ECE 445
Senior Design Laboratory
Design Document

Camera Gimbal

Team 75
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Abstract

This document will provide detailed information for the design and implementation of our senior design project. This will set out the information on the parts we plan to use, system cost, tolerances for the subsystems in our design, schedule and estimated cost, and the ethics and safety for our project.

Contents

1. Introduction

1.1 Problem

A major problem in video processing is footage that is shaky. If you take the forward direction as +y, right direction as +x, and up direction as +z; Shaky video footage is a result of the camera rotating around the +y and +x axes at minute steps. For example, if you take out your hand with your palm facing forward and pretend that it is a camera. Wave your hand as if you are waving hello. Moving your hand left and right is the camera rotating around the y axis also known as roll. If you move your hand up and down, bending at the wrist, it is the camera rotating about the x axis also known as pitch. Many video stabilization solutions are expensive and can cost upwards of $300 for a phone camera gimbal. The camera gimbal we will create will be a cheaper alternative that will still achieve industry standards in camera stabilization.

1.2 Solution

Camera stabilization, countering the shift in pitch and roll, is the key to solving this issue. To do this, we want to make a camera gimbal. This will allow for stability in camera footage given an initial starting orientation of the camera. Once a button is pressed, the camera gimbal will take in an initial orientation from a gyroscope sensor. This reading will go to an encoder to the microcontroller. Two servo motors, controlled by the microcontroller, will be used to maintain the initial orientation by opposing the shift in pitch and roll, keeping the camera stable.

1.3 Visual Aid

Figure 1: Visual Aid

1.4 High Level Requirements

For our project to be considered successful, we will need to meet the following requirements:

i. Camera is stabilized on +x axis (Pitch)
   This can be tested by isolating one of the servo motors and seeing how they oscillate as the gyroscope/gimbal is moving around. After researching industry standards [5] for gimbal slew rates (speed at which the gimbal can rotate in a given direction), we will try to achieve a minimum slew rate on the x axis of 100 degrees/second.

ii. Camera is stabilized on +y axis (Roll)
   This can be tested by isolating one of the servo motors and seeing how they oscillate as the gyroscope/gimbal is moving around. We will try to achieve a minimum slew rate on the y axis of 100 degrees/second.

iii. User interface (button) works
   - First button press turns on and starts reading from the gyroscope sensor.
   - Second button press locks the camera orientation by saving gyroscope reading and turns the gimbal mode on.
   - Third button press turns the system off.

