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(Research Article)

The Human-Robot Interactive Helmet

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Abstract

The human-robot Interactive helmet (HRI Helmet) project was created to enhance the safety features for cyclists. Advanced technological integration enabled real-time health monitoring, GPS navigation, and emergency communication. Equipped with a Raspberry Pi 4B, pulse sensors, GPS module and the Google Maps API, this helmet can deliver several vital safety features: heart rate tracking, turn-by-turn navigation, and SOS functionality that activates automatically and manually. Although there have been challenges, like setting up the microphones and permission issues with the serial port, the project satisfied the design objectives. Testing at the final stage confirms the reliability of the helmet in health monitoring, navigation support, and emergency communication, with further improvements planned in its performance and usability.

Keywords: Raspberry Pi 4B; SOS Calling; Pulse sensors; Google map API; GPS module; Helmet

1. Introduction

The HRI Helmet project aims to develop a better bicycling helmet that utilises the best technologies to significantly enhance the rider's overall well-being. It brings together numerous expectations of sensors, communication devices, and adequate algorithms to provide emergency services, health checks, and calls for directions and assistance. This specific helmet adds value to cycling by tackling vital safety factors while enhancing the Cyclist's overall welfare.

Recent advancements in wearable technology present new possibilities for enhancing safety across several sporting disciplines, such as cycling. Smartwatches & fitness bands draw on enhanced software and hardware features deep & improved. They are supplemented with additional options such as measuring the heartbeat rate, GPS navigation, and even detecting a fall. New concepts have been developed over time, and the technology known as smart helmets involves adding electronics to helmets for protective headgear concerning safety and utility. These developments are significant in cycling as helmets are the most critical safety equipment. The basic traditional helmets are used to prevent the head from being injured in case of a fall or an incident that's why there are very few elements in a helmet that can be called preventative. Current smart helmets still tend to be confined to specific areas, for example, GPS or communication, while neglecting other safety issues and challenges those cyclists face concerning their health.

Hence, this HRI helmet was developed to cater to this need by offering more than mere protection. It employs today's available sensors, communication devices, and artificial intelligence algorithms to construct a helmet that would not just shield bikers in the event of an accident but also try to prevent occurrences and enhance the well-being of everyone. This project is motivated with the aim of providing cyclists with a more enjoyable, safer and smarter riding experience. The major features of the helmet involve real-time health monitoring, emergency signals, and controls. to the response capabilities and navigation aids all of which are tailored to the specific issues that cyclists confront. These strategies are specific to the problems that cyclists encounter out on the roads. By incorporating these aspects in this compact device,

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the HRI helmet wants riding safety to advance and improve. This project is grounded on conceptual progress made in wearable electronics and smart helmets. but its purpose is to take it even further by achieving greater advances by creating a far-reaching safety solution.

Relative to previous smart protective apparel, this HRI helmet can be said to represent a progressive growth in the enlightenment of protective equipment specifically designed for bicycles since it attends to both the preventions and the responses to the instance as a protective gear.

1.1. Literature Review

Smart helmets have emerged as a significant innovation across various domains, focusing on safety for road users, construction workers, motorcyclists, and cyclists. These helmets integrate sensors, communication modules, and artificial intelligence to provide features beyond basic head protection.

- **Smart Helmets for Motorcycling and Cycling:** Technological advancements have made smart helmets essential for motorcyclists and cyclists. Key features include GPS, fall detection, and SOS functionality to ensure rider safety. Increasingly, health monitoring devices such as heart rate and body temperature sensors are incorporated, offering real-time monitoring and timely health alerts (Choi & Kim, 2021).
- **Smart Helmets for Construction:** In construction, smart helmets enhance worker safety and productivity by detecting risks like toxic materials, excessive noise, and extreme temperatures. These helmets utilize communication technologies for real-time monitoring and emergency response, significantly reducing workplace accidents (Aliyev et al., 2020).
- **Integration between IoT and AI:** The integration of the Internet of Things (IoT) and Artificial Intelligence (AI) elevates smart helmet capabilities. IoT-enabled helmets connect to cloud systems, enabling real-time data processing. AI algorithms analyze patterns to predict and mitigate risks, such as fatigue-related mishaps or health anomalies (Edirisinghe, 2019).
- **Prospects** Smart helmet development is poised to expand into new industries, driven by the demand for enhanced safety measures. Future research will focus on optimising technology integration, improving usability, and reducing costs to boost adoption. The ultimate goal is to create comprehensive safety solutions that seamlessly fit into users' daily routines, benefiting bikers and construction workers alike (Hazarika, 2016).

