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Wearable solution for health monitoring of car drivers

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Abstract

The need for creative solutions in real-time health monitoring has been highlighted by the rise in health-related incidents involving drivers of motor vehicles. It has led to the development of wearable technology that seamlessly integrates with the Internet of Medical Things (IoMT) to improve driver safety and healthcare responsiveness. The development of a revolutionary wearable technology system is presented in this study as an innovative approach to vehicle safety and healthcare. This system's real-time ability to track a driver's health is a significant development in guaranteeing driver safety and wellness. The study examines the hardware component's complex design and implementation, particularly concerning the printed circuit board (PCB) layout and electrical schematic. The gadget emphasizes wearability, robustness, affordability, and user-friendliness and is a shining example of valuable and effective medical technology. The research delves deeper into possible improvements for the system, like adding complex algorithms and a user-friendly interface. Enhancing user involvement and system intelligence hopes to maximize the system's potential for real-time health monitoring. The significance of this study in utilizing Internet of Medical Things (IoMT) technology is highlighted by its junction with multiple fields, including electronics, hardware engineering, human-computer interaction, and health informatics. This dissertation emphasizes the potential of wearable technology in bridging the gap between healthcare monitoring and vehicle safety by focusing on real-time health monitoring in the automotive context.

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1. Introduction

Nowadays, we frequently rely on various types of appliances or gadgets, such as computers, copy machines, mobile phones, microwave ovens, refrigerators, air conditioning and television remotes, smoke detectors, infrared (IR) thermometers, turning on and off lamps, and fans, which help us interact with the physical environment. Many of these applications perform their task with the help of sensors [1]. For example, driving healthcare monitoring with IoT and wearable devices is an application that uses medical sensors to measure the driver's data during driving. The application calculates the data in real-time and performs different tasks to assist the driver's well-being, such as providing and displaying data to a health professional and performing decision-making employing artificial intelligence. Internet-of-Things (IoT)-assisted wearable sensor systems are becoming pivotal in healthcare applications, as they can connect information from different sectors into one application through innovative technologies [2].

The basic layout of a Healthcare Monitoring System (HMS) is a sensor (or sensors) that, most of the time, is wearable [3]. A sensor is a device or module that aids in detecting changes in physical quantities, such as pressure, heat, humidity, movement, force, and an electrical quantity like current, thereby converting these to signals that can be detected and analyzed [1,4]. The sensor is the heart of the measurement system. The sensor's data are sent to the cloud via a communication protocol like Zigbee, Bluetooth, Wi-Fi, or others [5]. These data are then transmitted via a communication layer to the data center for further processing. For emergency awareness, the same data is visible in real time to the doctor, patient, and the patient's caretakers.

IoT wearable devices have increased drastically over the years, not only in healthcare but in many other verticals. The combined use of hardware, electronics, and software programs makes improving and achieving many results for a patient's healthcare possible. Undoubtedly, these devices are already part of people's lives. For instance, a fitness tracker can monitor a person's pulse, movements, sleep schedule, etc. When the person adds valuable information to the device, such as its weight, height, and age, it is possible to calculate metrics such as the number of calories they have burnt, the altitude of the highest points they have been to, or the number of stairs they have climbed or descend. Some of the most common IoT applications in healthcare are activity recognition, stroke rehabilitation, blood glucose monitoring, cardiac monitoring, respiration monitoring, sleep monitoring, blood pressure monitoring, stress monitoring, Alzheimer's Disease monitoring, cancer patient monitoring, and medical adherence.

The technology used in Internet of Medical Things (IoMT) applications differs significantly from one application to another, depending on what the application requires. Over the years, several IoMT projects have been tested and built for different scenarios. One of these scenarios is the automative industry, where is shifting toward a networked system that provides remote monitoring and control of numerous vehicle parameters. Therefore, preventing traffic accidents – which remains a leading cause of death and serious injury – is a crucial solution to minimize fatalities and morbidity associated with with traffic-related incidents [6].

