Modeling and Design of a Smart Helmet for Cyclists

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I. Introduction to the Problem

In Denmark, cycling is one of the most common forms of transportation. It does not matter if it rains or snows - people will still use their bikes to go to work, school or any leisure activities. The main reasons why Danes choose to bike instead of driving are that it is cheaper, eco-friendly and beneficial for their health. It also helps that the country is fully prepared for cyclists and the terrain is primarily flat.

According to [1], 9 out 10 people in Denmark own a bike, which is quite surprising compared to only 3 out of 10 Danes owning a car. Overall, cycling in Denmark accounts for 26% of the trips under 5 km and even though it is very safe to ride a bike in this country, accidents still happen. The Danish society has not internalized the need to wear a helmet yet, since only 11% of cyclists wear a helmet regularly. In fact, in 2020, 799 bike accidents were registered and 28 of those resulted in death. The most common factors that play a role in accidents are: low visibility, distractions with electronics, incorrect signalling and speeding. Having in mind these problems, it was decided to design a smart helmet to improve the navigation and safety of the cyclists.

II. The Solution: SafeHelmet

SafeHelmet is a smart helmet that uses technology to ensure the cyclists' safety when riding. This product is formed by three components: the helmet itself, the controller and the mobile application. Thanks to SafeHelmet, cyclists can navigate the streets safely at night, since the helmet has a smart headlight that turns on when it's dark out. It also comes with a position and brake light matrix on the back of the helmet that changes into blinker lights to communicate the intention of turning to the right or left. The controller is attached to the bike handlebar and the cyclist can move the joystick to the right or left to communicate their intention. If the cyclist wants to turn right, In the event of an accident, SafeHelmet detects the fall and makes an automatic call to the emergency services, sharing the SafeHelmet's location and the person's health data. Using the GPS, users can even find their SafeHelmet through the app, if lost or stolen.

III. Electronics

The system consists of two main parts: the helmet and the controller. They both have an ESP32 as the core of the device, and several components attached to them. The devices are powered by Lithium-ion batteries. ESP32 is an excellent choice for this application, because it has many digital and analog inputs, I2C pins and UART pins. It also has a Bluetooth chip, which is essential for this project: an easy to use, short distance communication protocol, which is going to be used between the devices.

A. *The controller*

The controller's purpose is to detect the direction created by the joystick, and then to forward this signal to the helmet. The joystick sends its current position through 2 analog channels: X and Y. Based on this information, the desired *left, right, brake* events can be **defined**.

The components used for the controller are the following:

- ESP32 DevKit V1
- Joystick
- Switch / SPDT (ON-OFF button)
- Lithium-ion battery

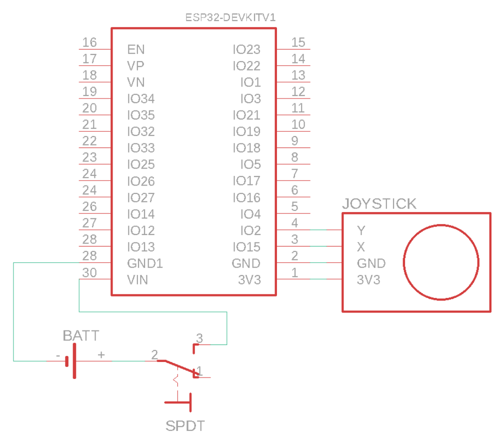

Fig. 1. Controller's circuit diagram

B. *The helmet*

The helmet has plenty of components. The smart headlight function is created by the combination of a photo-diode and an LED,and they are both connected to analog pins. The accelerometer is responsible for detecting the accidents, and it communicates with the ESP32 board through the I2C pins. On the other hand, the GPS module is connected to ADC inputs and the NeoPixel is controlled by a general pin. All components are powered by the same source: a lithium-ion battery.