Building on these advancements, the HRI Helmet project aims to deliver autonomous protection for bikers, combining preventive and responsive safety measures to exceed current standards.

2. Methodology

2.1. Project Overview

HRI Helmet is a cycling helmet that harnesses state-of-the-art technology to enhance the safety and well-being of riders. This innovative helmet can track the rider's health, navigation aid, and trigger emergency alerts through its range of sensors, communication modules, and AI-powered algorithms. The main objective of this initiative is to offer solutions for modern-day cyclists by pushing the boundaries of helmet features.

2.2. Approach

The development process encompasses the integration of hardware components and software applications to ensure a user experience while upholding stringent safety measures.

Hardware Configuration: The design of the HRI Helmet focuses on integrating elements that collaborate to deliver real-time monitoring, navigation assistance and emergency communication capabilities. Each component is meticulously interconnected to uphold the functionality of the helmet while prioritizing user convenience and safety.

- **Raspberry Pi 4B:** Acts as the central processor, managing data flow between sensors and communication modules.
- **Pulse Sensor & MCP3008 IC:** Monitors heart rate, converting analog signals into digital data for the Raspberry Pi. The MCP3008 converts this analog signal into a digital format that the Raspberry Pi can process, as the Raspberry Pi does not have an in-built ADC. This real-time data is crucial for monitoring the user's health and detecting potential emergencies.

- **Microphone and Speaker:** The microphone enables voice commands, while the speaker provides navigation instructions using text-to-speech (TTS).
- **SIM7600E Module:** Provides GPS data and 4G communication, enabling SOS messages with precise location information.
- **LCD Display and LED Indicators:** Displays real-time health data and provides visual feedback for GPS and SOS modes.
- **Power Supply:** Powered by a 5V/3A supply, ensuring stable operation.

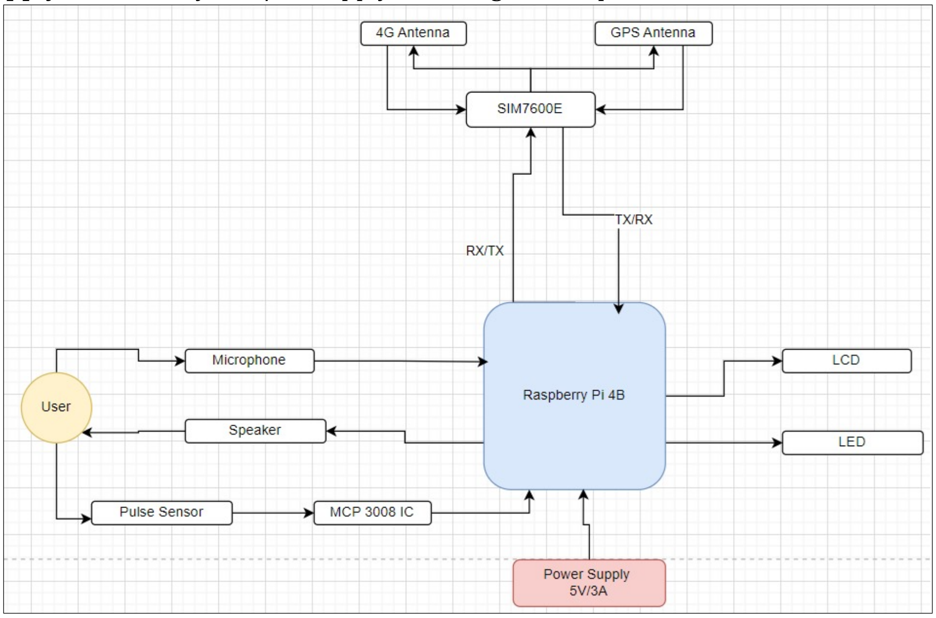

Figure 1 Hardware block diagram

2.3. Software Implementation

The software for the Robotic-Aided Helmet integrates technologies to ensure functionality in sensor data processing, voice commands, communication management, and real-time feedback. Key aspects include:

2.3.1. Python Environment Setup

- **Virtual Environment:** The isolated environment (vosk_porcupine_env) manages dependencies, preventing conflicts with the system Python. Key libraries include pvporcupine (wake word detection), pyaudio (audio stream handling), vosk (offline speech recognition), and googlemaps (navigation).

2.3.2. Wake Word Detection

- **Porcupine Library:** Handles real-time wake word detection with low latency for responsive interaction.
- **Sensitivity Adjustment:** Customizable to reduce false positives or missed detections based on the environment.

2.3.3. Audio Stream Management

- **PyAudio Integration:** Captures audio at 48 kHz for high-quality processing, and buffering input for the Porcupine engine.
- **Device Indexing:** Ensures the correct audio source, critical for external microphones.

2.3.4. Speech Recognition

- **Vosk Model:** Enables offline recognition, transcribing commands with high accuracy even without the internet.
- **Command Processing:** Handles complex inputs like navigation requests.

2.3.5. Google Maps API

- **API Integration:** Retrieves navigation directions using an authenticated client.

- **Route Calculation:** Converts directions into user-friendly TTS outputs. Includes error handling for ambiguous destinations or lost connections.

2.3.6. Text-to-Speech (TTS)

- **FLITE TTS Engine:** Lightweight and optimized for real-time speech synthesis with a natural voice.
- **Speech Synthesis:** Ensures clear, timely instructions critical for safe navigation.

2.3.7. Emergency SOS Functionality

- **Triggers:** Automatically activates on specific conditions (e.g., heart rate anomalies) or manually via a button.
- **SMS Messaging:** Sends GPS coordinates via SIM7600E to emergency contacts, ensuring precise assistance.

2.3.8. Systemd Automation

- **Service Configuration:** Starts the Python script on boot, maintaining active safety features.
- **Restart Policies:** Automatically restarts the service if interrupted, ensuring consistent operation.

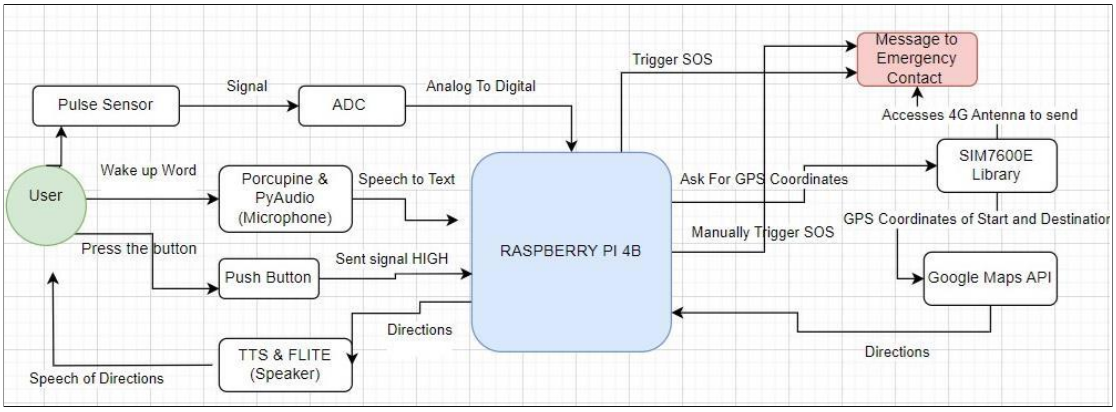

Figure 2 Software block diagram

- **MCP3008 IC with pulse sensor**: During the testing stages, the pulse sensor and MCP3008 IC together provide dependable heart rate monitoring. The sensor does detect the heart rate and as tested, it needs a particular amount of pressure to be added and about a minute or so

