Self-adjusting Helmet

ECE 445 Design Document

Team 23: Minghao Liu, Shuhan Li, Yichen Gu
TA: John Kan
2/20/2019

1 Introduction

1.1 Objectives

Helmets are ubiquitous in our daily lives. We can see construction workers or bicyclists wearing them, and helmets prevent people from potential hurt. In many scenarios, the users are under strong direct sunlight, which can cause potential skin problems such as sunburn. Here comes the problem. Most helmets do not provide enough shade. Even if some do, they don't function well because the orientation of the brim doesn't always align with the sunlight. Besides, using hands to adjust the helmet is quite inconvenient, especially for people with both hands occupied. Therefore, we come up with a solution – a self-adjusting helmet.

The primary objective is to make the helmet brim rotate to the direction that shields most of the sunlight. Besides, we also consider the safety issue and extend its functionality by adding a safety alarm to it. In a dark environment, light indicators will be automatically turned on and flash at the normal mode. In the case of falling down and possible coma after, the emergency mode will be triggered and an alarm will keep ringing to notify people passing by.

1.2 Background

Sunlight is critical to our lives, but too much ultraviolet exposure can cause serious disease such as skin cancer [1]. Many people such as construction workers have to work outdoors and on sunny days, long exposure to strong sunlight can cause damage to their health. Certain modification to their hard hats or safety helmets can be helpful to prevent overexposure.

At the same time, we notice a large number of accidents incurring construction workers. According to a 2017 article on Bloomberg, said that head injuries lead to the death of 992 construction workers from 2011 to 2015, and many accidents started from a simple fall [2]. On one hand, we have to improve helmets to provide more protection. On the other hand, spotting accidents instantly ensure that the injured worker is rescued in time. Consequently, we come up with the idea of installing an emergency system on the helmet.

The number of construction workers employed in the U.S. is over 8 million in 2017 [3]. Beneath this huge market is the potential to improve the functionality of helmets by automating the sun-shielding function and adding an emergency system. As there has been little effort on this aspect, we feel it a good idea to be the first team to solve this problem.

1.3 High-level Requirements

Our design faces several basic requirements:

1. The designs function properly.

    1) Our controller should react to the light intensity properly. The mechanical system provides shadow for at least both eyes, while the movement should be limited at a reasonable speed and temporarily paused when the sunlight is weak.

    2) The controller should spot the case of falling down and the shock accurately. The emergency actuators (lights and speaker) should be triggered automatically until manually being reset.

2. The self-adjusting helmet has to be free of safety issues. This means the mechanical parts should be shielded from human touch. There are protection circuits on the board to avoid battery overcharge.

3. The self-adjusting helmet should be light enough. Hardware and extra mechanical parts in the design should not add too much weight to it for users' comfort. We want the weight to be less than 700 g.

2 Design

This is a modular design, and it can be divided into the following modules: the power system, the sensing module, the control unit, and the mechanical part. The power system contains a lithium-ion battery that outputs two different voltages, one for the motor driver and the other for the control unit and the sensing module. The sensing module detects the physical signals, converts them to electrical signals and sends the data to the control unit. The control unit contains a microprocessor and some memory to handle the data and sends instructions to the actuator, which is the mechanical part. The block diagram and physical design are shown below.

