ECE 445
Design Document
Spring 2020

VR Motion Control for Drones

Team 46
Anushrav Vatsa (avatsa2), Colin Sandstrom (colinls2), Ioan Draganov (idraga3)
Professor: Rakesh Kumar
TA: Jonathan Hoff (jehoff2)
16 April, 2020 (Thur.)

Contents

1. Introduction

1.1 Problem and Solution Overview

Drones are becoming more and more available to hobbyists, but the controls are a hurdle both to amateurs looking to use their first drone and to more experienced users desiring more precise movements. Almost all drone systems use an RC controller with joysticks to control the thrust of the motors on the drone, which is unintuitive and imprecise. We would like to create a method of controlling a drone with a user's body and head movement so that it becomes easier for the consumer to control their drone.

1.2 Background

Quadcopter style Unmanned Aerial Units (UAVs) often dubbed as drones are ubiquitous today. With cheaper parts via 3D printing and with various kits to design these drones, they have flourished in both hobbyist and business markets.

However, a prominent issue with drones is the lack of intuitive controls. Most commercial drones used for research in geospatial technologies and GIS surveys require the user to have a pilot's license due to the complexity of controls.

We want to use the motion of the body of the user to extrapolate where they are looking and adapt a VR headset and the drone to mimic that motion allowing for a seamless and intuitive control system.

There exist drones on the market today that involve using motion controls, mostly with the user holding a mouse-shaped device that transmits instructions based on the angle of the controller. These models universally have very small range and many are specifically for indoor use[1]. We look to expand the horizons of drone control technology to control a larger, more specialized drone over a further range and with easier controls.

In Spring 2019, Group 22 created an intuitive drone controller that utilized a glove with gyroscopes and accelerometers to control the motion of a drone [2]. Our project is fundamentally different in that we are incorporating a VR headset to give the user visual feedback from the drone's perspective in addition to using gyroscopes and accelerometers to control the drone's motion. The drone will also be a model with a movable camera, which will also be controlled with the movement of the user's head.

1.2 Visual Aid

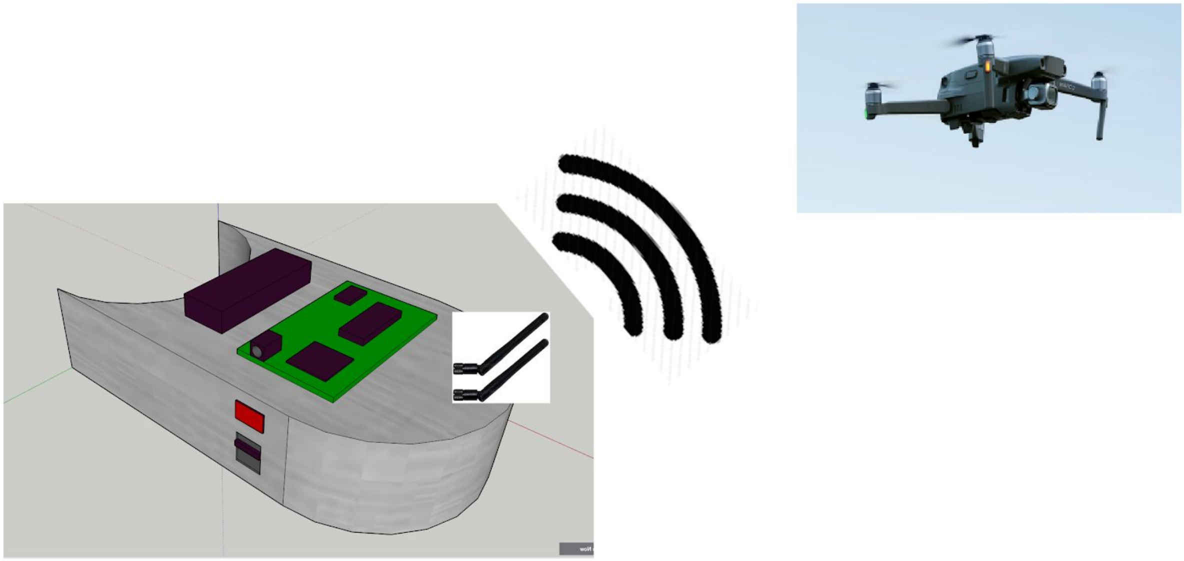

Figure 1.