3. Results

The HRI Helmet project, was shown to have fulfilled its design objectives at the last testing stage. Important results comprised:

- **Health Monitoring**: The helmet's inbuilt pulse sensor was quite effective in monitoring the rider's heartbeats during the testing cycles. It could continuously track and update the heart rate information in real-time on the helmet's LCD screen. If the rider's heart rate strays outside the normal range in any case, the helmet would trigger visual alerts so that the rider is immediately warned about the impending health risks and an automated SOS message is sent to emergency contact. This was especially strong during cycling sessions, even with intensive exercise, therefore characterizing a system that is capable of health monitoring in real-time and with accurate readings.

Figure 3 Results of health monitoring

- **Navigation Support:** The integration of the Google Maps API ensured perfect and seamless navigation support. Field tests showed that the helmet provided turn-by-turn directions in real-time via the TTS, letting the rider keep his eyes on the road and not have to constantly look at a map or some other type of device. These directions were timely, clear, and dynamic according to the rider's current GPS location. This feature was very reliable, even in areas with a huge amount of road networks and ensured the rider could ride safely and efficiently. This functionality has been quite successful, which shows the effectiveness of the GPS module and the Google Maps API in providing correct and real-time navigation support.

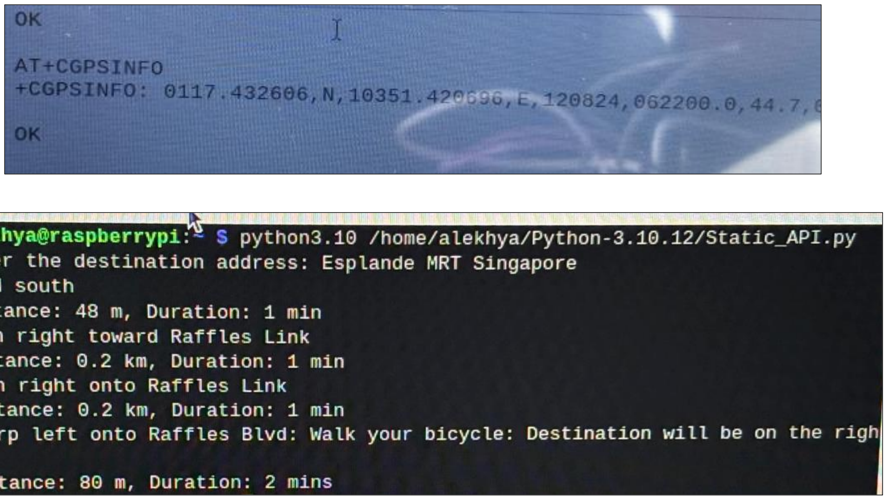

Figure 4 Results of Google Map API Navigation

- **SOS Emergency Communication:** This is a very critical safety feature on the helmet, so testing it involved SOS in manual and automatic modes. When the SOS button was pressed, it sent, on the spot, an emergency SMS containing GPS coordinates to pre-set the contacts of the rider. Abnormal heart rate readings, sudden impacts detected by the sensor, and the consequent automated SOS trigger all worked well to increase the overall level of safety. The reliability of the system was guaranteed where help could be quickly summoned and located with high accuracy through several scenarios that the SOS feature works on consistently.