For hardware aspect of the IoMT applications, there are many components available and of different categories. On the other hand, the panorama is like software and revolves around functionalities related to saving and charting data. Sensors such as the Passive Infrared (PIR) sensor, Electrocardiogram (ECG), Radio-Frequency Identification (RFID), and Blood Pressure (BP) sensor are some of the many used in several prototypes [7–9].

Moreover, microcontrollers are an essential part of these projects. Some examples are the Raspberry Pi, Arduino, STM32 Microcontroller, ARM7, Intel Galileo, and other [10–15]. For instance, in [9], a blood monitoring study was designed to use an Electromyography (EMG) sensor to measure the changes and disbalance between the neurons and muscles, and the data were shown on the Liquid Crystal Display (LCD). A heartbeat monitoring application uses An ECG sensor to measure and graphically represent the heart's electrical activity. It is used in most healthcare systems to detect heart conditions and helps identify chest pain and other common symptoms. The research in [16] deals with anomaly detection in the ECG readings taken, using filters, and calculating the energy variances.

In terms of comfort and safety of the user, a wearable device, e.g., a sensor, should be comfortable enough so that the person wearing it can use it throughout the day. Hence, the device should be lightweight, ergonomic, water-resistant, skin-friendly, and durable. Besides, safety should be a priority in wearable sensor development. Together with the devices, sensors should be safe to wear. Wearing them should neither have any side effects nor be harmful to the body in the long term.

Considering such technologies, this paper proposes the creation of the Driver Health Tracker, an IoMT wearable device that can track several aspects of driver health in real-time. The device offers a viable way to improve road safety, demonstrated by the capacity of notifying medical professionals and drivers about any health problems that could impair driving ability, which is achieved by continually monitoring vital signs and sending data to a mobile application. This real-time monitoring could contribute to the development of a more responsible and safe driving environment by preventing accidents that could be caused by a driver's health problems. Essentially, this project aims to address the fundamental obstacles preventing the smooth integration and broad acceptance of IoMT technologies in addition to attempting to innovate through real-time driver health monitoring. The Driver Health wearable system seeks to improve and mature IoMT in the healthcare industry while tackling these obstacles head-on and building a solid foundation for improving road safety.

2. Methodology

2.1. Study participants

Portugal registered 110,559 new drivers in 2022, a 35% increase over the previous year. In the previous 12 years, this is the fourth-highest annual total. According to this reference, the number of drivers who now operate in Covilhã defines the population to be researched dynamically, and a large enough sample size should be available to produce results with a 95% confidence level. The subjects to be studied, who must be of the same age and gender, will actively cooperate in the recruitment process. Depending on the number of drivers based in Covilhã, the sampling strategy specified will be used. This study opted for direct contact with the individuals, given that data collection is not always easy, either because the respondents are unavailable or because poor-quality information is obtained.

2.2. Materials

The backbone of any electronic device is its electronic components. These components perform various tasks, including signal amplification, power switching, and data storage. The choice of electronic parts profoundly influences the device's performance and functionality. The standards and specifications of these components play a crucial role in determining how well the device operates. Additionally, these components impact the device's dimensions, weight, and cost.

In the Driver Health project context, selecting the right components is a critical step. To achieve this, an in-depth investigation was conducted to identify the optimal components for the application's wearable device. Parameters such as comfort, wearability, size, cost, and functionality were selected.

The first component is an nRF52832-QFAA microcontroller, a versatile Bluetooth 5.4 system-on-chip (SoC) supporting Bluetooth Low Energy, Bluetooth mesh, and NFC. An all-purpose, multiprotocol SoC is the nRF52832. It overcomes the difficulties presented by a wide range of applications that demand advanced Bluetooth® LE features, protocol concurrency, and a large and varied assortment of peripherals and functions. Additionally, it provides RAM and Flash memory. The MCU supports full protocol concurrency and is multiprotocol capable. The advanced 2 Mbps Bluetooth Low Energy functionality is supported.

Additionally, ANT and 2.4 GHz proprietary protocols are also supported. It is constructed on an Arm Cortex-M4 CPU with a 64 MHz floating point unit. It has numerous digital peripherals and interfaces, such as PDM and I2S, for digital microphones and audio.