1.3 High Level Requirements

- Interpretation:

  The device must be able to sense the orientation of a user's head with an error margin of ± 5 degrees when measuring pitch, yaw, and roll.

- Transmission:

  The device must be able to transmit orientation and acceleration data to the drone wirelessly in real time (less than 100ms for our purposes).

- Execution:

  The device must be able to control the camera angle and rotation of the drone based on data from the headset while movement mode is enabled.

2. Design

2.1 Block Diagram

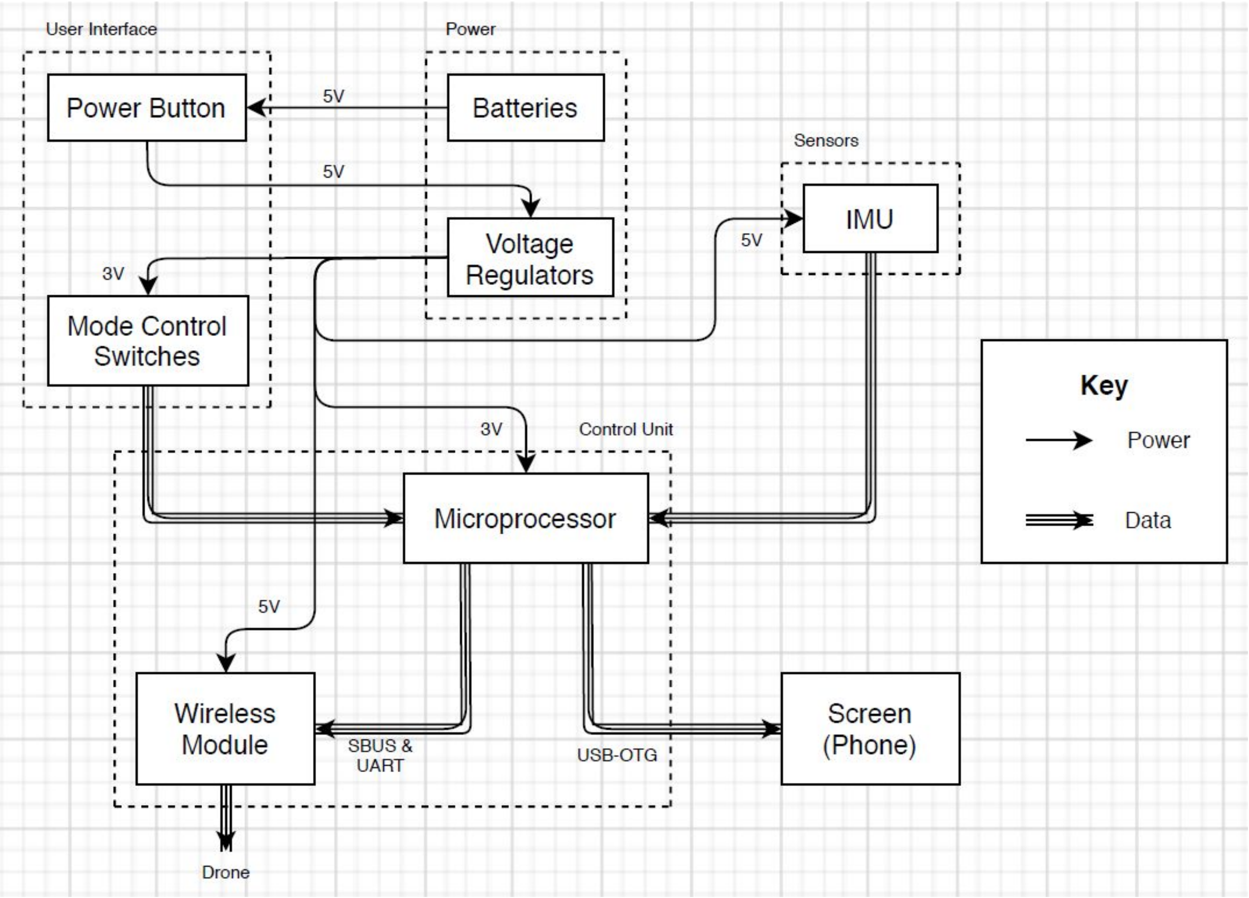

Figure 2. Drone Controller Block Diagram

2.2 Physical Design

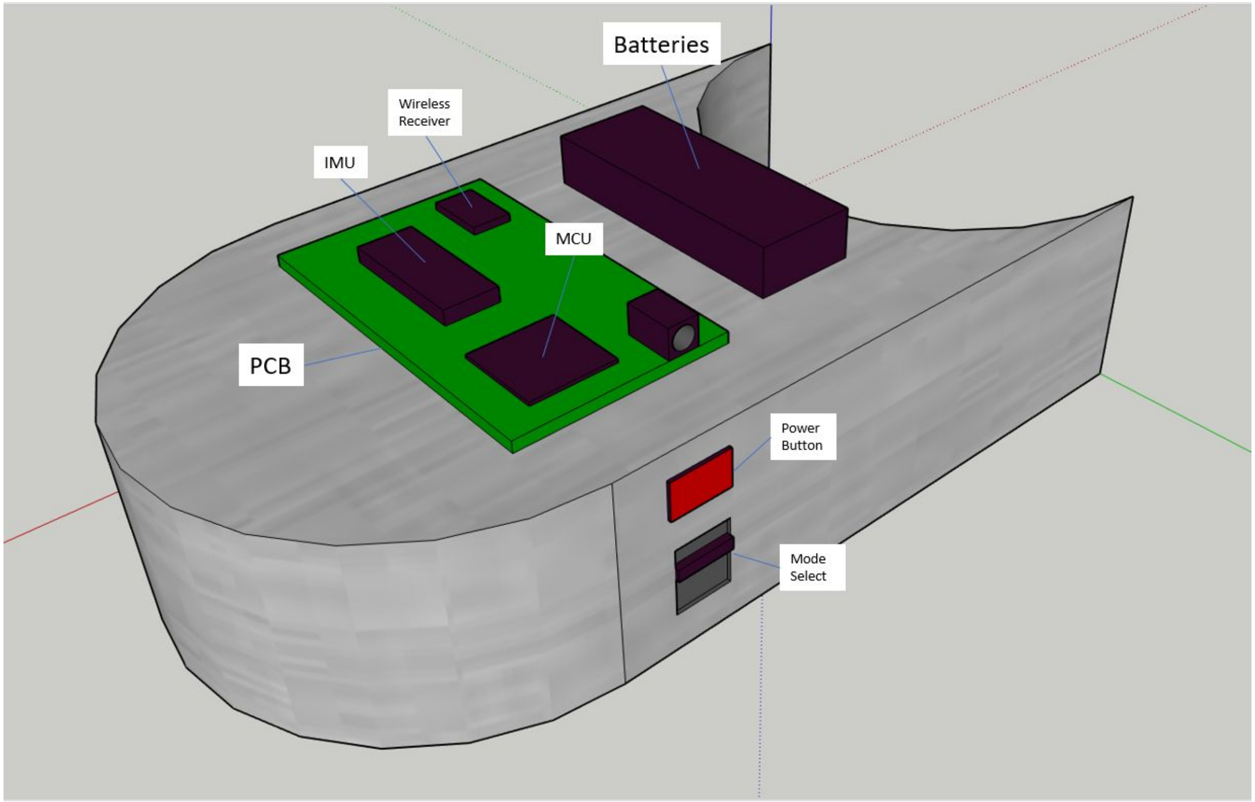

Figure 3. Physical Design of Drone Controller

2.3 Subsystems

2.3.1 Control System

The Control Subsystem is responsible for processing data from the sensors, transmitting instructions to the drone, and receiving video from the drone.

