摘要

具有医疗保健的物联网 (IoT) 为医疗物联网 (IoMT) 的实施提供了有希望的支持，通过实时生命体征监测和早期发现患者的异常健康状况，提供了许多潜在降低生命风险因素的应用司机。每天，车辆和道路事故的数量都在快速增加。每年约有 1.3% 的车祸是由于医疗状况造成的。因此，有机会通过在车内放置生物识别传感器进行实时生命体征监测来预防此类事故，以避免与健康相关的事故，并有可能针对可能导致车祸和快速紧急情况的异常健康状况寻求警告在可能降低生命危险因素的医疗紧急情况下发出警报。本论文设计并开发了一种基于物联网（IoT）的非侵入式驾驶员健康监测系统，用于对驾驶员健康状况进行生物监测，以提高道路安全并密切观察驾驶员监测心电图（ECG）等重要生命体征。 、氧饱和度水平、心率和体温来检测异常健康状况，例如心动过缓、心动过速、心律失常、缺氧和体温过高，这是医疗保健监测系统中的重要现象。拟议的驾驶员健康监测系统（DHMS）由三个主要部分组成； (i) 硬件和移动应用程序的设计和实施 (ii) 物联网基础设施实施和 (iii) 实验。

(i) 为开发该设备，使用带有多路复用器 (ADS1115) 和生物传感器 (AD8232、MAX30102、心脏传感器、LM35) 的商用 Raspberry pi 4 开发套件来读取生命体征司机。该移动应用软件旨在验证用户身份，从云托管的实时数据库中获取实时生命体征数据，根据医疗标准阈值显示健康状态，以及使用 GPS 和警报系统触发紧急/警报警告 GSM 技术适用于护理人员和医生。该应用程序允许驾驶员和医生远程可视化交互式移动应用程序上的健康状况。所提出系统的整体处理设计为 6 层架构；从传感器层开始，依次是信号处理层、建模分析层、网络通信层、存储层、应用层。

(ii) 使用云托管的实时数据库实施物联网架构，以实现对生命体征的远程实时监测。医生可以在其中远程添加驾驶员并可视化驾驶员的生命体征。 Firebase 已配置并与 DHMS 设备和 Android 应用程序链接，以在云数据库上提供实时数据处理、用户身份验证和媒体存储。

(iii) 实验；通过与医疗标准设备的比较分析对所提出的系统的结果进行了评估，并发现了令人满意的结果。与之前显示噪声 ECG 信号的研究工作相比，DHMS 设备上用于 ECG 信号处理的信号处理提供了最佳质量的信号。所实现的滤波器和算法具有收敛速度快、计算速度快的优点。使用所提出的系统获得的来自各种受试者的实验结果具有相当大的潜力来检测异常和严重的健康状态以触发警告/警报。此外，警报系统分为自动和手动警报系统，通过编译包括生命体征值、紧急消息和位置的紧急短信来触发警告（避免驾驶）和紧急警报，以发送给看护人和医生以立即采取行动在基于医疗标准阈值的医疗紧急情况下。为避免错误的严重警报，通过语音命令进行确认。如果驾驶员通过语音提示回答“是”，这将在预设的计时器内触发紧急警报，或者通过按下应用程序上的紧急按钮确认警报触发。

因此，所提出的系统对于加强道路安全和早期紧急响应以寻求医疗救助以及避免可能导致事故的驾驶的警告系统将具有重要意义。

关键词：物联网，生命体征，HIoT（医疗物联网）， 医疗物联网 (IoMT)，道路交通安全，身体互联网（IoB），驾驶员监测、健康监测、ECG/EKG、氧饱和度、心率.