Next, a MAX17260SETD+ chip as an ultra-low power fuel gauge integrated circuit (IC) can be used to implement the Maxim ModelGauge™ m5 algorithm. The IC monitors a single-cell battery pack and supports high- and low-side current sensing. The IC provides precision measurements of current, voltage, and temperature. The battery pack's temperature is measured using an internal temperature sensor or external thermistor. A 2-wire I2C interface provides access to data and control registers.

Furthermore, the WS2812B-2020 RGB LED was selected, featuring a 12mA operating current per channel, a built-in electric reset circuit and power lost reset circuit, a cascading port transmission signal by a single line, and a data speed of 800Kbps. The control circuit and RGB chip are integrated into a package of 2020 components to form a complete addressable pixel. Its internal includes an intelligent digital port data latch and signal reshaping amplification drive circuit, a precision internal oscillator, and a voltage programmable constant current control part, ensuring the pixel point light color height consistency.

The following used component is the LIS2DW12 chip, which is an ultra-low-power, high-performance three-axis linear accelerometer. The LIS2DW12 can measure accelerations at output data rates ranging from 1.6 Hz to 1600 Hz and has user-selectable complete scales of 2g/4g/8g/16g. The 32-level first-in, first-out (FIFO) buffer on the LIS2DW12 enables users to store data and limit host processor involvement. Thanks to the incorporated self-test feature, the user can examine the sensor's performance in the intended application. The LIS2DW12 includes an internal engine that is specifically designed to handle motion and acceleration detection, including free-fall, awakening, highly adjustable single-tap and double-tap identification, activity/inactivity, stationary/motion detection, portrait/landscape detection, and 6D/4D orientation.

The BH1790GLC optical sensor is essential for the project since it is an IC heart rate monitor with an LED driver and a photodiode for green light detection. The sensor acts as a photoplethysmogram (PPG) sensor and provides the intensity of light reflected from the body, which also powers LEDs. LED driver current and light emission duration both affect LED brightness.

Accurate pulse wave detection is made possible by photodiodes with great sensitivity to green light, excellent wavelength discrimination, and excellent cut (a filter that passes visible light and blocks infrared light) characteristics. The BH1790GLC optical sensor uses two LXZ1-PM01 power single-color green LEDs.

A BMP581 barometric pressure sensor with excellent accuracy was also selected for the device. The 24-bit absolute barometric pressure sensor has low power and noise and a substantially smaller footprint than earlier generations. It offers exceptional design flexibility and a complete package.

An AT24C512C-XHM-T chip that provides 524,288 bits of serial electrically erasable and programmable read-only memory (EEPROM) is crucial for the Driver Health device. The device's cascadable functionality enables up to eight devices to share a common 2-wire bus. The gadget is designed with various industrial and business applications in mind, where low-power and low-voltage operations are crucial.

The MCP73831T-2ACI_OT linear charge management controller is necessary for power control. It is designed for use in portable applications with few external components required. The MCP73831T-2ACI_OT adheres to all the specifications governing the USB power bus for applications charging from a USB port.

Finally, an STLQ015 chip is used to complement the power section of the device. It is a 150 mA, ultra-low quiescent current linear voltage regulator from STMicroelectronics. It is designed to provide a stable output voltage from an input voltage higher or lower than the output voltage.

2.3. Study protocol

The experimental protocol will consider the sensors above with regular daily measurements. The expected duration of the study is 2 years, and the experimental phase will be carried out at 2 different times, comprising the following procedures:

1. Initial inquiry to the individual about personal data and state of health;
2. Carrying out the test on a specific group of chosen individuals (moment 1);
3. Analyzing the data collected;
4. Validation of the findings by carrying out new experiments on the same individuals (moment 2).

2.4. Statistical analysis

The survey answers will be organized in a database for subsequent statistical treatment using SPSS software. The qualitative survey results will be transformed into numerical data (coded) for possible statistical treatment. In the first phase, frequency tables and graphs will be produced to characterize the drivers' data and detect possible data entry errors. In the next phase, hypothesis tests will be carried out for qualitative variables to evaluate the use of the device and the mobile application.