Accelerational and directional data is provided from the Sensors subsystem to the MicroController Unit (MCU), a MSP430F5529IPN chip, which performs several filtering operations to extract the relevant data to calculate directional inputs from the user. The directional inputs are then translated to the drone’s API and transmitted via the wireless transmitter.

The drone chosen for this project is a DJI drone that uses the DJI Ocusync 2.0 system for transmitting data [3], the Ocusync 2.0 system consists of custom hardware created by DJI for their products, and it accepts SBUS and UART input and output for streaming video and transmitting controls to the drone (both are needed)[4]. The MCU routes video information from the wireless receiver to the screen of the VR Goggles (the User’s phone) via USB-OTG to allow for compatibility with all devices. Android phones use USB-OTG by default, and although iOS devices use iAP2, the iAP2 documentation states that it is compatible with standard USB-OTG instructions [5].

Requirement	*Verification*
1. *Accurately translate directional input to corresponding controls for the drone, with less than 1% incorrect translation.* 2. *Accurately transmit instructions to the drone and receive video from the drone with a packet loss of less than 2.5%.* 3. *Correctly displays video data from the drone on Android and iOS devices in the VR Goggles.*	1. *The command sent to the wireless module can be broadcasted to another device or obtained via a trace to confirm that accuracy of the translation.* 2. *Instructions can be read from a file or manual input and sent to the drone to confirm that it is executing the intended command.* 3. *Controller can be connected to an Android or iOS device and displays video from the drone.*

Table 1: Control System Requirements.

2.3.2 Sensors

The Sensor Subsystem consists of an integrated IMU containing a three-axis gyroscope, accelerometer, and magnetometer. The IMU outputs a data stream for each sensor to the MCU, and automatically re-calibrates to account for potential drift so that the MCU is receiving clean data.

Requirement	*Verification*
1. *Reliably relay the momentum and motion vector of the user's head with an error margin of 5 degrees for each axis.*	1. *The Sensor subsystem can be cross-referenced with a controlled IMU to compare the observed values to ensure that the Sensor subsystem is working properly. Ensure that the error margin is never more than 5 degrees between the two IMUs.*
2. *Properly account for drift and noise, so that the observed noise does not offset the sensor values by more than 5%.*	2. *The output of the IMU can be measured when stationary and with noise introduced through vibrations to observe if it can still function as intended under non ideal conditions. Ensure that positional data is stable over time with noise from the IMU compensated for.*

Table 2: Sensor System Requirements.

2.3.3 User Interface

The User Interface consists of the buttons on the VR Goggles used to control the current state of operation. A SPST switch serves as a power button controlling the Power subsystem, and a sliding SPDT switch serves as a mode-select switch, transitioning between "Periscope" mode and "Fly" mode.

Requirement	*Verification*
1. Reliably power on and off	*1. Using a multimeter, check the current and voltage when the power switch is toggled on and off to confirm that there is power only when intended.*
2. Reliably switch between the Periscope mode and Fly mode	*2. Using a multimeter, measure the voltage across the Periscope and Fly channels to confirm that the correct mode is being selected by the switch.*
3. The switches should be distinct and easy to identify.	*3. Confirm that a blindfolded user can power on the device and switch between modes to ensure functionality during normal operation.*

Table 3: User Interface Requirements

2.3.4 Power

The Power Subsystem relies on two primary power sources, the drone's onboard battery and a 5V Lithium Ion battery attached to the PCB. The Drone's power management system is not affected by this project since it is professionally designed and very well integrated with the drone. The PCB battery module is a standard 5V Lithium Ion Battery with a charging and discharging module that ensures the battery's stability over time and during use. This battery is used to power the MCU, IMU and the wireless module.

