Self-adjusting Helmet

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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.
4. The cost must be reasonable, ideally below 30 dollars, since we want to make it affordable to the public.
5. The battery, when fully charged, provides energy for the circuit to operate for at least 12 hours in the absence of sunlight.

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 is shown below.

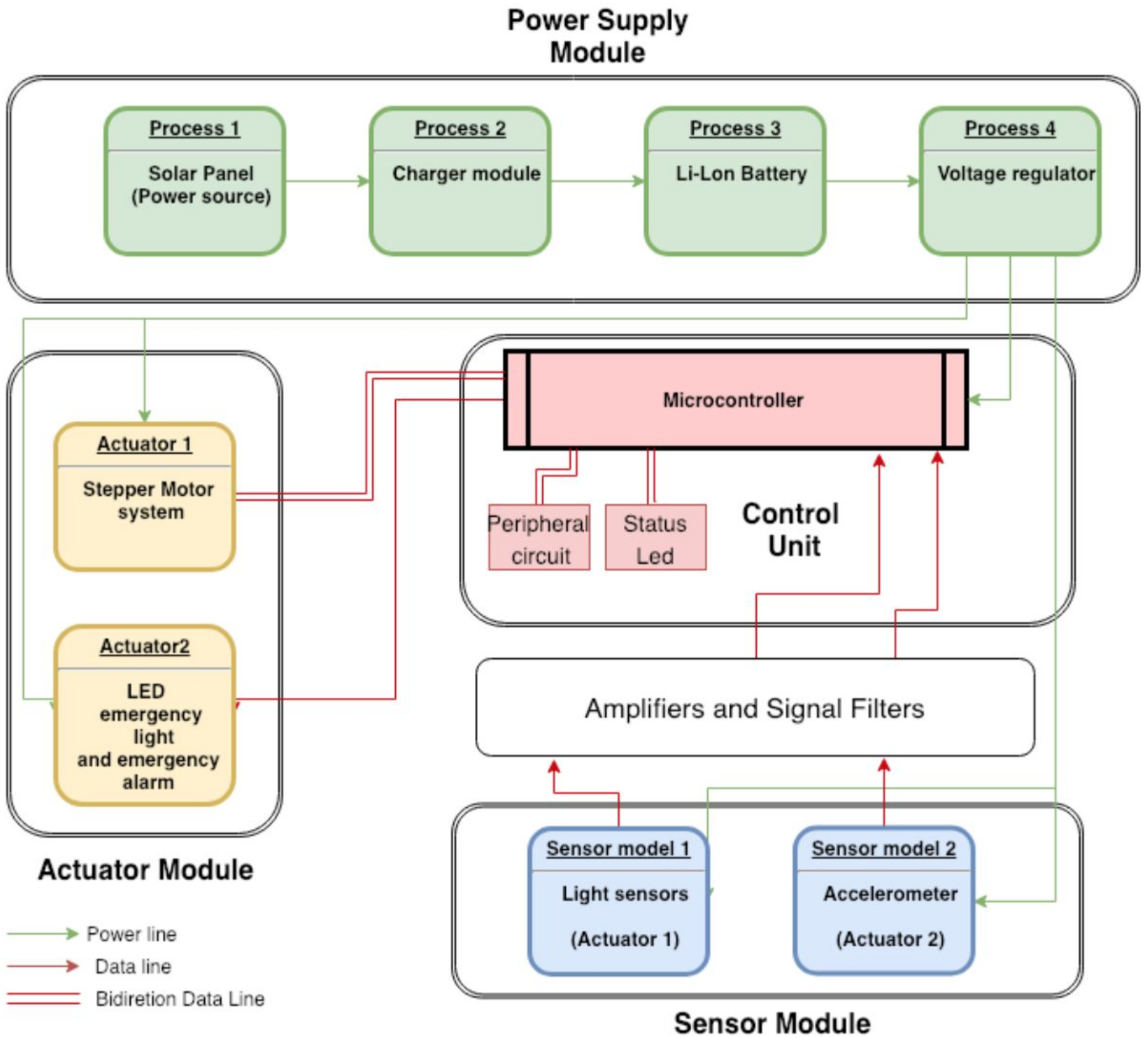

Figure 1. Block diagram

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. As described in the previous section, the circuit should work for at least 12 hours with the charged lithium-ion battery. The input is sunlight and the outputs are two voltages, 3.3V and 12V.

2.1.1 Solar Panel

Functional Overview

The solar panel provides a portion of the total power for the circuit. It covers the brim to charge the lithium battery through a battery charger.

Requirement
Considering possible bending, we choose flexible solar panels in our design.

2.1.2 Battery Charger

Functional Overview
This module charges the Lithium-ion battery. It serves as a connection between the solar panel and the lithium battery.

Requirement
It contains a voltage regulator that converts the unstable input to a stable DC output of 4.2V +/- 5% (the normal charging voltage of a single Lithium battery).

2.1.3 lithium-ion battery

Functional Overview
The Li-ion battery is responsible for providing all the power needed for our subsystems. It can be pre-charged and also can be charged by the solar panel. It supplies power to the sensing module, the controller and the mechanical system. Therefore, it functions as a power reservoir.

Requirement
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. We expect the battery to power the whole design for at least 12 hours after it's fully charged. (Expect a 2000mAh battery)

2.1.4 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.

Requirement
It needs to output two stable DC voltages: 3.3V for the microcontroller and sensing module and approximately 12V for the stepper motor. The two output voltages should vary only within 5%.

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.

Requirement
According to Wikipedia [4], the light intensity of the brightest sunlight is about 120,000 lux, and it goes below 1 lux at night. Therefore, we need light sensors that can detect the range from 1 to 12000 lux. The sensor should work normally under a supply voltage from 3 to 4V.

2.2.2 Accelerometer

Functional Overview
The accelerometer collects data about the motion of the head and sends them back to the controller.

Requirement
There are different types of accelerometers. Since we need to transmit data to the microprocessor, we need a digital-based accelerometer. We can assume the acceleration of falling down is about g (9.8 m/s^2), so a sensing range of +- 2g is enough. For the purpose of detecting falling down, we need a shock-detecting accelerometer with low sensitivity.

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 some 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.

Requirement
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
This LED light indicates the work status of our controller and let the users spot any anomaly in time.

Requirement
For a good visualization result, we pick the red LED. The LED should work normally at 3.3V and power consumption less than 100mW.

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.

Requirement
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 size should be as small as possible, not exceeding 4 cm in diameter. The torque should be at least 20 g-cm.

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 speak 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 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

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