Abstract

Internet of things (IoT) with healthcare provides promising support in the implementation of the Internet of Medical Things(IoMT), offering many applications that potentially reduce life risk factors through real-time vital signs monitoring and early detection of an abnormal health condition of the driver. Day by day the number of vehicles and road accidents is increasing at a rapid rate. Approximately 1.3% of car crashes are due to medical conditions per year. Therefore, an opportunity exists to prevent such accidents by placing biometric sensors in the car for real-time vital signs monitoring to avoid health-related accidents and the possibility of seeking warnings for an abnormal health condition that might lead to a car crash and quick emergency alert in case of a medical emergency that potentially reduces life risk factors. This dissertation designed and developed a non-invasive driver health monitoring system based on the Internet of Things (IoT) for biomonitoring of driver health status to enhance road safety and keeping a driver in close observation for monitoring important vital signs such as Electrocardiogram (ECG), oxygen saturation level, heart rate, and body temperature to detect abnormal health condition such as bradycardia, tachycardia, arrhythmia, hypoxia, and hyperthermia, that is a significant phenomenon in the healthcare monitoring system. The proposed Driver Health Monitoring System (DHMS) consists of three main parts; (i) Design and implementation of hardware and mobile application (ii) IoT infrastructure implementation and (iii) Experimentation.

(i) To develop the device, a commercial-off-the-shelf development kit of Raspberry pi 4 with a multiplexer (ADS1115), and biosensors (AD8232, MAX30102, Heart sensor, LM35), were used to read the vital signs of the driver. The mobile application software is designed to authenticate users, fetch real-time vital sign data from the cloud-hosted real-time database, show health status based on medical standard threshold values, and an alert system to trigger emergency/alert warning using GPS and GSM technology to care takers and doctor. The application allows both driver and doctor to visualize health status on interactive mobile applications remotely. The overall processing of the proposed system is designed in 6 layers architecture; starting from the sensor layer, followed by the signal processing layer, modeling and analysis layer, network communication layer, storage layer, and application layer. (ii) Internet of Things architecture is implemented for long-range real-time monitoring of vital signs using a cloud-hosted real-time database. Where doctors can add drivers and visualize the vital signs of drivers remotely. Firebase is configured and linked with both DHMS devices and android applications to provide real-time data processing, user authentication, and media storage on a cloud database. (iii) Experimentation; Results of the proposed system are evaluated by comparative analysis with medical standard devices and found satisfactory results. Signal processing at DHMS device for ECG signal processing gives the best quality signal as compared to previous research work that shows noisy ECG signals. The implemented filter and algorithm have the advantages of fast convergence and high computing speed. The experimental results from a variety of subjects obtained using the proposed system have considerable potential to detect abnormal and critical health statuses to trigger warnings/alerts. Moreover, the alert system is categorized into automated and manual alert system that triggers warning(to avoid driving) and emergency alert by compiling emergency SMS that includes vital

sign values, emergency message, and location to send to the caretakers and doctor for taking immediate action in case of a medical emergency based on medical standard threshold values. To avoid a false critical alert, there is confirmation through voice command. If the driver replies "yes" via voice prompt which will trigger an emergency alert within pre-set timer or by pressing the emergency button on the application that confirms the alert to trigger.

Hence, the proposed system will be having great significance to enhance road safety and early emergency response to seek medical attention and a warning system to avoid driving that may lead to an accident.

Keywords: IoT, Vital Signs, HIoT (Healthcare IoT), Internet of Medical Things (IoMT), Road Safety, Internet of Bodies (IoB), Driver Monitoring, Health Monitoring, ECG/EKG, Oxygen Saturation, Heart Rate