2 Design

2.1 Block Diagram

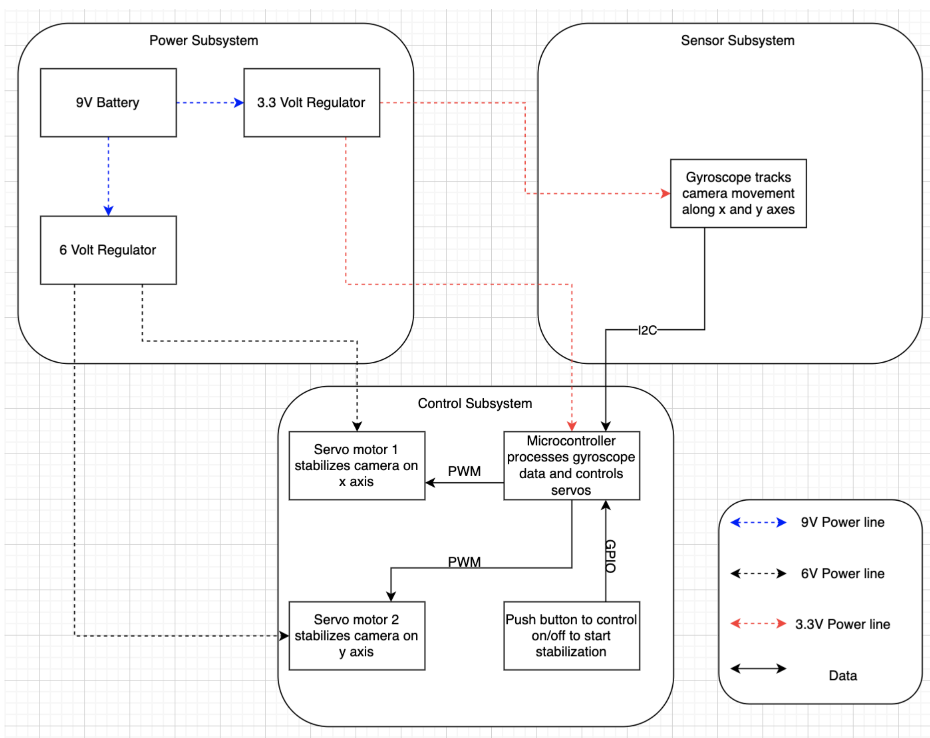

Figure 2: Block Diagram

2.2 Physical Design

In order to obtain safe and sound readings, we decided to place our gyroscope (which will be soldered onto the board) inside the enclosure so that there will be no variance of the orientation of the gyroscope compared to the handle. If the gyro was placed elsewhere, slight errors in the servo positions could be dangerous. We can then use inverse kinematics to send signals to each motor individually to maintain the camera's orientation.

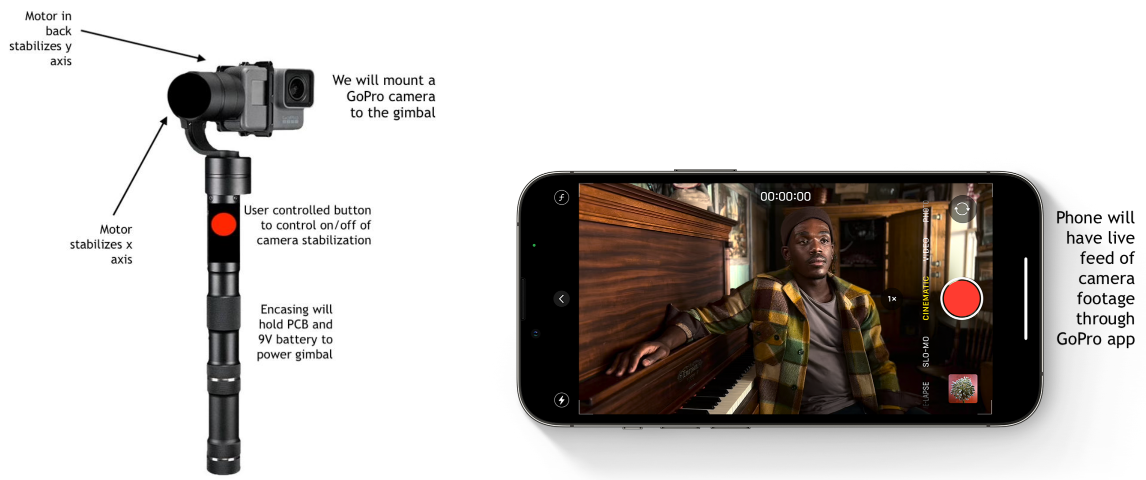

Figure 3: Physical Design

2.3 Power Subsystem

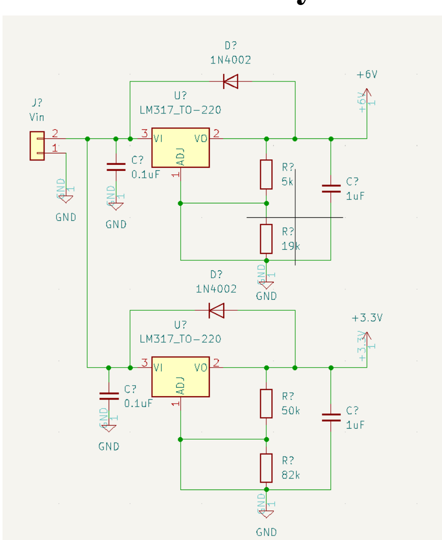

Figure 4: Power Subsystem Schematic

2.3.1 Overview

The purpose of this subsystem is to pull power from our 9-volt battery and route the required amounts to our other components: servo motors, gyroscope, and the microcontroller.