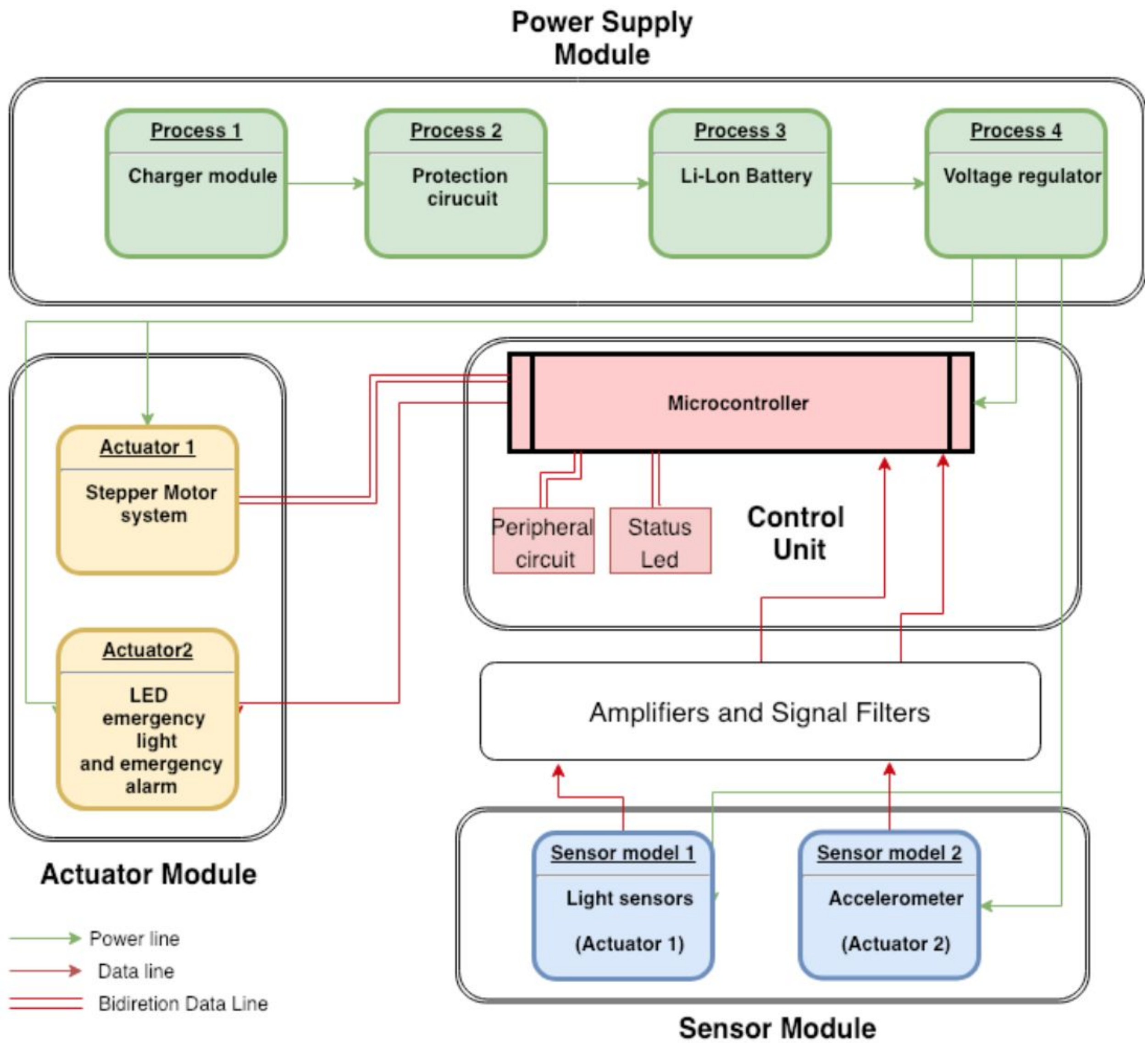

Fig. 1. Block diagram

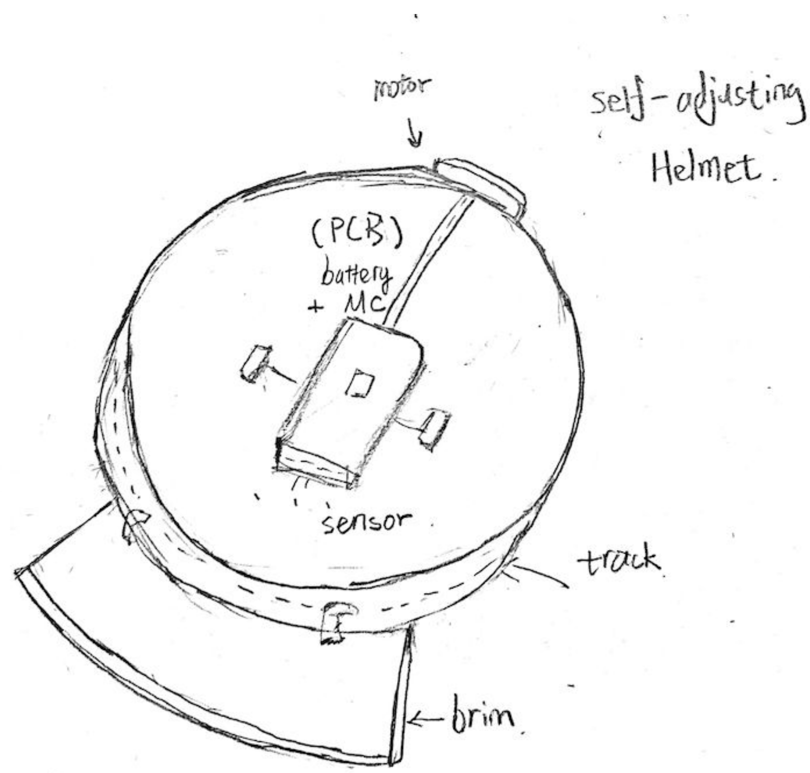

Fig. 2. Physical design sketch

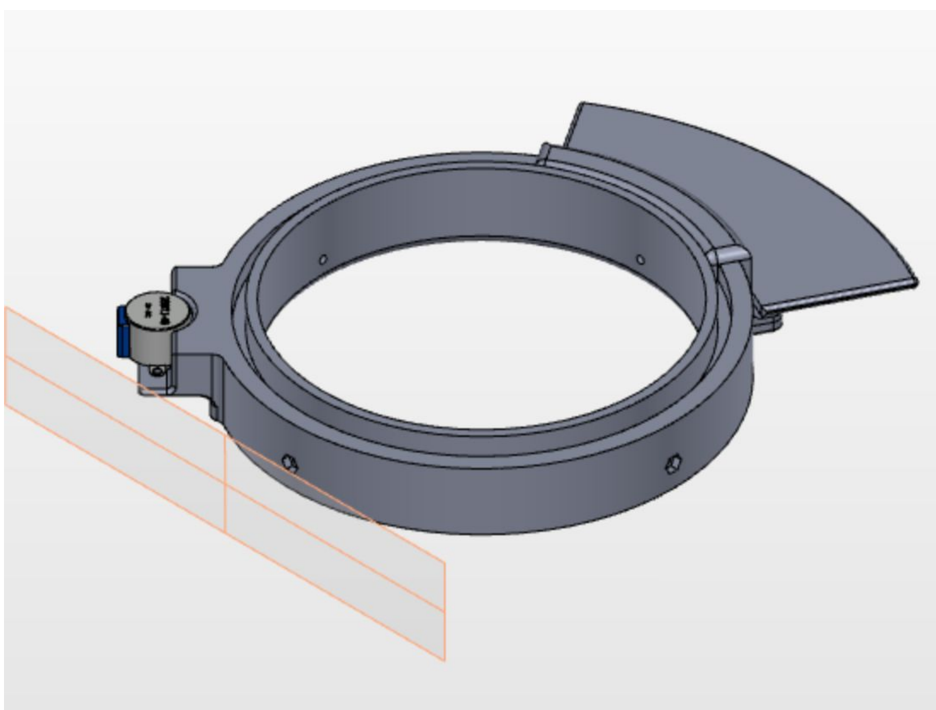

Fig. 3. CAD Design Isometric View

2.1 Power Supply

The power supply offers enough power for the circuit to operate normally, but meanwhile, there are limits on its size and weight to make the product wearable. A 500 mAh Lithium battery is enough for our project. The battery can be charged via a charging port, and the output voltages are 3.3V and 5V. The former supplies the sensing and controlling circuits, while the later is required for the motor driver.