3. Proposed Solution

3.1. System Architecture

The primary purpose of the Driver Health project is to deliver a comfortable, high-performance, and easy-to-use device that integrates an intelligent and user-friendly mobile application with features that help users monitor their health and improve their well-being. To achieve an application of this sort, based on the Driving healthcare monitoring with IoT and wearable devices: A Systematic Review, the available sensors and connectivity technologies were examined to identify the best options for the Driver Health device. For instance, an ECG sensor is crucial to monitor the user’s heart rate in a precise way. However, this component requires complex wearability and is unsuitable for such a small and compact device as the Driver Health. The same applies to an electroencephalogram (EEG) sensor, which could be beneficial to monitor stress and mental well-being but could also apply challenging portability.

A GPS sensor would be a valuable feature to include in the device since it contributes to data processing and analysis of the user’s well-being in multiple ways. Still, such a sensor requires significant energy, which is not sensible for a low-powered device. For connectivity, the device could also integrate 5G technology. Nonetheless, this would require a sizable component and demand considerable space for incorporation. Finally, an LCD, a frequently used component in portable devices to display data in real-time, was evaluated for the user interface. Still, using the mobile application as the primary user-interface method is more favorable due to energy efficiency and practicability. By carefully considering the options, the selected sensors and connectivity technologies were considered the best for the Driver Health device to achieve its primary purpose of being a valuable tool for users who want to monitor their health and improve their well-being.

The system is a unique IoMT wearable because of its small size, effective data processing, and easily accessible architecture. Each layer, illustrated in Figure 1, plays a distinct role in data collection, transmission, and processing, seamlessly interacting to ensure optimal system performance. This innovative device increases the standards for IoMT technology by providing consumers with real-time health data and enabling rapid interaction with medical professionals.

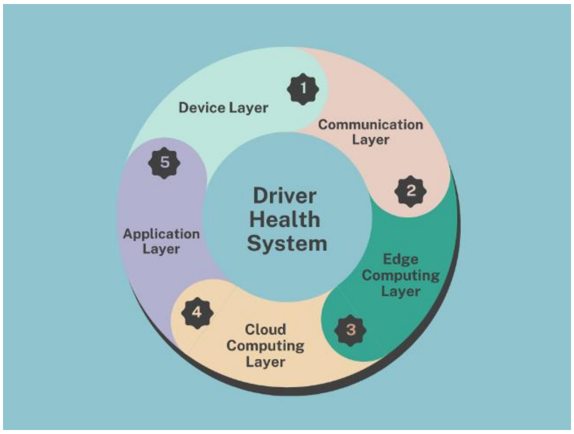


Fig. 1. Architecture representing the different layers of the system.

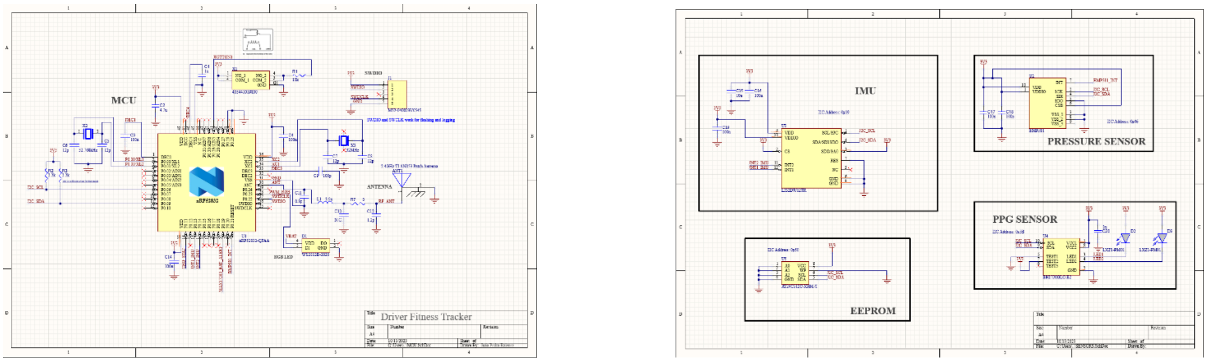
The device layer consists of the physical device that performs the data collection operation from the many sensors integrated into its design. In this layer, the wearable device, attached to the driver's wrist or arm, gathers health data, such as heart rate, blood pressure, barometric pressure, and device orientation, and sends it over via the BLE. The communication layer integrates the BLE technology to transmit data between the device and the smartphone. The smartphone connects with the device and is a gateway to transmit the data to the cloud server. It can also provide security features, such as encryption and authentication, to protect the data in transit. The edge computing layer is very close to the raw data and performs the primary data processing before the data is sent to the cloud. It performs critical operations, such as filtering and aggregating, to improve the system performance and eliminate inapplicable data. The cloud computing layer handles and stores the collected data in a cloud server. In this layer, the data is stored in the database. The AI models analyze and process the data to generate alerts for potential health problems and transmit the data to medical personnel. Ultimately, the application layer is the closest to the user's experience, i.e., the highest level of the system architecture. This layer provides the user interface and functionality of the system. The mobile application represents it. The user can interact with the device through this interface and visualize the data in real-time. The application layer can also produce notifications regarding the driver's vital signs, contacting the user's healthcare professionals directly and ensuring the security and privacy of the driver's data.