2.3.2 Requirements and Verification

Requirements	Verification
• Route the 9-volt ~500 mAh battery to two regulators where the 6 volt regulator can support up to 1A output (need a minimum of 800 mA to support servo stall). The 3.3 volt regulator can support up to 1.5 A of current, well surpassing the amount needed to support both the microcontroller and the gyroscope	• Ensure that the resistors used to control Vout have at least a ½ W power rating • Continuously check battery after testing in order to make sure it is outputting at least 6 V

Table 1: Power Subsystem Requirements and Verification

2.4 Control Subsystem

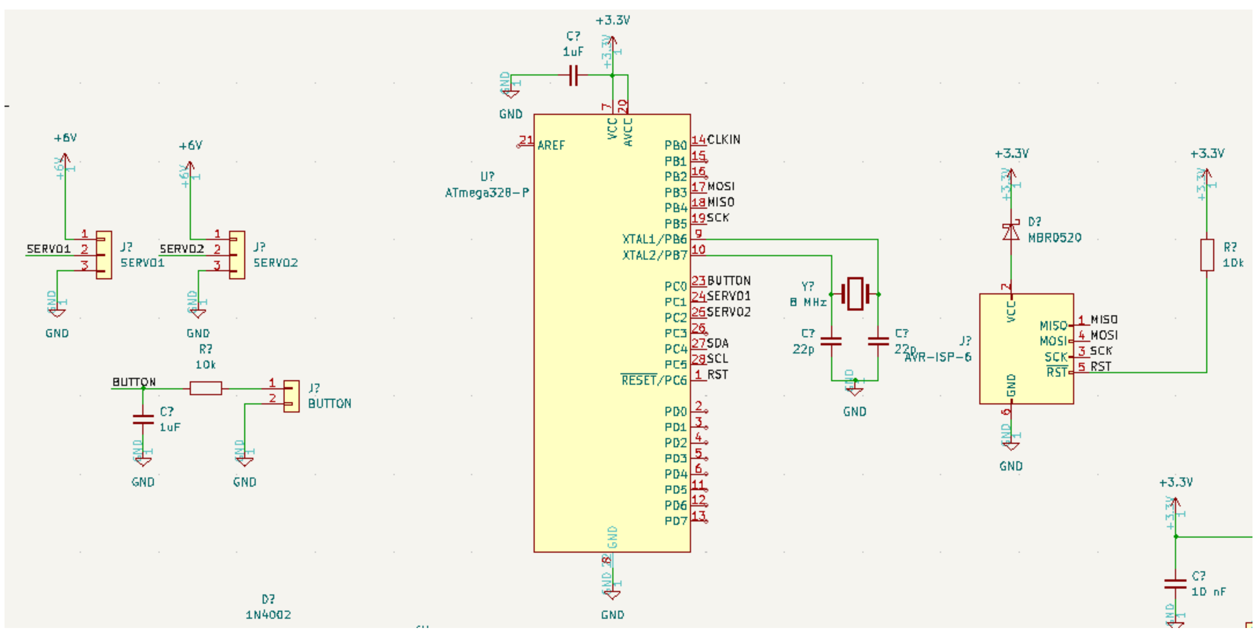

Figure 5: Control Subsystem Schematic

2.4.1 Overview

The purpose of this system is to actuate our motors in order to mimic a gyroscopic gimbal. We will use a microcontroller which interprets data from a gyroscopic sensor to set control inputs to motors.

2.4.2 Requirements and Verification

Requirements	Verification
• The microcontroller will read data from the gyroscope, calculate necessary signals for both motors individually and update the motors input signal all in real time	• The ATMega328p can support up to 10 MHz, which allows for a considerable update rate. • Motors have a speed of 0.15sec/60° so a full rotation could be completed in 0.50 secs • Motors will be able to keep up with consistent movement since the user physically won't move faster

• Each motor must be able to hold and alter the position to within 5° all while bearing the load of up to 250 grams.
  ○ The first motor must be able to support the second motor as well as the camera mount and camera(< 250 g)
  ○ The second motor must be able to support the camera mount and the camera
	• With a torque of 5.5 kg/cm, the Gimbal can support up to 180 grams at the camera mount
	• As long as the first motor, placed at the base, can support the weight at the "end-effector" the second motor will be perfectly fine
	• In order to ensure that all weight could be easily supported for this prototype, we will be using a GoPro which weighs about 80 grams.