2.1.1 Battery Charger

Functional Overview

This module charges the Lithium-ion battery. It serves as a connection between power sources and the lithium battery. It converts the input to a stable DC output of 4.2V.

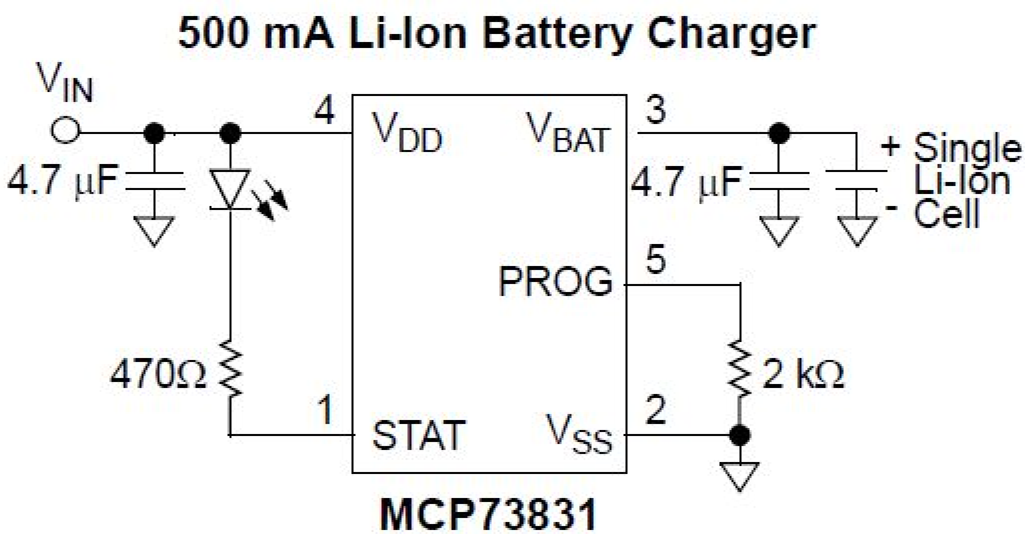

Fig. 4. 500mA Battery Charger Circuit

Requirement and Verification

Requirement	Verification
1. The battery charger should charge the lithium battery to 4.15 - 4.25V when the input is between 4.5 and 6V.	1. (1) Discharge a Lithium battery fully using a 10K resistor. (2) Connect a fully charged power bank to the charging port (3) Charge the Lithium battery using the configuration above for about 2

	hours. (4) Measure the battery voltage using a digital multimeter.

2.1.2 lithium-ion battery

Functional Overview

The Li-ion battery is responsible for providing all the power needed for our subsystems. It supplies power to the sensing module, the controller and the mechanical system. Therefore, it functions as a power reservoir. Considering the consumption of our stepper motor, it needs to provide enough power to turn on the motor and keep it rotating, as well as the power of the sensing module and controller.

Requirement and Verification

Requirement	Verification
1. The battery should have a capacity of at least 1 Ah.	1. (1) Connect a fully charged battery to a 10k Ohm resistor and discharge it. Use an oscilloscope to record the voltage across the resistor. (2) Use the data collected by the oscilloscope, divide the voltage by the resistance to get current, and finally, integrate the current to get the capacity.

2.1.3 Voltage Regulator

Functional Overview

This part converts the battery voltage to the working voltage of the circuit and the motor. It's connected between the battery and the working circuits. We need 2 voltage regulators, one for the sensing and control units, and the other for the motor driver.

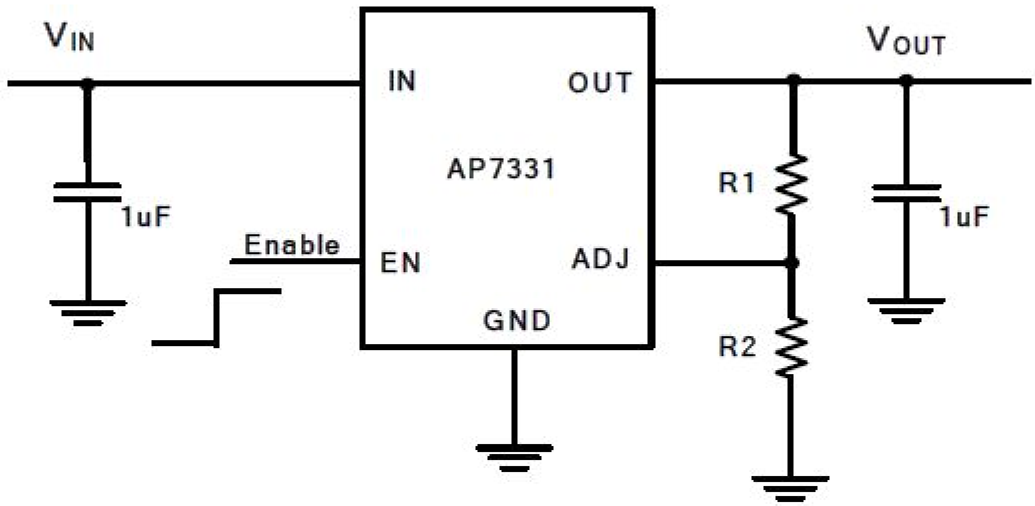

Fig. 5. Voltage Regulator

Requirement and Verification

Requirement	Verification
1. The output of the Voltage Regulator should include 3.3V and 5V, +/- 5%, when the current is at its maximum, about 80 mA and the input voltage varies between 3.7V and 4.2V.	1. (1) Connect a 4.2V DC source to the voltage regulator. (2) Add a load resistor of 40 Ohm (62.5 Ohm) to the output. (3) Measure the voltage across the resistor at 3.7V and 4.2V input respectively and check whether it's within the range.