Requirement	*Verification*
1. *Provide 5V +/- 0.3V supply to the PCB*	1. *Thorough testing of the charging module by collecting time based data on the battery pack's peak voltage value and lowest voltage value.*
2. *Ability to charge and discharge without getting unstable*	2. *Charging:* ○ *Test the discharge cut-off voltage to ensure the battery pack never gets unstable* ○ *Cross reference the battery characteristics with the manufacturer documentation* ○ *Run a few complete charging and discharging cycles in the lab using the multimeter to ensure the battery has desired output voltage and charge levels over time*

Table 4: Power System Requirements

2.4 Tolerance Analysis

The IMU unit is the most critical aspect of this design. It ensures that we are interpreting the user's gestures correctly and manipulating the force vectors on the drones accordingly. There are some technological challenges that come with the use of an IMU unit like the BMX055[6] . We have laid out the issues below and our mitigation strategies for the same:

- Gyroscopes are subject to bias instabilities, in which the initial zero reading of the gyroscope will cause drift over time due to integration of inherent imperfections and noise within the device. We are using the TI's nine axis IMU drift correction algorithm [7] that allows for fixing the drift on the fly for the BMX055 [6].

- We are also running a script that uses initial correction algorithms as discussed by M. Kok et. al [8] on the device to ensure the motion parameters received from the drone are realistic and part of normal behavior. This will require some robust computation on the PCB but the MSP430 has more than enough computation power to handle these algorithms.

Between these two implementations we create a real time correction module that prevents drift in the values collected via the IMU and allows for more precise control of the drone unit during flight. We will also collect data in the stationary state of the drone unit to supplement the error correction algorithms in order to achieve a slightly more stable control response for the drone.

3.Differences

3.1 Overview

The previous project from Spring 2019 involved using a glove with accelerometers and potentiometers to control the motion of a drone by moving the user's hand. The developers used the orientation of the glove and its acceleration as inputs to the drone, causing the drone to mimic the movements of the hand. This was intended to solve the issue of drone controllers on the market being difficult to use for a beginner, but introduced a new issue of range because the drones compatible with this project had no camera, and the connection to the drone was made using a NRF24L01+ wireless module [2]. This module is known to have low ranges and spotty connection to the receiver [9].

We intend to solve the problem of range by using a wireless communication method that has a longer connection range with better reliability through obstacles [3]. Our addition of a camera on the drone that broadcasts to a VR headset also allows for the user to see the surroundings of the drone even if the drone is not within the user's line of sight. Our design will be using a larger, more expensive VR-capable drone, which will drive up the price significantly. The core of our project's differences from the previous project lies in the tradeoff between the previous project's low price and our version's enhanced range and functionality.

3.2 Analysis

The problem we are trying to solve is that the previous project had limited range for their controller. We are also expanding on the idea of making drone controls more intuitive by adding VR to the solution. We will be using the DJI Goggles' Ocusync 2.0 wireless communicator, which has a transmission range of up to 5 miles (8 km) and the ability to communicate through obstacles [4]. This is vastly improved from the NRF24L01+, which has a range tested to drop off at 480m and when an object is between the emitter and receiver [9].

In addition, our project has a different focus from the user's perspective. The previous project had a final demonstration of the drone navigating an obstacle course, suggesting that their users wanted a maneuverable drone with a shorter range for indoor use and light outdoor use under stable conditions. Our users will be more interested in long range observation or exploration using a drone, and that is why we include a camera and VR headset as well as increased range on our communications.