Table 2: Control Subsystem Requirements and Verification

2.3 Sensor Subsystem

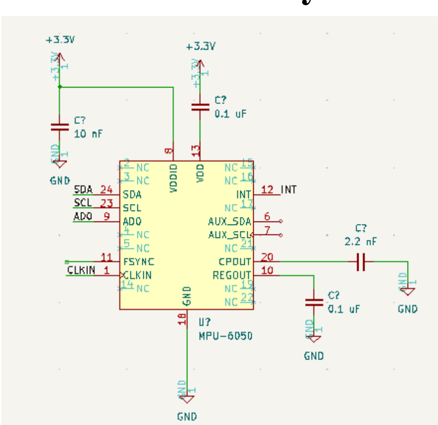

Figure 6: Sensor Subsystem Schematic

2.3.1 Overview

To understand the purpose of this subsystem, we need to first understand the mechanics of the device. We will have a user controlled handle where the control end of the handle will house our Pitch movement, and directly above that another motor will control the Roll movement. The gyroscope will be attached at the base of these motors so that the far end of the handle will be the modular platform (refer to the visual aid). Our gyroscopic sensor will read positional data to tell us how the gimbal is oriented. We will continuously read these output values in order to simultaneously control servo positions.

2.3.2 Requirements and Verification

Requirements	Verification
• The gyroscope must be able to obtain accurate readings throughout gimbal activation at a rate of at least 1000 Hz.	• Our Gyroscope will be powered and taking readings at all times there is any power supplied to the Gimbal • The constant readings at 30 kHz allows us to pinpoint the motors positions at all times

Table 3: Sensor Subsystem Requirements and Verification

2.4 Tolerance Analysis

The most critical portion of our Gimbal is ensuring that the gimbal is able to react to changes in movements in a small enough time frame that there is very minimal to no visual shake in the camera feed. As there is no real metric to measure the shakiness of a camera feed in either mechanics or the digital output, our standard we want to achieve is at a minimum, an emulation of the industry standard camera gimbal [5]. This gimbal setup achieves a slew rate of 100°/sec which is the minimum for our project, but since this is for a much larger camera load than our intentions, we plan to perform at a rate of 200°/sec. In order to achieve this, we needed to first ensure that our data protocols could run at a sufficient speed in order for this to work.

In our testing and application, the GoPro HERO Session can record 1080p footage up to 60 fps. Since our HS-311 performs at a rate of 400°/sec with no load at 6.0 Volts.

$$0.15\, sec/60\,° \;=>\; (60°/0.15\, sec) * \frac{3}{20} \;=>\; 400°/sec$$

This maximized strength of the motor means that we are able to perform well above the required speed in order to maintain stable footage.

60 fps and a motor speed of 400°/sec allows us to complete a full servo rotation in between each frame in the video.

The data signals to control this movement originate from the gyroscope which has an output data rate of 8 KHz [2]. This data is then sent to the microcontroller with an internal clock of 1 MHz [2] and processing speed of about 12 MHz at 3.3 Volts [1].

The ATmega328P is configured to use Timer/Counter 1 for both PWM signals, and a prescaler value of 64 is used with a TOP value of 255 (8-bit resolution) [1], the total number of clock cycles required for one PWM cycle for each motor would be:

(1 / (12 MHz / 64)) * (256 cycles + 1 cycle for overflow) = 0.00136533 seconds = 1365 clock cycles.

Since we are only doing a simple read of the gyroscope, this will add another 200 clock cycles. This plus the amount of time to send PWM signals to both motors, we are at 2930 clock cycles total to get positional data from the gyroscope, process data in the microcontroller, then send PWM signals to the motors. With a 12 MHz clock, we are able to constantly update our motor positions through PWM signals more than 4000 times a second. This many updates within each frame means that we will have steady footage even after the physical movement time of the HS-311 motors.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

As Computer Engineering students, we will estimate the cost of labor based on the median starting salary for students that graduate with Computer Engineering degrees from the Grainger College of Engineering which is $105,352 [6]. Based on a 40 hour work week, it comes out to $50.65/hour.

Category of Work	Estimated Hours Girish	Estimated Hours Harrison
Circuit and PCB Design	20	20
Software Programming	20	20
Soldering	1	3
CAD for Encasing/Gimbal Grip	15	5
Prototyping and Debugging	40	40
Documentation and Logistics	40	45
Total Hours	136	133

Table 4: Estimated Labor Hours

Based on the estimated labor hours from table 4 and the computed hourly salary for each member the total cost of labor is:
$50.65 (Hourly Rate) * 269 (Total Estimated Hours) = $13,624.85

This comes out to $6812.43 per partner. When adding a 2.5x overhead multiplier, the total cost of labor comes out to $34,062.13 or $17,031.06 per partner.