2.2 Sensing Module

The sensing module is composed of sensors and connected to the microprocessor. In our design, we need ambient light sensors and accelerometers for the two main functions.

2.2.1 Light Sensor

Functional Overview
The light sensors collect data of light intensity and send them back to the controller. They have I2C interfaces and can communicate directly with the microcontroller. According to Wikipedia [4], the light intensity of the brightest sunlight is about 120,000 lux, and it goes below 1 lux at night. The light sensor should detect a wide range of light intensity.

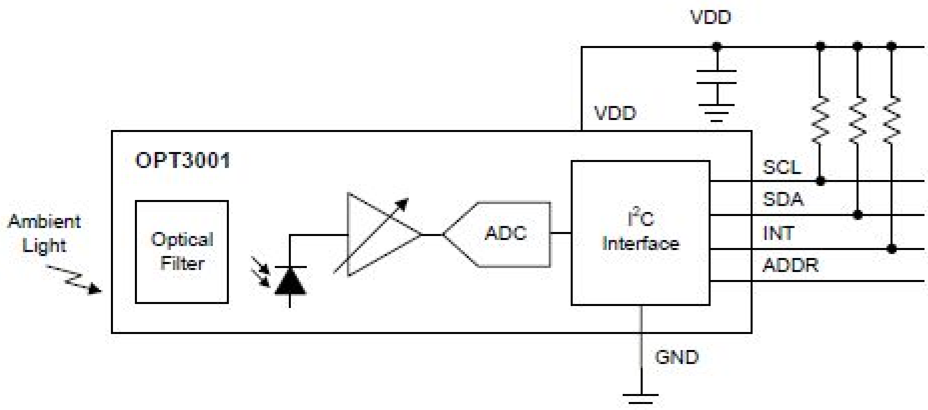

Fig. 6. OPT 3001 Ambient Light Sensor

Requirement and Verification

Requirement	Verification
1. Sensing Range The light sensors can detect the range from 1 to 32000 lux. 2. The output doesn't fall below 80% of the original output when the incidence angle is about 45 degrees.	1. (1) Connect a voltage regulator with output ranging from 1.6 to 3.6V to the 5V DC output of the Arduino board. Then connect the light sensor to the output of the voltage regulator. (3) Place the sensor in a dark room and direct sunlight. Record the data. Observe whether the data covers the range in the requirement. 2. (1) Repeat step (1) and (2) in 1. (2) In a dark room, shed torchlight to the light sensor at 45 and 90 degrees to get the data. The torch should be of the same distance, 2 - 10 cm, from the sensor. (3) Compare the measured light intensity at 45 and 90 degrees and check whether the ratio is above 80%.

2.2.2 Accelerometer

Functional Overview

The accelerometer collects data about the motion of the head and sends them back to the controller. There are different types of accelerometers. Since we need to transmit data to the microprocessor, we need a digital-based accelerometer. We choose LIS3DH accelerometer from STMicroelectronics which has the free-fall detection functionality. The sensor should work normally under a supply voltage from 3 to 4V.

Requirement and verification

Requirement	Verification
1. Sensing should cover the range of +-2g for freefall detection. 2. Any orientation of the free fall movement should be accurately captured by the accelerometer. 3. High shock survivability	1. (1) Connect the accelerometer as the sensor input to the Arduino Board (for test purpose) with a voltage regulator in between and collect data. (2) Calculate the magnitude of the acceleration and make sure it's less than 2g. 2. (1) Repeat 1(1) (2) Add a testing LED to one of the Arduino output pins to indicate whether free fall is detected. (2) Simulate different possible free-fall situations and see whether free-fall movement is detected by the accelerometer.

2.3 Controller

The controller part includes a microcontroller, extra memory, and I/O ports. The microcontroller handles data from the sensing module and outputs instructions to the mechanical system. Some kind of memory is necessary for storing enough data. Some peripheral circuits are also needed.

2.3.1 Microcontroller

Functional Overview

The microcontroller is the “brain” in our design and critical to good performance. It receives the data from the sensing module, runs data analysis algorithms, recognizes different lighting conditions and cases of emergency, and finally sends instructions to the motor or the emergency system to react to the scenarios. The microcontroller Atmega328 is used to build the system for its affordability and reliable performance.

Requirement and Verification

Requirement	Verification
1. The microcontroller has an internal clock of at least 1 MHz. 2. The microcontroller communicates normally with the slave devices via the I2C interface.	1. (1) Power the microcontroller and connect a 1K resistor at the clock output pin. (2) Measure the output using an oscilloscope and measure the period. Check whether the period is less than 1 us. 2. (1) Program the microcontroller with our program for I2C communication. (2) Connect the accelerometer and the 4 light sensors to the microcontroller. (3) Send read commands to each slave device and check whether the microcontroller receives the data correctly.

2.3.2 Peripheral Circuit

Functional Overview

The peripheral circuit includes extra memory (if necessary) and I/O ports to connect to the outside circuits. Memory is used for storing data and I/O ports are used for connecting to other devices.

2.3.3 Status LED

Functional Overview

The flashing LED lights indicate the work status of our controller and let the users spot any anomaly in case of the emergency. We use red LEDs for good visualization purpose.

Requirement and Verification

Requirement	Verification
1. A good visualization result from at least 10m away.	1.Measure 10 meters distance from the LED circuit

2.LED should work normally at 3.3V (output of voltage regulator) with corresponding resistors and power consumption less than 100mW	2. Ensure that LED is clearly visible when pointed in the viewer's direction (from the back) 3. Connect the LED to test circuits with different load resistors to check the power consumption and visibility at the same time.