3.2. Electrical Schematic

The electrical schematic of the Driver Health device was precisely designed using Altium Designer, a robust EDA software that empowers electronic engineers to easily navigate the complexity of circuit design. The extensive collection of electronic components in Altium Designer, together with its user-friendly routing and placement capabilities, made it easier to create the design accurately and efficiently.

The electrical schematic design process involved a thorough investigation of the components employed in the project, ensuring their compatibility with the device's functionality. The result of this thorough research was the creation of the schematic for the microcontroller (MCU), which is shown in Figure 2(a).

It was also important to carefully choose the sensors that interface with the microcontroller. The sensor connection is presented in Figure 2(b).



(a) (b)

Fig. 2. Electrical schematic of the (a) microcontroller section of the electrical schematic consists of the MCU connection with the button, RGB LED, antenna, and serial wire debug header and (b) sensor section of the electrical schematic consists of the IMU, pressure sensor, EEPROM, and optical sensor connection.

Additionally, the device is powered by a small-sized battery that is integrated with a Battery Management System (BMS) and a Low-Dropout (LDO) regulator to safely operate the voltage delivered to the low-power components, i.e., the microcontroller, the sensors, and the BMS. This section is presented in Figure 3.

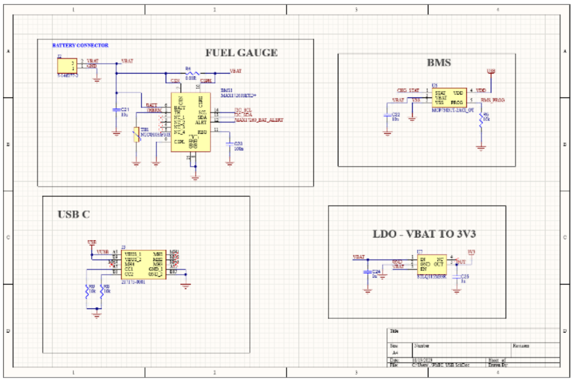


Fig. 3. Power section of the electrical schematic related to the USB C connection, the interface between the different components for battery management and voltage conversion.

That way, the project is divided into 3 parts:

- MCU: The microcontroller used for this project is the NRF52832, which is responsible for interfacing with the other devices by an I2C protocol communication and can provide information wirelessly through Bluetooth Low-Energy. A button is connected to the MCU, and its purpose is for user interface. The MCU takes care of driving an RGB LED using its internal TIMER. A nRF52 DK is a device responsible for flashing the code to the MCU and debugging it. The Serial Wire Debug (SWD) headers communicate between the nRF52 DK and the MCU. A PCB antenna is manufactured onto the board for the BLE functionality to provide a stable radio frequency (RF) performance.
- Sensors: The sensors in this project provide necessary measurements for the user. The LIS2DW12TR inertial measurement unit (IMU) can measure movement and rotation in 6 degrees. The BMP581 offers barometric pressure information. The BH1790GLC is an optical sensor for heart rate monitors. Additionally, the AT24C512C-XHM-T stores the sensor data.
- Power: the device will be powered by a 250mAh Li-Po battery (the device's current consumption is estimated at around 150mAh). A fuel gauge IC is connected to the battery to provide fast and accurate power information, i.e., state of charge and temperature. A BMS chip is connected to the fuel gauge, which manages the battery power performance and controls the USB charging parameters. A USB-C offers the functionality of providing power to the battery. As the device

