Self-adjusting Helmet
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. It 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.
2. It 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.
3. The design functions properly.
   (1) Our controller should react to the light intensity properly. The mechanical system provides shadows 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 accurately and avoid false alarms. The emergency actuators (light and speaker) should be triggered in time.

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 charges lithium ion batteries with solar power and outputs two different voltages, one for the motor 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.
Figure 1. Block diagram
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 the solar panel and the lithium battery. It converts the input to a stable DC output of 4.2V.
Requirement and Verification

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The battery charger should charge the lithium battery to 4.15 - 4.25V, when the input is between 4.5 and 6V.</td>
<td>1. (1) Discharge a Lithium battery fully using a 10K resistor.</td>
</tr>
<tr>
<td></td>
<td>(2) Connect a fully charged power bank to the charging port</td>
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<td></td>
<td>(3) Charge the Lithium battery using the configuration above for about 2</td>
</tr>
<tr>
<td></td>
<td>hours.</td>
</tr>
<tr>
<td></td>
<td>(4) Measure the battery voltage using a digital multimeter.</td>
</tr>
</tbody>
</table>

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**
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.

**Requirement and Verification**

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>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.</td>
<td>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.</td>
</tr>
</tbody>
</table>

### 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.

**Requirement and Verification**

<table>
<thead>
<tr>
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</thead>
</table>
| 1. Sensing Range  
The light sensors can detect the range from 1 to 32000 lux. | 1. (1) Program an Arduino board (used only for testing in our project) with a program that measure the light intensity.  
(2) 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. The output doesn't fall below 80% of the original output when the incidence angle is about 45 degrees. | 2. (1) Repeat step (1) and (2) in 1.  
(2) In a dark room, shed torch light 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

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Sensing should cover the range of +-2g for free fall detection.</td>
<td>1. Connect the accelerometer as the sensor input to the Arduino Board (for test purpose) and collect data.</td>
</tr>
<tr>
<td>2. Any orientation of the free fall movement should be accurately captured by the accelerometer.</td>
<td>2. Simulate different possible free-fall situations and see whether free-fall movement is detected by the accelerometer.</td>
</tr>
<tr>
<td>3. The sensor should work normally under a supply voltage from 3 to 4V</td>
<td></td>
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<tr>
<td>4. High shock survivability</td>
<td></td>
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</tbody>
</table>

## 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

<table>
<thead>
<tr>
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</table>
| 1. The microcontroller has an internal clock of at least 1 MHz. | 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. |
First, the clock frequency should be at least 100 kHz. This is quite low because we can tolerate a relatively large delay in this application. Second, it should be at least 8-bit. (Atmega328 may be used)

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 flash LED lights indicate the work status of our controller and let the users spot any anomaly in case of the emergence. We use red leds for good visualization purpose.

**Requirement and Verification**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
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</thead>
<tbody>
<tr>
<td>1. A good visualization result from at least 10m away.</td>
<td>1. Measure 10 meters distance from LED circuit</td>
</tr>
<tr>
<td>2. LED should work normally at 3.3V (output of voltage regulator) with</td>
<td>2. Ensure that LED is clearly visible when pointed in the viewer's direction</td>
</tr>
<tr>
<td>corresponding resistors and power consumption less than 100mW</td>
<td>(from the back)</td>
</tr>
<tr>
<td></td>
<td>3. Connect the LED to test circuits with different load resistors to check</td>
</tr>
<tr>
<td></td>
<td>the power consumption and visibility as the same time.</td>
</tr>
</tbody>
</table>

2.4 Mechanical System

2.4.1 Stepper Motor System

Stepper Motor

**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.

**Requirement and Verification**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Verification</th>
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</thead>
<tbody>
<tr>
<td>1. The motor should produce enough torque to make the brim slide along the circular track.</td>
<td>1. (1) Connect the brim and the track to the motor via a belt.</td>
</tr>
<tr>
<td></td>
<td>(2) Connect a 5V DC source to the motor driver and add the motor to the output of the driver.</td>
</tr>
<tr>
<td></td>
<td>(3) Check whether the brim slides along the track.</td>
</tr>
</tbody>
</table>

**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.

**Requirement**
The helmet brim, with the solar panel covering it, is mounted to a track around the head. There are wheels embedded in the groove on the track and thus, the helmet brim can move with little friction. The friction is supposed to be less than 20 grams of force (about 0.2N).

**2.4.2 Emergency Reaction**
This part functions as a reminder or alarm in dark conditions as well as in emergency situations.

**Emergency Light**

**Functional Overview**
These lights are turned on automatically in dark environments and flashes rapidly when an emergency happens. They are controlled by the controller.

**Requirement**
These lights flash regularly, at around 0.5Hz, in normal conditions. In case of emergency, the light automatically switches to the emergency mode so that they will have higher intensity and flashing rate (about 2Hz).
Emergency Alarm

**Functional Overview**
The speaker functions as a sound reminder when accidents happen. It is controlled by the controller.

**Requirement**
The speaker should play a noticeable alarm to remind mainly people passing by who can reach for necessary medical help in time. People within 30 meters should hear the sound clearly.

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. We have two power sources, the lithium battery, and the solar panel. Each lithium battery supplies 3.7V. The stepper motor needs 12V and a large current 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.

In order to achieve the goal of our project that our device could operate for at least 12 hours, we need to integrate all the components together and create a reasonable power management algorithm. We shall do some experiments and calculation at the early stage of the development to determine some physical quantities of the component to ensure our battery can last long enough and our solar panel will provide enough current in a practical environment.

Severity: High Probability: Medium

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: Low

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.

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

3 Costs

Our fixed development costs are estimated to be $30/hour, 10 hours/week for three people. We consider approximately 60% of our final design in this semester (15 weeks), neglecting the any testing and building tools used in the development process. 

\[3 \times \$30/hr \times 10 \text{ hours/week} \times 15 \text{ weeks}/0.6 = 22,500\]

4 Schedule

<table>
<thead>
<tr>
<th>Week</th>
<th>Minghao Liu</th>
<th>Shuhan Li</th>
<th>Yichen Gu</th>
</tr>
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<tbody>
<tr>
<td>2/18</td>
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<td>2/25</td>
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<td>3/11</td>
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</table>
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 [5]. 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 [6].” 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