2.4 Mechanical System

2.4.1 Stepper Motor System

Stepper Motor and Motor Driver

Functional Overview

The stepper motor serves as the actuator that rotates the brim of the helmet. It is controlled by the controller and drives a belt on the track to which the helmet brim is mounted. For this application, we don't need a large torque, so a stepper motor small in both size and power is the best. Since the helmet brim has a large area, we don't need too much precision for the rotation. A step angle of 18 degrees or less is enough. The stepper motor driver provides enough current to enable the motor to rotate normally. It uses the H-bridge structure to drive the motor.

Requirement and Verification

Requirement	Verification
1. The motor driver should successfully drive the motor. 2. The motor should produce enough torque to make the brim slide along the circular track.	1. (1) Connect the brim and the track to the motor via a belt. (2) Connect a 5V DC source to the motor driver and the corresponding logic pins from the Arduino board (only for test purpose) to the motor driver. Add the motor to the output of the driver. (3) Check whether the motor rotates and the brim slides along the track.

Track and Helmet Brim

Functional Overview
This part is the mechanical device that provides the shade. The brim is mounted to the track and rotates synchronously with the motor.

2.4.2 Emergency Reaction

This part functions as a reminder or alarm in dark conditions as well as in emergency situations.

Emergency Light and Alarm

Functional Overview
These lights are turned on automatically in dark environments and flashes rapidly when an emergency happens. The speaker functions as a sound reminder when accidents happen. It is controlled by the controller. The speak should play a noticeable alarm to remind mainly people passing by who can reach for necessary medical help in time. These parts are controlled by the microcontroller.

Requirement and Verification

Requirement	Verification
1. The emergency lights flash regularly, at around 0.5Hz, in normal conditions. The light should be recognizable within 20 meters of distance. 2. In case of emergency, the light automatically switches to the emergency mode so that they will have higher intensity and flashing rate (about 2Hz). People within 30 meters should hear the alarm clearly.	1. (1) Connect the light to the microcontroller, which receives data from the accelerometer. (2) Place the main board on the table and observe the number of flashes within a minute. (3) Stand at a distance of about 20 meters to check the visibility of the LED light. 2. (1) Repeat 1(1) (2) Drop the main board from about 20 cm above the table and check whether the red light flashes faster and the speaker beeps.

2.5 Risk Analysis

2.5.1 Power System

Our greatest risk lies in the power system. The product needs enough electrical power, and the design of our power system is critical to our success. Each lithium battery supplies 3.7 - 4.2V. The stepper motor needs 5V and a current of 125mA/phase to maintain its rotation. Our main concern is that the power system may be insufficient for driving the stepper motor. The limit on the weight makes this problem even more challenging. Adding more batteries may enable us to fulfill the power requirement, but it makes the product heavier.

Severity: High Probability: Low

2.5.2 Sensing Module

Accuracy is an issue with the sensing module. We may have noise interruption from many sources and the positioning of the sensors also impacts the signal they measure. Therefore, we need some robust sensors that produce accurate measurements.

Severity: Medium Probability: Medium

2.5.3 Controller

For the controller, two algorithms are very critical and also challenging. The first one is to distinguish between different light conditions and motions. From the data given by the sensing module, the microcontroller can detect the direction of the sunlight accurately and there should be no miss or false alarm. The accelerometer follows the same requirement. The second one is the motor control algorithm. We need to make sure that the motor rotates at precise angles and proper speed. Besides, the communication between the controller and slaves needs special handling.

Severity: High Probability: Medium

2.5.4 Mechanical System

Our mechanical system is quite unique since there's no such structure used on helmets. This also means that we may have to make it ourselves from scratch. For the track, we've thought about making use of some products such as a bendable curtain track. This is viable from our perspective.