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Abbreviations

DHMS: Driver Health Monitoring System

IoT: Internet of Thing

HIoT: Healthcare Internet of Thing

IoMT: Internet of Medical Things

IoB: Internet of Bodies

ECG/EKG: Electrocardiogram

BPM: Beats Per Minute

CVDs: Cardiovascular Diseases

GPS: Global Positioning System

SMS: Short Message Service

WHO: World Health Organisation

ICT: Information Communication Technology

AI: Artificial Intelligence

BD: Big Data

ML: Machine Learning

DL: Deep Learning

PPG: Photoplethysmograph

LCD: Liquid Crystal Display

TCP/IP: Transmission Control Protocol/Internet Protocol

IEEE: Institute of Electrical and Electronics Engineers

GPIO: General-Purpose Input/ Output

URL: Uniform Resource Locator

IDE: Integrated Development Environment

Chapter 1 Introduction

Advancement in technology brings enormous opportunities to the health care system in the modern hectic world. The healthcare we are experiencing today will be completely changed by tomorrow. An enhanced healthcare system with cutting-edge technologies such as the Internet of things (IoT), big data analysis, machine learning, wireless sensing, cloud computing, and mobile computing has improved the accessibility of healthcare facilities [1]. IoT creates huge opportunities as the physical world is transformed into a hyper-connected world. This transformation results in a reduction of human participation, and improve efficiency along with economic benefit, accessibility, and accuracy. According to the World health organization (WHO), it has been estimated that the heart disease rate might increase to 23.3% worldwide by the year 2030. An estimated 17.9 million people died from CVDs in 2019. Out of these deaths, 85% were due to heart attack and stroke[2], [3] People with cardiovascular disease need early detection and management using counseling, medicines, and lifestyle changes to overcome the potential risk. Detection, screening, and treatment of NCDs, as well as palliative care, are key components of the response to NCDs [4].

Day by day the number of vehicles is increasing at a rapid rate. According to a study done by the Harvard Health Watch, an average American spends 101 minutes per day driving [5]. The rate of accidents is exponentially increasing as shown in Table 1.1 [6]. Road accidents might cause due to many factors like rash driving, drowsiness, drug intake, a lack of attention, health, stress, etc. Approximately 1.3% of car crashes are due to medical conditions per year [7] an opportunity exists to prevent such accidents by placing biometric sensors in the car to increase the possibility of seeking help before a car crash if possible. There is some health monitoring system to monitor patients at home and in hospital but we are lacking to have a sophisticated healthcare system to monitor driver health as a road safety measure to avoid road accidents. Industry 4.0 and its main enabling information and communication technologies are completely changing both services and production worlds [8]. Internet of Things (IoT) is the backbone of Industry 4.0 It has the potential to revolutionize the healthcare sector. As, telemedicine, personalized healthcare, disease monitoring, patient tracking, medical record management, medication intake management, and wearable devices, are a few examples.

Table 1.1 Road Traffic Accidents Review 2018

Country	Deaths	Percentage	World Rank
Pakistan	30,046	2.42	95
China	284,986	2.91	89
India	299,091	3.39	60
United Kingdom	1,805	0.36	179
United State	38,203	1.59	120

1.1 Healthcare Evolution

Healthcare 4.0 is also known as hospital 4.0 [9] Healthcare 4.0 is the interactive digital version of healthcare that brought various opportunities for patient tracking, health tracking, and wireless access to visualize vital signs remotely and other data to take timely decisions to cure the acute and chronic illness before it enters into a critical phase. By incorporating Artificial Intelligence (AI), Big Data (BD), Machine Learning (ML), or Deep Learning (DL), biosensor devices are making it capable enough of diagnosing and predicting health issues. Hence healthcare evolution transformed from sick care to healthcare in a real sense. Digital health also referred to as electronic health (eHealth) is the information communication technology (ICT) support in healthcare. Another term Mobile Health (mHealth) is also used that comes under eHealth a submodule that uses mobile wireless technology for healthcare. Healthcare transformed from 1.0 to 4.0 as shown in Figure 1.1. Initially, there were traditional paper-based systems in healthcare 1.0 with no record tracking further in health care 2.0 ICT based solutions were introduced for digital reports and record sharing in the network. Healthcare 3.0 gives us wearable devices for real-time patient tracking with a web interface while healthcare 4.0 changed the way in the healthcare industry by leveraging state-of-the-art technologies to give us a new experience. In 4.0 real-time patient health monitoring is implemented by cloud computing, the Internet of Things, edge computing, fog computing, and data analytics to perform prediction by using AI, machine learning, and deep learning methodologies. The key technology in Healthcare 4.0 is the Internet of Things (IoT) which allows the real-time patient and health tracking of the individual. IoT infrastructure allows biosensors to send data over the internet to cloud-hosted real-time databases that can be retrieved anytime from anywhere in the world to analyze and visualize health status in interactive mobile applications and physicians can track history to prescribe in a more customized way remotely.