4. Cost and Schedule

4.1 Cost Analysis

Part	**Part #**	**Quantity**	**Cost**
Microprocessor	MSP430F5529IPN	1	$7.65
Inertial Measurement Unit (IMU)	BMX055	1	$5.456
Various basic circuit elements (resistors, wires, etc.)	N/A	Irrelevant	<$1.00
Lithium Ion Battery Pack (5v battery + Charger Circuit)	TP4056	1	$10.57
Voltage regulator (5V - 3V)	Texas Instruments LM2940CT-5.0/F01	1	$1.49
Drone Kit and the VR Headset	DJI Mavic 2 Pro Drone with Hasselblad Camera Kit + FPV Pilot VR Headset Bundle	1	$1243.45
PCB Estimate	N/A	1	$30.00
Total for parts	N/A	N/A	$1299.616
Labor estimate	N/A	3 partners, 10 hours per week for 15 weeks = 450 manhours	$50.00/hour for 450 hours = $22,500 For exec's salary: 22,500 * 2.5 = $56,250
Total	N/A	N/A	$57,549.62

4.2 Schedule

Week	Anushrav’s Responsibilities
1	Compile Parts list and create start prototyping circuit design
2	Evaluate circuit design and start working on PCB layout
3	Finalize PCB layout and place PCB order
4	Start assembling PCB components and soldering
5	Unit test each subsystem
6	Initial full system testing (Software tests followed by full Hardware test)
7	Consider any redesigns, field testing
8	Final integration and debugging

Week	Colin’s Responsibilities
1	Initial characterization of gyroscopes and IMU
2	Bias sensor module with appropriate resistances for maximum/minimum voltage outputs
3	Fine-tune IMU algorithm to account for drift from sensors
4	Hook up wireless receiver to drone, ensure proper communication with PCB
5	Test sensor module in field conditions (mount on headset, monitor drift and noise)
6	Initial full system testing
7	Full system testing, redesign non functional parts
8	Final integration and debugging

Week	**Ioan's Responsibilities**
1	Research Microprocessor, IMU, and Drone API's
2	Start writing code to accept sensor inputs
3	Program Microprocessor to translate inputs to controls from drone API
4	Program Microprocessor to communicate with the drone
5	Debug and expand functionality
6	Initial full system testing
7	Full system testing, consider any redesigns
8	Final integration and debugging

4. Discussion of Ethics and Safety

5.1 Ethical and Safety Concerns

Our project raises several safety concerns involving using batteries and flying drones, and privacy issues related to mounting a camera on a drone. We need to ensure that our project is ethical by following the IEEE Code of Ethics [10] as a guideline to help mitigate all safety and privacy issues.

Because we are using batteries to power our device, we introduce a risk of electrocution. Our battery system will output a maximum of 5.3 V and has the possibility of causing a current that can shock or burn a person. We will need to ensure that our device is safe either by shielding the user or limiting the current output of the battery module.

One more concern is that the drone might collide with a person or someone's personal property. Due to the high rotational velocity of a drone's rotors, this can cause significant injuries and property damage. We need to ensure that we follow the IEEE code of ethics concerning avoiding damage to people and property [10]. To this end, we will ensure that we have a clear area when testing our drone so that we mitigate the risk of any injury or property damage.

Finally, we must be aware of the privacy risk introduced when mounting cameras on flying vehicles. A drone with a camera on it could be used to intrude upon the privacy of others by recording private events or flying over private property. We must ensure to the best of our ability that we and any potential users of the product do not violate anyone's privacy while operating the drone.

5.2 Project Countermeasures

In order to address the risk of electrocution, we will mention that the minimum current to cause a slight sensation in the hands is 0.6 mA and the minimum current to cause pain is 3.5 mA [11]. Our battery system will have a maximum voltage of 5.3 V, which when applied to the worst case scenario of contact with a wet hand (1,000 Ohms) leads to 5.3 mA [11]. This means that the only way someone could experience a shock from our equipment would be to directly touch the positive and negative terminals of the battery with a wet hand. In order to prevent even this small chance of a shock, we will be encasing the battery in silicone and creating a casing for the whole circuit.