Severity: Medium Probability: Medium

2.6 Schematics

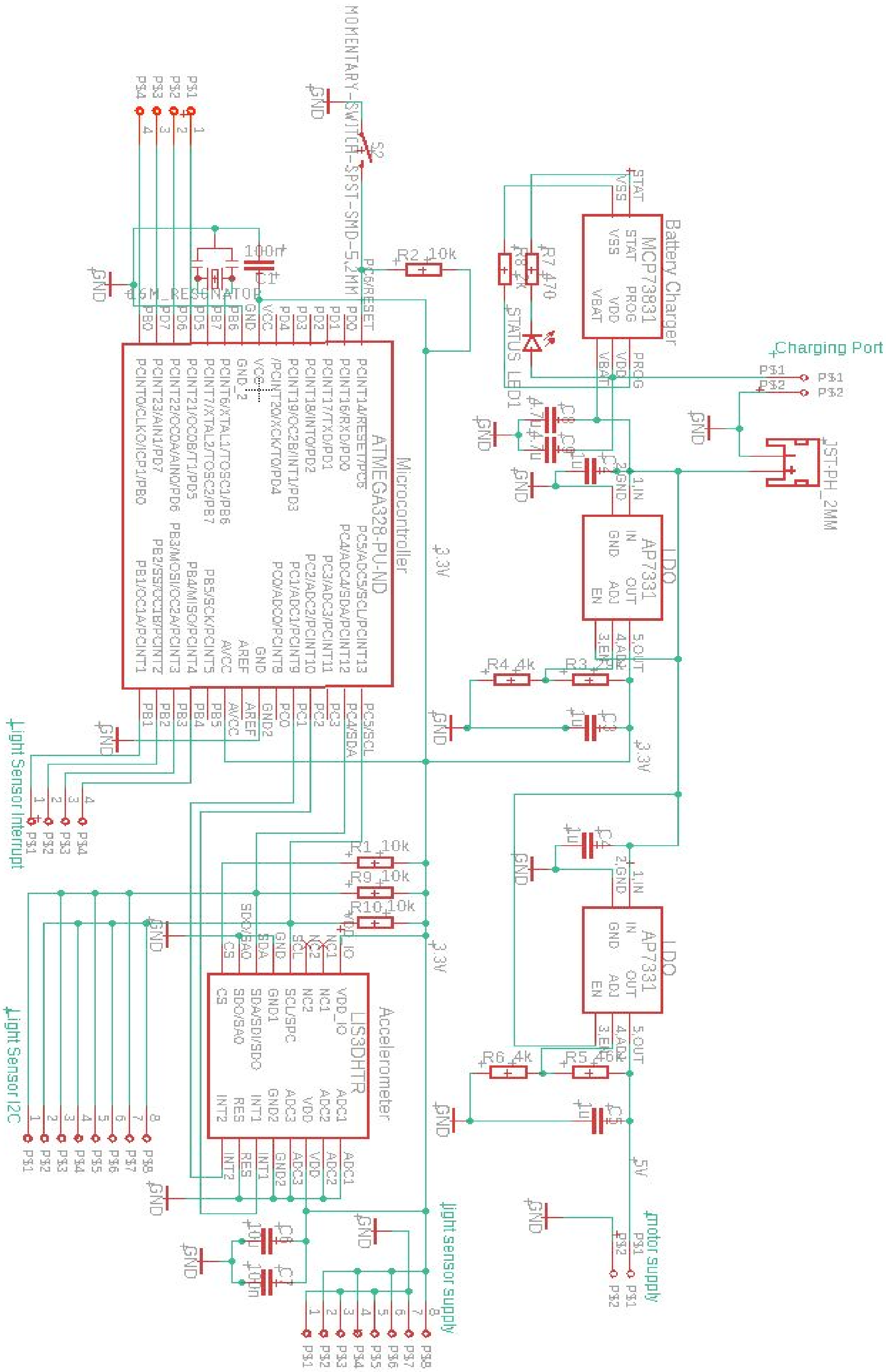

Fig. 7. Circuit Schematic (Main Board)

2.7 PCB Layout

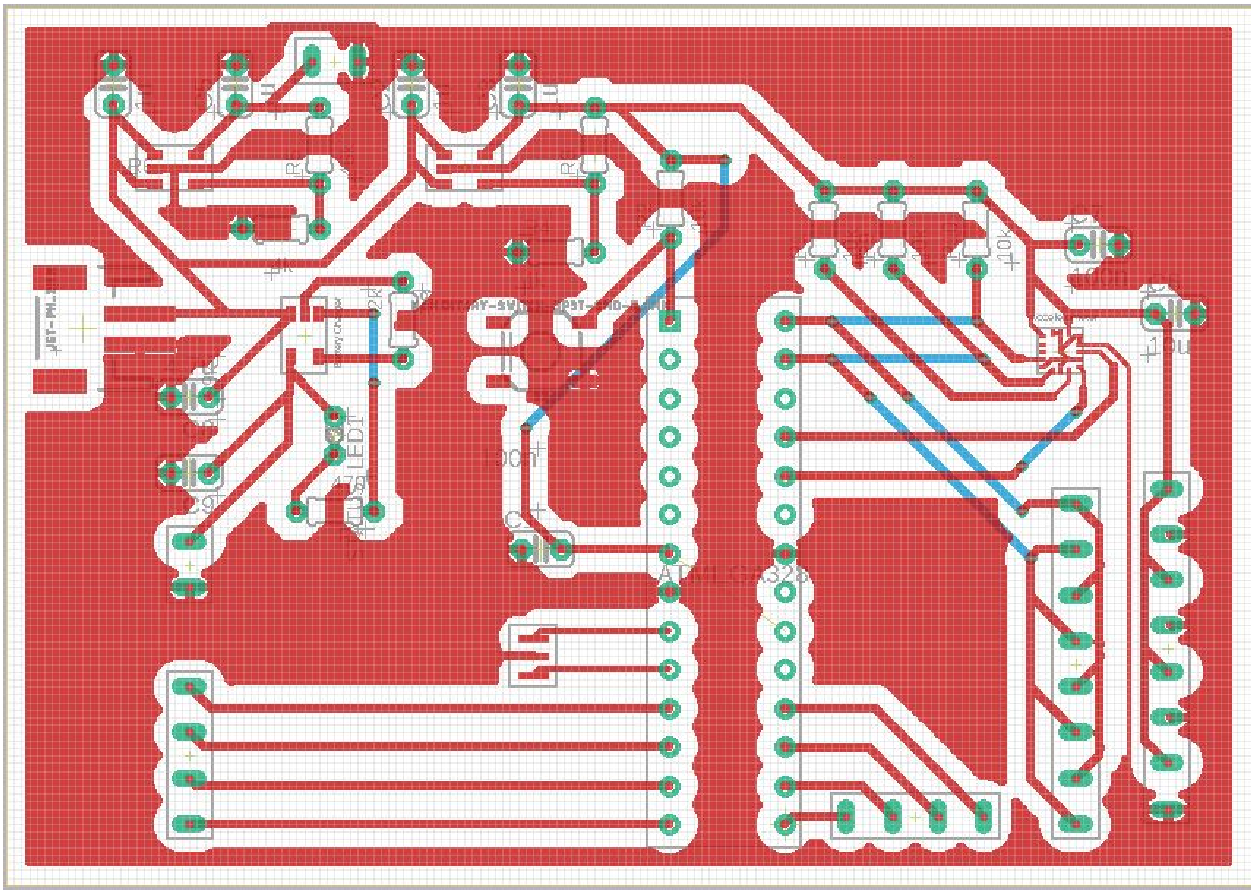

Fig. 8. PCB Layout (Main Board)

2.8 Software

The software control involved in this project mainly composed of two parts, the accelerometer data for the fall over warning part, and the light angle data for the brim shadowing part. Those two parts shall be operated independently. The flowchart below represents the data flow and decision tree for the project.

