11 - Mar. 17	Both: Order PCB, Finalize placement on glove and attach thrust control.
Week 5: Mar. 31 - Apr. 7	Elaine: Attach PCB to glove and sew/hide wires on glove. Adam: Solder parts to PCB and flash microcontroller.
Week 6: Apr. 8 - Apr 14	Both: Testing final glove, and adjusting code as needed.
Week 7: Apr. 15 - Apr 21	Both: Mock demos and presentation writing.

Table 7: Project Schedule

6 Ethics and Safety

Our project poses possible safety concerns in two ways. The first, electrocution, rises from the fact that we are attaching electrical components to a wearable device; however, the battery size we are using (3.7 V) is not powerful enough to cause a harmful current across human skin. The minimum resistance for dry skin is $\sim 1000\,\Omega$ which results in a current much too small to cause damage [5]. This resistance is greatly reduced when wet so a warning would be attached to the product advising not to operate when wet.

The second possible concern is the drone injuring someone while being controlled by our product. Unlike the former issue, this one cannot be dismissed. All drone operation is accompanied by some hazard for injury to oneself and others. In addition to warnings advising users to not fly in crowded areas or near people, we plan to include an emergency shut-off feature as part of the glove. This would disable the drone in the event of user incapacitation or device malfunction.

Addressing both of these concerns falls under the IEEE Code of Ethics Policy 1, "hold paramount the safety[...]of the public[...]and to disclose promptly factors that might endanger the public[...]". We feel that the warnings and preventative measures we have enacted adequately satisfy this mandate.

Drones for public and private use are regulated by the Federal Aviation Administration (FAA). According to current guidelines, all "Unmanned Aircraft Systems" being piloted in public airspace for non-recreational, non-commercial purposes fall under "Part 107" [6]. This regulation mandates that all drones used for educational purposes be registered with the FAA and all operators be "FAA-Certified Drone Pilots". As both of these processes require time and money, we have decided to confine our testing to within campus buildings. The regulations do not cover indoor spaces allowing for a streamlined project timetable.

Additionally, the University of Illinois at Urbana-Champaign has a policy on drones used for non-recreational purposes that mandates operators obtain approval from the Division of Public Safety if operating outdoors on campus property and from Code Compliance & Fire Safety if operating indoors on campus property [7]. We plan to contact the relevant departments immediately.

References

[1] A. Pasztor, “Faa projects fourfold increase in commercial drones by 2022,” Mar 2018. [Online]. Available: https://www.wsj.com/articles/faa-projects-fourfold-increase-in-commercial-drones-by-2022-1521407110

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[4] “Mpu-6050 datasheet.” [Online]. Available: https://store.invensense.com/datasheets/invensense/MPU-6050_DataSheet_V3%204.pdf

[5] “Q & a: The human body’s resistance,” Oct 2007. [Online]. Available: https://van.physics.illinois.edu/qa/listing.php?id=6793

[6] “Recreational fliers & modeler community-based organizations,” Feb 2019. [Online]. Available: https://www.faa.gov/uas/recreational_fliers/

[7] E. D. of Public Safety, “Aerial activities over, on, or in campus property,” Sep 2015. [Online]. Available: https://cam.illinois.edu/policies/fo-05/

Appendix A Compatible Products

Attop YD-822/YD-829/YD-829C

BayangToys X6/X7/X9

BWhoop B03

Cheerson CX-10/CX11/CX12/CX205/CX30/SH6057/SH6043/SH6044/SH6046/SH6047

EAchine CG023/CG031/3D X4/E010/H7/H8 mini/H8 mini 3D/JJRC H20/JJRC H22

Floureon FX10/H101

FQ-777-124 Pocket Drone

FY326Q7

HiSky RXs/HFP80/HCP80/HCP100/FBL70/FBL80/FBL90/FBL100/FF120/HMX120

JJRC DHD D1/H36 mini/H6C/JJ850

JXD 385/388/389/391/393

MJX X600

NiHui NH-010

Syma X5C/X5C-1/X11/X11C/X12/X2

WLToys V202/252/252 Pro/272/343/930/931/939/966/977/988/933/944/955

XinXun X28/X30/X33/X39/X40

Yizhan Tarantula X6