3.1.2 Parts

Description	**Part #**	**Manufacturer**	**Quantity**	**Cost**
Adjustable Linear Voltage Regulator 1.2-37V	LM317T	STMicroelectronics	2	$0.00
Gyroscope	MPU-6050	TDK InvenSense	1	$8.00
9V Battery	EN-22	Procell	1	$1.67
9V Battery Clip	233	Procell	1	$0.60
3 Position MTA 100 Header	640456-3	TE Connectivity	2	$0.28
2 Position MTA 100 Header	6404562	TE Connectivity	1	$0.06
Servo Motor	HS-311	HiTec	2	$27.08
ATMega Microcontroller	ATMega328-P	Atmel	1	$7.20

Crystal 16.0Mhz SMD KX-7T 12pF,	12.88722	Geyer Electronic America, Inc.	1	$0.35
16mm Momentary Push Button Switch SPST	R13-507	weideer	1	$8.99
Thin Film Resistors - SMD RA73F 2A 10K 0.1% 1K RL	RA73F2A10KB TDF	TE Connectivity	2	$4.32
Thin Film Resistors - SMD RQ 603 82K5 0.1% 10PPM	RQ73C1J82K5B TDF	TE Connectivity	1	$1.09
Thin Film Resistors - SMD 3503G 2B 19K1 1% 1K RL	3503G2B19K1F TDF	TE Connectivity	1	$1.64
RES SMD 50K OHM 0.1% 1/4W 1206	RT1206BRD075 0KL	YAGEO	1	$0.65
RES SMD 5K OHM 0.1% 1/4W 1206	RT1206BRD075 KL	YAGEO	1	$0.65
Multilayer Ceramic Capacitors MLCC - SMD/SMT T101 COMMERCIAL	04023C104KAT 2A-62	KYOCERA AVX	4	$1.48
Multilayer Ceramic Capacitors MLCC - SMD/SMT 25V 1uF X8L 1206 10% AEC-Q200	C1206C105K3N ACAUTO	KEMET	4	$2.12
Multilayer Ceramic Capacitors MLCC - SMD/SMT 25Vol 22pF X7R 0603 10% AEC-Q200	C0603C220K3R ACAUTO	KEMET	2	$0.30
Multilayer Ceramic Capacitors MLCC - SMD/SMT CGA 0603 50V 0.01uF X7R 10% AEC-Q200	CGA3E2X7R1H 103K080AA	TDK	1	$0.10
Multilayer Ceramic Capacitors MLCC - SMD/SMT 25V 2200pF X7R 0402 5% AEC-Q200	04023C222J4T2 A	KYOCERA AVX	1	$0.11

Rectifiers Diode, DO-41, 100V, 1A	1N4002	Diotec Semiconductors	2	$0.80
Schottky Diodes & Rectifiers 20Vr 14Vrms 20V 5.5A 0.45V 30pF	MBR0520-TP	Micro Commercial Components	1	$0.34
CONN HEADER VERT 6POS 2.54MM	BHR-06-VUA	Adam Tech	1	$0.25

Table 5: Parts and cost

The total cost of parts before shipping as shown above in Table 5 is $67.53. With around 5% in shipping and a sales tax of 6.25%, the total cost of parts will be around $75.13.

3.1.3 External Materials and Resources

We plan on 3D printing the PCB enclosure/grip as well as the motor mounts. With a rate of $0.10 per gram [7] from the Illinois makerlab to 3D print, and an estimated weight of around 200 grams for our external parts, this will cost us around $20.

3.1.4 Total Sum of Cost

Category	**Cost**
Labor	$13,624.85
Parts	$75.13
External Materials	$20
Total Cost	**$13,719.98**

Table 6: Total Cost

3.2 Schedule

Week	Task	Person
Week of 2/20	Design Document	Everyone
	CAD PCB board	Everyone
	Order Parts	Harrison
	Team Contract	Everyone
Week of 2/27	Design Review	Everyone
	PCB Board Review	Everyone
	CAD enclosure for PCB	Harrison
	CAD motor mounts	Girish
	Start prototyping on breadboard	Everyone
	Research integration of gyroscope data with microcontroller	Everyone
	Power and Sensor Subsystem Development	Harrison
	Control Subsystem Development	Girish
Week of 3/6	Revise PCB board	Harrison
	Pass PCB audit	Everyone
	First Round of PCB Orders	Everyone
	Power and Sensor Subsystem Development	Harrison
	Control Subsystem Development	Girish
Week of 3/20	Debug code for microcontroller	Everyone
	Solder PCB board	Girish
	Ensure PCB is working	Everyone
	Finalize 3D print design for enclosure and mounts	Everyone
	3D print enclosure and mounts	Everyone