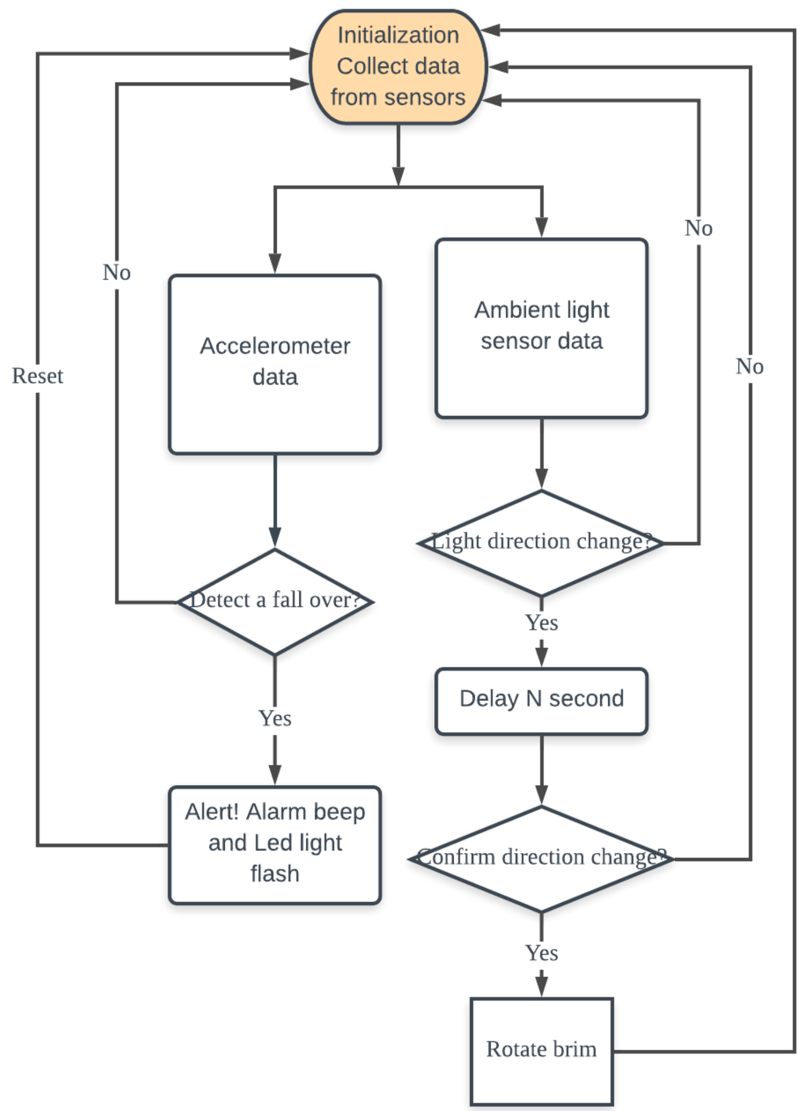

Fig. 9. Data flow diagram

The system boot into the initialization state and constantly checking new data sent from sensors. The main chip for process all the data is the Atmega328p processor. The protocol communicates with the sensor are the I2C bus. The motor driver and LEDs are driven by the digital signal. Once the accelerometer detects a sudden acceleration in a direction, a user falls over is detected. Then, the alarm will sound and the LED light will flash until manual reset. When the ambient light sensors detect a change in light direction, delay for several seconds and detect again. This makes sure the user does not turn continuously and preserve battery life. If the user indeed makes a turn after several second, execute the step motor to rotate the brim accordingly.

2.9 Tolerance Analysis

To guarantee the performance of the design, we discuss the tolerances of our system here.

2.9.1 Motor Torque

For the motor to work properly, we first need to ensure that the motor torque is sufficient for pulling the string connecting the motor and the helmet brim. The string is made of Nylon, with a cross-section radius of 2mm and area of about $A = \pi \times (2mm)^2 = 4\pi\ mm^2$. The density of Nylon is $1.15\ g/mm^3$, so the mass is

$$m = \rho V = \rho \times 2\pi R \times A \simeq 8.67\ g$$

The friction coefficient of Nylon is 0.15-0.25. If we consider the worst case when it's 0.25. An estimate of the Friction is

$$f = \mu_{Nylon} mg = 21.2\ mN$$

Therefore, the friction torque is $T_f = fR = 2.03\ \ mN \bullet m$

To overcome the friction, the motor should have a torque larger than 2.03 mN*m. In our design, we found that almost all the stepper motors fulfill this tolerance requirement. Therefore, we picked the 28BYJ-48 motor, which has a small diameter of 1.1 inch and sufficient torque (34.3 mN*m).

2.9.2 Light Sensing Accuracy

Since the incidence angle from the sun to the earth is not exactly the right angle, the light intensity reading collected by light sensors at sunrise and sunset will be far below the usual day time value. However, we don't want to accidentally turn on the night light at sunrise and sunset. Therefore, we need to make sure that the detected light intensity is greater than 20 lux, which is the light intensity of dark surroundings. According to Dr. David Maslanka [5], the incidence angle (angle between the incidence line and the vertical line) in Chicago at winter solstice is 65.3 degrees. For safety, we want to ensure that a 75-degree incidence angle will still give us a measurement larger than 20 lux. From Wikipedia [4], the light intensity at sunrise and sunset is about 400 lux. Therefore, the normalized response at an incidence angle of 75 is at least $20 \div 400 = 0.05$. The light sensor we have selected, the OPT3001 chip has the normalized response of 0.15 at 75 degrees, within our tolerance.