In order to avoid colliding with people or property, we will adhere to all of the state and federal laws that are applicable to small UAV in the state of Illinois [12]. This mostly restricts any form of flight in restricted zones and flying in proximity of state-owned infrastructures like transmission lines, public offices, or airports etc. In addition, we can use the built in system statuses and telemetry to determine if there are any potential risks, as the drone is aware of obstructions to its field of vision and height off the ground at any time [13].

The final concern raised by our project is that of privacy. This is less of a concern about our system and more of a concern with drone-mounted cameras in general. Laws in many states have been passed to control the usage of drones, including several laws that prohibit flying drones over private property and certain public institutions without permission [12]. We will only be flying on locations where we have express permission from the land owner or an authorized representative. Regarding any end users breaking the law should our project become popularized, we believe that including a warning that tells users to ensure that they have read local regulations will be sufficient. We can never remove the possibility that someone uses our technology for nefarious purposes, but the responsibility for breaking the law will be on the shoulders of the user.

5. References

[1] Force Flyers, "Explorer 12" Motion Control Drone". *Force Flyers*. [Online]. Available: https://forceflyers.com/products/force-flyers-explorer-32cm-motion-control-drone [Accessed: 4/17/2020].

[2] University of Illinois, "ECE 445 Web Board: Projects: Sp2019: Group 22" *University of Illinois.* [Online]. Available:https://courses.engr.illinois.edu/ece445/project.asp?id=7116 [Accessed: April 16, 2020].

[3] "DJI OCUSYNC 2.0: WHAT YOU NEED TO KNOW ABOUT THIS FPV TRANSMISSION SYSTEM," *djibestdrones.com*, Sept. 4, 2018. [Online]. Available: http://djibestdrones.com/dji-ocusync-2-0/#Compatibility. [Accessed: April 16, 2020].

[4] DJI Technical Staff, *DJI Goggles, Racing Edition, Quickstart Guide*, DJI, SS3-OAS11709, 2017. [Online]. Available: FCC ID, https://fccid.io/ [Accessed: April 16, 2020].

[5] Apple Inc. Technical Staff, *Accessory Design Guidelines for Apple Devices, Release R12*, Apple Inc., 2020. [Online]. Available: https://developer.apple.com/accessories/ [Accessed: April 16, 2020].

[6] Bosch Sensortec, "Small, versatile 9-axis sensor module," BMX055 datasheet, Revised Nov. 7, 2014. [Online]. Available: https://www.digikey.com/product-detail/en/bosch-sensortec/BMX055/828-1060-2-ND/6136303 [Accessed: April 16, 2020].

[7] Erick Macias, Daniel Torres, and Sourabh Ravindran,"Nine-Axis Sensor Fusion Using Direction Cosine Matrix Algorithm on MSP430F5xx," Texas Instruments, Tech. Report. SLAA518A, Feb. 2012. Available: http://www.ti.com/lit/an/slaa518a/slaa518a.pdf [Accessed: April 1, 2020].

[8] Manon Kok, Jeroen D. Hol and Thomas B. Sch¨on (2017), "Using Inertial Sensors for Position and Orientation Estimation", Foundations and Trends in Signal Processing: Vol. 11: No. 1-2, pp 1-153. Available: https://arxiv.org/pdf/1704.06053.pdf [Accessed: April 16, 2020].

[9] "Testing the range of NRF24L01+ modules". EmbedBlog. http://embedblog.eu/?p=187 [Accessed: April 16, 2020]

[10] “IEEE Code of Ethics”. IEEE. https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed: April 3, 2020].

[11] EETech Media. “Ohm’s Law (again!)”. All About Circuits. https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/ohms-law-again/

[12] “Illinois Drone Laws”. StateDroneLaw. https://statedronelaw.com/state/illinois/ [Accessed: April 3, 2020].

[13] DJI Technical Staff, *Mavic 2 Specifications*, DJI, 2019. [Online]. Available: https://www.dji.com/mavic-2/info#specs [Accessed: April 16, 2020.]