The components that were used in the helmet are listed below:

- ESP32 DevKit V1

- Photo-diode / light sensor
- LED / flashlight (head light)
- GPS module
- Accelerometer ADXL345
- NeoPixel (display of directions)
- Switch / SPDT (ON-OFF button)
- Lithium-ion battery

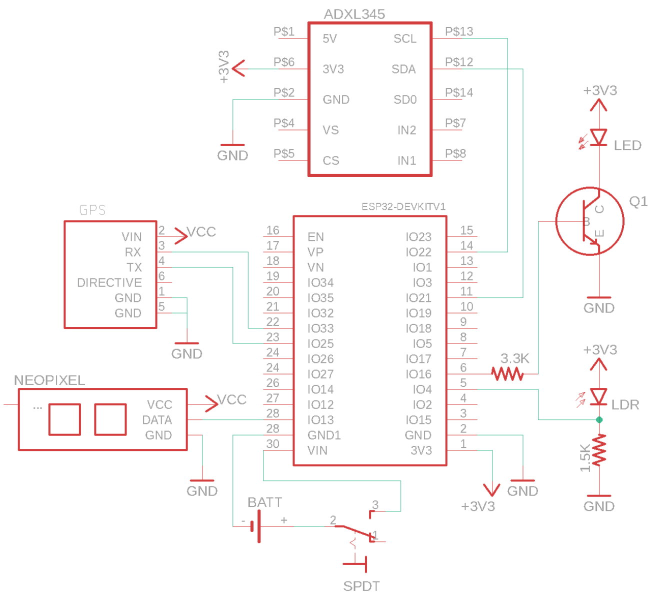

Fig. 2. Helmet's circuit diagram

IV. SOFTWARE

There are many functions implemented in the helmet to ensure a safer experience for cyclists. The concept includes two main parts: a firmware for the controller and a firmware for the helmet. The two devices have to collaborate flawlessly, otherwise they would lose their purposes. In this section, each part and its embedded functions will be discussed.

The project was created in Arduino environment and the source code is available in **this** GitHub repository.

A. The controller

The firmware of the controller is rather simple, since its only purpose is to detect the direction signalled by the joystick, and then forward it to the helmet via Bluetooth. First, the program starts by setting up the Bluetooth communication. The device's hard-coded name is "Controller", so that the helmet can be easily differentiated from the other devices.

In the main loop of the program, the analog input of the joystick is continuously measured. It reads (X;Y) values coming from two channels. Both values can be in the range of [0; 4095], therefore 3 different directions can be defined:

- $X <= 100 \rightarrow Brake$
- $Y <= 100 \rightarrow Left$
- $Y >= 3800 \rightarrow Right$

When one of these conditions is fulfilled, the associated direction is then forwarded to the helmet as a single byte ('B', 'L', 'R'). The implemented communication protocol is *BluetoothSerial* and the required library can be downloaded from **GitHub**.

B. The helmet

The firmware of the helmet has to handle many functions and they have to perfectly work together. If one of the components takes too much computational power, it can ruin the whole system.

1) Communication: First of all, the helmet needs to build up the Bluetooth connection with the controller. The helmet will act as *master* and the controller as *slave*. While searching for available devices, it tries to reach the previously specified name *Controller*, so that the helmet can't connect to any other device. For additional security, the controller's MAC address could be used instead. If the message buffer is not empty, the function reads the first available character ('B','L' or 'R'), then displays an animation accordingly. The message buffer is *First In First Out*, so the animations will be played in the order of their entry. The communication runs on a parallel core, meaning it can accept messages even if other functions are being executed at the same time.

2) Smart headlight: Automating the headlight can save hours of battery power, since it's only turned on when it is really necessary. The concept of the smart headlight is pretty simple: the device has a built-in lux sensor, which can accurately measure the amount of light in the surrounding environment. Based on this information, the voltage level of the headlight can be controlled, using Pulse Width Modulation. The analog input has values in the range of [0; 4095], the PWM signal can be varied in the range of [0; 180] (higher values don't make a noticeable difference in the brightness of the light), so the exact output is calculated by the following equation:

$$if(lux < 2900) \rightarrow pwm = (3000 - lux) * 0.06$$

$$else \rightarrow pwm = 0$$

Since the lux value doesn't normally exceed 2900 during daylight (based on our experiments), that point was defined as an upper threshold - at this point the headlight will turn off.