3 Costs

3.1 Labor

Our fixed development costs are estimated to be $40/hour, 10 hours/week for three people. We consider approximately 60% of our final design in this semester (14 weeks), neglecting any testing and building tools used in the development process.
3* $40/hr * 10 hours/week * 14 weeks/0.6* 2.5 = 70,000 dollars
The total cost for labor would be 70,000 dollars for our group(three group members in total).

3.2 Hardware Cost

Here's a list of the components required in this project and their price.

Part	Unit Price (Prototype, in USD)	Amount
1 Ah Lithium-Ion Battery (Sparkfun PRT-13813)	9.95	1
4.2V Battery Charger (Microchip Technology MCP73831)	0.58	1
0.8-5V Output LDO (Diodes Incorporated AP7331)	0.48	2
Ambient Light Sensor with I2C Interface (TI OPT3001DNPR)	3.35	4
3-axis Accelerometer with I2C Interface (STMicroelectronics LIS3DHTR)	1.53	1
8-Bit Microcontroller (Microchip Technology ATmega328-PU-ND)	1.96	1
Stepper Motor Driver (TI SN754410)	2.52	1
5V Bipolar Stepper Motor (Mikroelektronika)	9.59	1
Status LED Light (Liteon Optoelectronics LTST-C191KGKT)	0.29	1

Emergency LED Light (Kingbright DE4SRD)	2.75	2
Emergency Alarm (Soberton Inc. SP-1605)	1.64	1
16 MHz Oscillator (CSTNE16M0V530000R0)	0.29	1
3D printing (helmet structure)	10	1
Total	44.93	18

Since we are making 10 unit, estimating PCB and manufacture cost to be $10 per unit. This adds the grand total to be 70459.3 dollars.

4 Schedule

Week	Minghao Liu	Shuhan Li	Yichen Gu
2/18	Collecting information and mechanical part design	Design document and background information	Design document and electrical parts selecting
2/25	Finalizing schematic and version 1 PCB design	Collecting parts and explore software protocols	Finalizing schematic and version 1 PCB design
3/4	Data transmission protocol	prototype breadboard on sensors and actuators	Sensor communication setup
3/11	Version 1 PCB testing and documentation	Software implementation and PCB order	Version 2 PCB prototype
3/18	Spring break	Spring break	Spring break
3/25	Communication implementation	Continue software implementation and functionality test	Functionality implementation
4/1	Version 2 PCB production and	Fix PCB build and loading algorithm	Version 2 PCB production and

	testing		testing
4/15	Conduct environmental testing	Finalizing algorithm and debug	Bugfix any problem
4/22	Prepare mode demo	Mock demo and check all requirements	Detailing requirements and prepare the final report
4/29	Prepare final presentation Begin final report	Prepare final presentation, final report	Prepare final presentation Begin final report

5 Safety and Ethics

Considering that our product is a wearable device and closely attached to the head, safety is one of our highest priority. There are several potential safety hazards in our project. Lithium-ion batteries used in our project can be harmful under certain circumstances [6]. Because our battery needs to function properly outdoors where direct sunlight might cause a rise in temperature, we need to design additional power management and a protection circuit that could cut off the power to prevent a potential explosion. In addition, the protection circuit also needs to handle the case when the battery is fully charged but the solar panel is still providing current. In such cases, the power management system should shut off the charging port to prevent overcharge.

Besides, the IEEE code of Ethics, #7 states: “to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others [7].” As electrical engineers, we should be honest in the whole design process and give credit to any reference or aid we get from others. The potential risk may cause defects in our final product, but we’ll try our best to correct the errors and face the defects honestly.

Last, according to the IEEE code of Ethics, #9: “to avoid injuring others, their property, reputation, or employment by false or malicious action“, we should notify the latent risk of the device [6]. Our device is not meant to operate in the raining or under high air moisture condition since such weather may cause circuit board shortage which may lead to damages of our product and cause potential injury. However, we will still provide some weather shield to add robustness of the system.

References

[1] Wong, Celestine C., et al. “Think UV, Not Heat!” Australasian Journal of Dermatology, vol. 56, no. 4, Nov. 2015, pp. 275–278. [Accessed 4 Feb. 2019].

[2] Bruce Rolfsen, “Safety Helmets Are Replacing Hard Hats on Construction Sites ”, 2017. [Online] Available: https://www.bna.com/safety-helmets-replacing-n73014461149/ [Accessed 7 Feb. 2019].

[3] Statistica, ‘Number of production workers within the U.S. construction industry from 1998 to 2017 (in 1,000s)’, 2017. [Online] Available: https://www.statista.com/statistics/193094/employment-in-production-within-us-construction-since-1996/ [Accessed 7 Feb. 2019].

[4] En.wikipedia.org,”Daylight”, 2019. [online] Available : https://en.wikipedia.org/wiki/Daylight [Accessed 5 Feb. 2019].

[5] Maslanka, D. (2019). [online] Mypages.iit.edu. Available at: http://mypages.iit.edu/~maslanka/SolarGeo.pdf [Accessed 19 Feb. 2019].

[6] D. Doughty and E. P. Roth, "A General Discussion of Li-Ion Battery Safety," The Electrochemical Society Interface, Summer 2012. [Accessed 5 Feb. 2019].

[7] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed 5 Feb. 2019].

[8] Arduino.cc. (2019). Arduino - StepperBipolarCircuit. [online] Available at: https://www.arduino.cc/en/Reference/StepperBipolarCircuit [Accessed 18 Feb. 2019].

[9] https://github.com/sparkfun/SparkFun-Eagle-Libraries