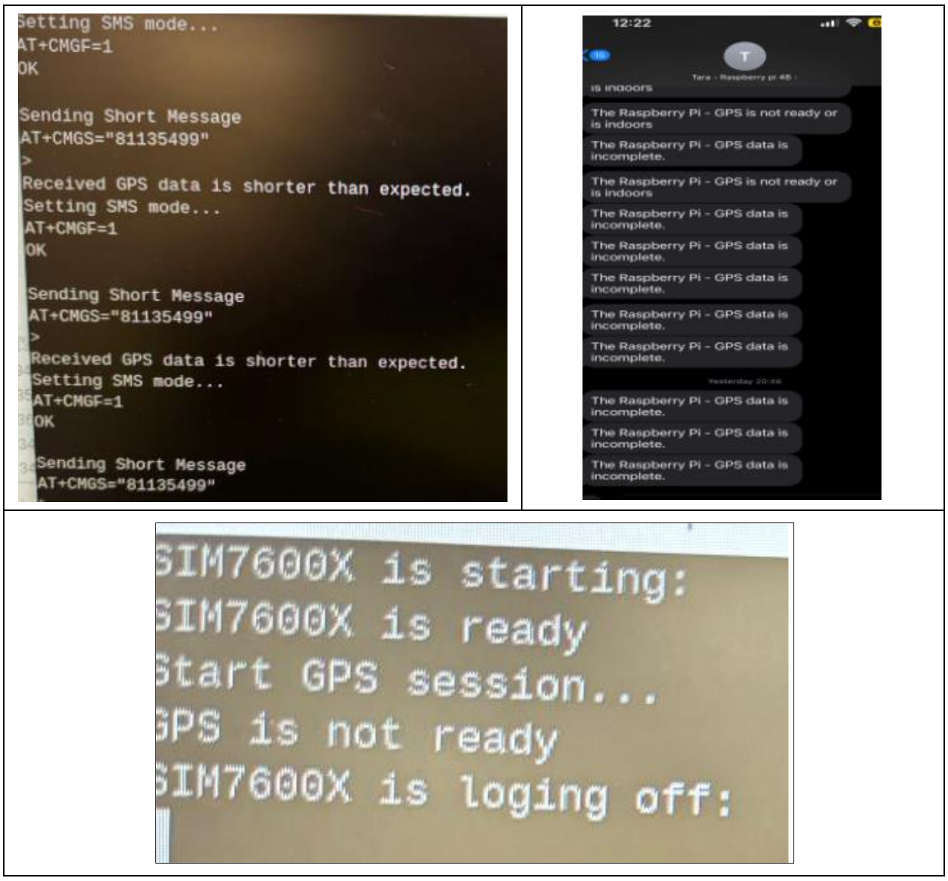

Figure 5 Results of SOS text

4. Discussions

The HRI Helmet, underwent multiple iterative phases in software development as well as hardware integration during development and deployment. The system's smooth operation was ensured by the careful selection and calibration of each component, guaranteeing that the helmet would fulfill its promise of improving bicycle safety.

4.1. Hardware Efficiency

MCP3008 IC with pulse sensor: During the testing stages, the pulse sensor and MCP3008 IC together provide dependable heart rate monitoring. The sensor does detect the heart rate and as tested, it needs a particular amount of pressure to be added and about a minute or so for the heart rate to get stabilized. However, it is not a very accurate sensor and a better sensor with higher touch sensitivity and accuracy reading the pulse would be better.

SIM7600E Module: The SIM7600E module handled 4G connectivity and acquired GPS data with reliability and consistency. The GPS fix time was within reasonable bounds, and the SOS feature functioned as planned, providing emergency contacts with precise position information when tested outdoors, and indoor the SOS message sent would indicate that the helmet was either indoors or in a place where the GPS data could not be retrieved completely.

4.2. Performance of Software

- **Speech Recognition and Wake Word Detection:** Even in loud settings, the porcupine-based wake word detection system functioned well, achieving a high detection rate. Although the Vosk model 15, was not precise hence the detection of words is not exact and might have to use a bit of a British accent to catch a few words, as well as a few places in Singapore such as “Jurong East” it would detect as “Jerome East”. Using a better Vosk model could help resolve the accuracy, however as it was taking more than 24 hours to download the Vosk 22, I was not able to test it.
- **Integration of the Google Maps API:** With success, the Google Maps API delivered precise and comprehensive navigational guidance. The seamless integration of TTS translated written instructions into intelligible speech,

which was essential for hands-free navigation. I had to trial and test a few software to get a normal human voice and not a robotic voice, hence I chose Flite to go along with the TTS.