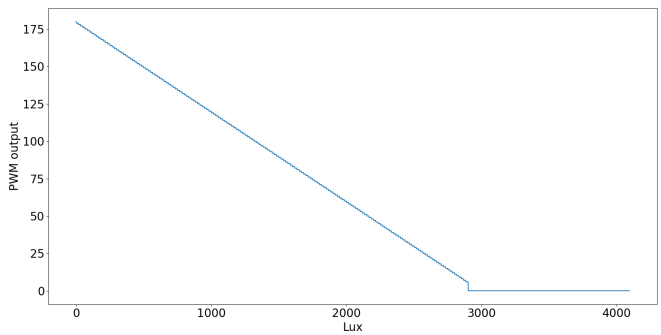

Fig. 3. PWM output for the headlight as the function of lux

3) Fall detection: Detecting accidents is the most important safety function in the helmet. In the event of an accident, the victim might not be able to call for help, so the most reliable solution is to automate an emergency call. It can be done by implementing an accelerometer in the helmet and continuously measuring the acceleration. Normally it varies between 0-2g, so it should be considered as a mild-accident when the value is above 4g [2].

4) GPS: As mentioned previously, when a fall is detected, the emergency services would be called automatically. However, a call is not enough, since the ambulance needs to know where the accident took place. To solve this, a GPS module has been implemented in the helmet, and the current location is requested every 30 seconds. However, it is not continuous because it would take a lot of computational power, which would prevent other functions to work properly. The required libraries are *TinyGPSPlus* and *SoftwareSerial*.

5) Display of directions: To indicate different directions, certain animations are displayed on the NeoPixel interface. The display consists of an array of RGB pixels and they can be addressed and set to certain colors individually. There are five animations implemented:

- Position light: A single red line in the bottom with a 50% brightness. The purpose is to increase the visibility of the cyclist.
- Brake light: The full display is red, with 100% brightness. It is meant to powerfully indicate the intention of decreasing speed.
- Left turn: Red arrows pointing and moving to the left, indicating the intention of turning left.
- Right turn: Red arrows pointing and moving to the right, indicating the intention of turning right.
- Accident: Yellow blinking light on the full screen

The library *Adafruit_NeoPixel* is being used here.

V. 3D CASING

The 3D design was developed using the professional software SolidWorks. The design consists of two parts: the controller, which is placed in the bike handlebar; and the helmet. The controller is composed by a joystick, an ESP32 and a battery, while the helmet has an ESP32, battery, a headlight, a GPS, an accelerometer, a light sensor and a matrix of RGB LEDs. The 3D design of the controller must be adjustable in size to the most common bike handlebars. A render of the design of the controller can be seen in Figure 5. The controller is attached to the handlebar with 4 screws, and to make it more inclusive, it can be attached to any side of the handlebar.

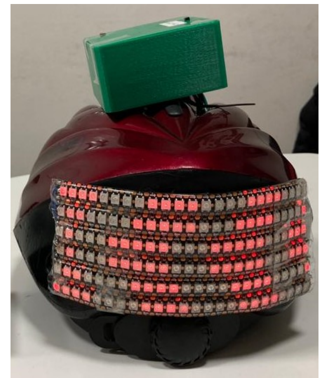

Fig. 4. Displaying a left turn by moving arrows

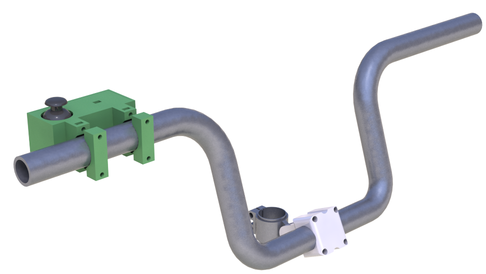

Fig. 5. Controller placed in the handlebar

The 3D design of the helmet must fit in our prototype helmet, and the best place to do that is on top of the helmet. The reason for this is that there is not much space inside the helmet and this position does not change the centre of mass of the helmet. Additionally, the enclosure must give access to the power switch and to the light sensor. The final design can be seen in Figure 6. This design is not aerodynamic, in a future design the electronics should be placed inside the helmet.