Week of 3/27	Pass audit and order 2nd PCB board if needed	Everyone
	Progress Reports	Everyone
	Continue to code and debug systems	Everyone
Week of 4/3	Continue to code and debug systems	Everyone
Week of 4/10	Fix minor bugs and other issues	Everyone
	Assemble gimbal	Everyone
	Start preparing for demo	Everyone
Week of 4/17	Mock Demo	Everyone
	Finalize Demo	Everyone
	Start work on final presentation	Everyone
	Start work on final paper	Everyone
Week of 4/24	Demo	Everyone
	Finalize presentation	Everyone
Week of 5/1	Final Presentation	Everyone
	Finish Final Paper	Everyone

Table 7: Schedule

4 Ethics and Safety

Our group will follow the IEEE Code of Ethics and will hold all team members accountable to the highest ethical standards which will include, but is not limited to:

1. To uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities. [4]

   We will make sure that our design will not put any users into harm's way and will disclose anything that may be deemed unsafe or can put people or the environment at risk. We will seek and accept honest criticism of our work by going to the professor or our TA often for feedback on our designs. We will also make sure that we are technically competent in what we do which includes the completion of Lab Safety Certification, CAD assignment, and soldering assignment.

2. To treat all persons fairly and with respect, to not engage in harassment or discrimination, and to avoid injuring others. [4]

   Our group will ensure that everyone in our team as well as the rest of our class is treated with respect regardless of age, gender, race, etc. Harassment and bullying will not be tolerated and will be reported. Everyone in the group will have access to all files and work done by members of the group. All group members are also roommates so there will be ample communication throughout the group. When working in the lab, the group members will avoid injuring others physically and emotionally.

3. To strive to ensure this code is upheld by colleagues and co-workers. [4]

   We will support each other in upholding the highest ethical standards and to speak up if someone is not following these standards.

In regards to the safety and regulations for our project:

1. We will enclose our motors and electronics in plastic boxes to ensure that nothing can pop out and harm the user.
2. We will ensure that our project follows relevant licensing terms and follow the terms of service for the software components used in our camera gimbal system.
3. We will be using lithium ion batteries in our project which can be dangerous, so we will be following the guidelines laid out in the ECE 445 General Battery Safety document [5] in order to mitigate the risk of fire and damage to life or property. This will be done by reviewing datasheets and restrictions for the battery we will use, ensure that all components used and circuit designs are reviewed and validated by all team members as well as a TA, simulating the power circuitry before connecting it to hardware, and ensure that the battery and the components it will be connected to are stored in a safe place.

5 References

[1] "Atmega88a," *Microchip ATMega88A*. [Online]. Available: https://www.microchip.com/en-us/product/ATmega88a. [Accessed: 09-Feb-2023].

[2] "Haoyu Electronics : MPU-6000 and MPU-6050 Product Specification Revision 3.3." [Online]. Available: https://www.haoyuelectronics.com/Attachment/GY-521/mpu6050.pdf. [Accessed: 09-Feb-2023].

[3] "HS-311 Standard Economy Servo," *HiTec*. [Online]. Available: https://hitecrcd.com/products/servos/analog/sport-2/hs-311/product. [Accessed: 08-Feb-2023].

[4] "IEEE code of Ethics," *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 08-Feb-2023].

[5] "Safe Practice for Lead Acid and Lithium Batteries", General Battery, ECE445 Senior Design Spring 2016 Course Staff, Jan. 2016. [Online]. Available: https://courses.grainger.illinois.edu/ece445/documents/GeneralBatterySafety.pdf.

[6] T. G. C. of Engineering. ""The Grainger College of Engineering - Computer Engineering"." (2022), [Online]. Available: https://grainger.illinois.edu/academics/undergraduate/majors- and- minors/computer- engineering#:~:text=Post%5C%2DGraduation%5C%20Success&text=The%5C%20average%5C%20salary%5C%20between%5C%202020,median%5C%20signing%5C%20bonus%5C%20of%5C%20%5C%2415%5C%2C000 [Accessed: 23-Feb-2023].

[7] "What we offer," *Illinois MakerLab*. [Online]. Available: https://makerlab.illinois.edu/pricingservices/#printing. [Accessed: 23-Feb-2023].