- **Emergency SOS Functionality:** There was a lot of trial and error while doing the SOS call. I had to install a library "pyserial" for the SOS calling to access the serial port of the SIM7600E module. It would take 20 seconds to start up the module, retrieve the GPS Coordinates, and keep blinking the LED as an indication of starting up. We can manually push the button to message in case of emergency, and at the same time it would automatically send SOS if the heart rate dropped below a certain rate. In both scenarios, the LED would light indicating that an SOS message has been sent. However, this might not be apt due to the current pulse sensor's lower accuracy.

5. Further Developments

The HRI Helmet project, has established a strong foundation for improving bike safety by incorporating cutting-edge technologies. However, the difficulties encountered in the latter stages of development—especially with the voice recognition and SOS features make it clear where further work and refinement are needed. This section describes the possible directions for future research and development to solve the problems found and add new features that could improve the helmet's functionality even more**.**

5.1. Transition to Legacy Bootware

Considering frequent failures of the current Debian-based bootware in the field of serial port permissions and especially microphone configuration, moving to a legacy bootware version is critical for further development. Certain legacy bootware versions are generally much more reliable and have fewer compatibility problems. This reduces the possibility of defects, including the sampling rate mismatch of the microphone and the inconsistent permissions of the serial port. These issues shall be corrected by booting the system configuration with legacy bootware so that both speech recognitionand SOS will work reliably at boot and under real-time usage.

5.2. Improved Voice Recognition and Command System

The Vosk15 model, which was initially used in the project for voice recognition, was functional but lacked the accuracy required for reliable performance, especially in loud conditions. Upgrading to the Vosk22 model, which provides better accuracy and handling of a variety of speech patterns, should be investigated in future development. Moreover, the incorporation of efficient voice recognition models—like those driven by deep learning—will dramatically improve the system's accuracy in interpreting commands under different environments. This, together with the transition into the stable environment of bootware, ensures a much more reliable and intuitive voice command system.

5.3. Enhanced Emergency Communication System

Future iterations of the helmet could include an automated event detection system that would automatically broadcast the SOS signal, an extension of the current SOS capabilities. This could be accomplished by enhancing the number of sensors within the system to include a gyroscope or accelerometer to identify unusual motion patterns or loud hits that might be characteristic of an accident. It could also involve real-time connection to emergency services, such that one's position could be continuously tracked along with status updates until assistance does arrive. This could also add another emergency contact for the ambulance in case of a fall and low oxygen detection

5.4. Integration of Environmental Monitoring Sensors

Other possible innovations that might fit perfectly into the helmet's safety theme are environmental monitoring sensors. These could detect hazardous situations like poor air quality, very high or low temperatures, and highly intensive UV radiation. For example, a gas sensor may warn the cyclist of high carbon monoxide levels during cycling in places with high traffic, and a UV sensor may alert them to dangerously high UV exposure. By using the helmet's TTS system to communicate these alerts, the cyclist will always know potential environmental hazards.

5.5. User Data Logging and Analysis

A data logging facility, logging ride statistics, health, and ambient factors in every riding session, would be an invaluable add-on to the helmet. Having the ability to upload the data to a cloud service or store it locally on the helmet, users can quantify, over time, their exposure to environmental threats, track their riding habits, and monitor health trends. This will be very helpful to serious riders who try to optimize their safety and performance.

6. Conclusion

The helmet has packed emergency communication, navigation support, and real-time health monitoring into one device to enhance bicycle safety. State-of-the-art technologies like the SIM7600E module, the Raspberry Pi 4B, and sophisticated software parts have been used to form an all-inclusive safety solution that meets the requirements of the modern rider. Checks were done on the hardware parts and integrated throughout the development process to ensure reliability. Under a variety of circumstances, the pulse sensor, GPS module, and other hardware parts functioned admirably, giving the system precise and timely data.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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