integrates low-power components, it is also necessary to lower the power voltage from the battery (3.7 V) and from the USB (5V) to 3.3 V. By that, the STLQ015M33R LDO is needed.

3.3. PCB Design

A Printed Circuit Board (PCB) was chosen for the Driver Health project due to its ability to miniaturize electronic circuits, an important consideration for wearable technology that needs to be both lightweight and easy to wear, hence its final dimensions are 31 mm length, 26.94 mm width and 10 mm height. The electrical schematic designed for this project was essential for designing and building the device's PCB. The PCB was created using the Altium Designer, which made it possible to interconnect the electrical schematic and PCB. The PCB integrates every component of the electrical schematic and provides a reliable and permanent connection.

Figure 4 displays the project's board, which utilizes a 4-layer construction to optimize signal integrity. The first and top layer is the signal layer and it primarily carries the electrical signals between various components on the PCB. It is designed with carefully controlled trace widths and spacing to minimize signal distortion and crosstalk, ensuring the integrity of the transmitted data. The second layer integrates the power layer, which is the responsible for providing a dedicated path for delivering power to the device's components. The third layer represents the ground layer that serves as a reference potential for all signals on the PCB, since it acts as a sink for electrical noise, preventing it from interfering with the sensitive signal paths. Finally, the last and bottom layer is the reference ground layer and return path. The fourth layer, specifically designed for RF applications, serves as a reference ground plane for the RF circuitry and provides a return path for RF currents. This dedicated RF ground layer isolates the RF signals from the power and signal layers, minimizing noise coupling and ensuring optimal RF performance.

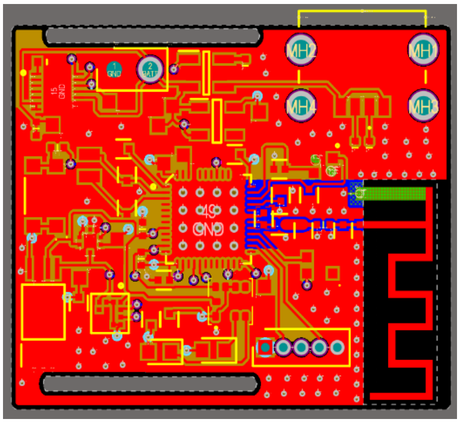


Fig. 4. PCB Top layer in focus with the components and antenna placed.

4. Discussion and Conclusions

This paper presented a wearable healthcare monitoring application for drivers to monitor their health while driving. The device, consisting of an MCU, health sensors, a memory chip, a battery, a button, and a fuel gauge, connects to a smartphone via Bluetooth Low Energy. The mobile application displays vital signs in real time, generates alerts for health problems, and transmits data to medical personnel. The device uses low-power components and software algorithms to ensure reliability and longevity.

The schematic offers simple and efficient guidance to how the components are connected. A printed circuit board was also created based on the connections of the components of the electrical schematic. The PCB efficiently integrates all the components in a small board without long cables and circuitry complexity. That way, the device can measure the driver's health conditions and the environment at a fast and reliable speed. The measurements are provided to the user and healthcare professionals in real time.

Future work related to data acquisition and user-interface (UI) features, where the device can gather data from the different sensors efficiently and consistently using artificial intelligence algorithm. The smart algorithm ensures data accuracy for the driver safety by implementing Convolutional Neural Networks model for PPG heart rate estimation. A user-interface interaction consisting of a mobile application will be developed to display the essential data and additional information about the driver's health condition.

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