VI. BUSINESS PLAN

SafeHelmet is the overall combination of a smart helmet, a controller and an app. Using special sensors and actuators

Fig. 6. Top view of the helmet

and connecting them in a smart way, a user friendly product was made to increase cyclists' security on the road. Thanks to the front and back lights, the user can be seen in the dark and signal the turns easily using the controller. The blinkers work in a similar way as those used in motorbikes so it is proved that this system works. The user can also feel safe in an accident situation, as the app will directly call the emergency services and send easily their location. Furthermore, the product is portable, easy and intuitive to use and resistant to all type of weather conditions as all the electronics are stored in a waterproof closed box.

The mission when creating this prototype was to increase the cyclists' safety when riding. This was achieved and after receiving positive feedback from students, some goals were set for further development. The next steps would be to implement an airbag system and alternative batteries in the helmet. In case of an accident, the helmet would not only detect the accident and call the emergency services, but it would also make sure to prevent further damage by activating the airbag system when a fall is detected. The other serious improvement regarding the battery must be analyzed in detail, as the lithium-ion battery is toxic and can be dangerous if it breaks with a fall. An alternative battery could be used such as a built-in rechargeable battery of another material.

The team that designed and created the SafeHelmet prototype is composed of a Design and Innovation engineer, a Computer Science engineer, an Autonomous Systems engineer and two Electrical engineers. As the team is diverse, all areas of the project are covered so there is no need to increase the team at the moment. When the product is further developed, an economist or business expert may be needed.

The work strategy that the team will follow in the future is to test new functions and make sure they are important improvements to add to the SafeHelmet. A funding request may be needed to continue improving the prototype, as testing new functions is not only time consuming, but also expensive. Creating a startup and professionalizing the project may be considered. A specific timeline for future procedure was not made yet but a business meeting with all the team members was already arranged for January 2022 and a rough goal of selling the first ten SafeHelmets at the end of next year was set.

VII. MARKET ANALYSIS

Analyzing the market opportunities of the product, the end result of it was positive, as the product resulted effective, with good growth opportunities and designed for a large end-user group.

The customers who may need this product are cyclists, that are worried about their actual safety in their bikes or just want to improve their security when riding a bike. The product can be used by different age groups, as the bike, and specially in Denmark, is a common transportation for many different people. It is user friendly for those who don't feel safe taking their hands off the bike to signal their right or left turns. With SafeHelmet both hands can be on the handlebar at all times and is therefore also appropriate for people who easily lose their balance.

After analyzing the market in detail, it can be found that the biggest competitor for the product is the company called "LUMOS" [3], as they are already selling smart bike helmets with LED-screens on the back part. However, even if this business is experienced in this area and offers similar products to the one modelled in this project, there is an opportunity to compete especially in terms of price. The helmets LUMOS cost around 200 euros and calculating the manufacturing and material costs for the prototype built in this project, the estimated price would be around 100 euros. If the end user realizes that this prototype is functionally as good as the competitors' but with a lower price, they will not hesitate to take an interest in the SafeHelmet. Marketing is needed in order to reach a broad end user and make the product known to many people.

There are many reasons why a cyclist should buy this product. First of all, because it is an effective solution to improve the safety when biking. It is not proven yet to be better than current solutions, but tests will be done when the product becomes a real market product. Even if there are some businesses as competitors, the current market size is not that big. However, a market growth is expected in the next years, as safety combined with smart technology is becoming more and more important every day.

The customers ability to pay for this product is big, as it is expected to be cheaper than the competitors. It also has to be mentioned that users who care about safety normally don't have big price concerns. The main challenges the team will have to face are marketing related topics, as making a new product known in the society is not always as easy as it seems at the beginning. Another challenge is the funding and the product development, because without a financial support the development of this product may be affected.

Taking all this into account, the overall potential of the product is high, while its overall challenge is mild. Therefore, the future of the SafeHelmet is bright!

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3 Lumos helmets. [Online]. Available: https://lumoshelmet.co/