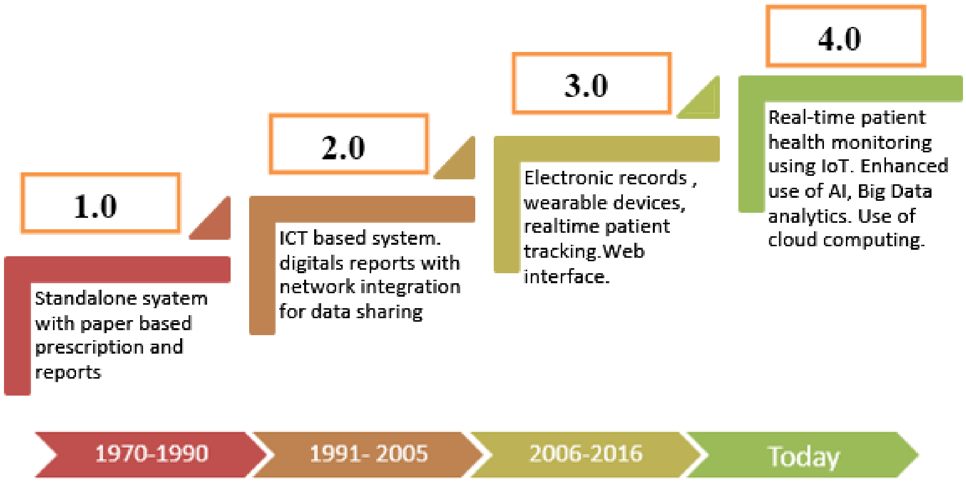

Figure 1.1 Healthcare evolution from 1.0 to 4.0

1.2 Internet of Things (IoT)

Internet of Things is a fast-growing enabling technology that has technical, social, and economic importance. IoT connects homogeneous and heterogeneous devices and sensors with bidirectional communication by using wireless network technology with great transformational potential in the hyper-connected world. The term “Internet of Things” (IoT) was coined by Kevin Ashton at a presentation to Proctor & Gamble in 1999. Current statistics show that there are more than 10 billion active IoT devices. It is estimated, that by 2030 IoT devices will surpass 25.4 billion active devices and by 2025, there will be 152,200 IoT devices connecting to the internet per minute. IoT solutions have the potential to generate $4-11 trillion in economic value by 2025. 83% of organizations have improved their efficiency by introducing IoT technology [10]. A lot of benefits that IoT application offers in the healthcare sector is most categorized into the tracking of patients, staff, and objects, identifying, as well as authenticating, individuals, and the automatic gathering of data from sensors. Hospital workflow can be significantly improved once a patient is tracked. Additionally, authentication and identification reduce incidents that may be harmful to patients, record maintenance, and fewer cases of mismatching infants. In addition, automatic data collection and transmission are vital in process automation, reduction of form processing timelines, automated procedure auditing as well as medical inventory management [11]. Sensor devices allow functions centered on patients, particularly, in diagnosing conditions and availing real-time information about patients' health indicators [12].

IoT is a rapidly saturated technology that outcome different applications of IoT such as the Internet of Medical Things(IoMT), Internet of Everything (IoE), Internet of Nano Things (IoNT), Internet of Mobile Things (IoMT), Internet of Mission-Critical Things (IoMCT) [13], Internet of Behavior (IoB), Internet of Bodies(IoB), Internet of Vehicles(IoV), Internet of Multimedia Things (IoMT), Industrial Internet of Things (IIoT), Infrastructure Internet of Things (IIoT), Internet of Military Things (IoMT). The application of IoT in healthcare (Internet of Medical Things, Internet of Bodies) unlocked many opportunities for simultaneous monitoring and reporting vital signs, remote monitoring, telemedicine, sleep tracking, stress management, etc. Virtual wards, wearable biosensors, telemonitoring systems, customized medicines, and personalized healthcare are the few outcomes.

1.3 Existing System for Driver Monitoring

In [14] the author presented an internet of things embedded low-cost Health monitoring system is designed and implemented using the Arduino Uno board. The system uses a combination of a pulse oximeter, heart rate, and temperature sensors to measure important human vitals continuously and non-invasively. In [15] author proposed a multimodal driver fatigue monitoring system that benefits from a distributed neural network. On one side of this IoT approach, there is a deep neural network named FCR-DNN to monitor the facial symptoms of the driver, and on the cloud side, there is a network to fuse facial driver information and other sensor information. In this paper [16], an approach to stress detection has been proposed, studied, and evaluated. This approach suggests an Enhanced Random Forest method that combines traditional Random Forest with Simulated Annealing algorithm, whose goal is to ensure a completely automatic and optimal process, to detect three levels of stressed car drivers from ECG signals. This paper [17] contributed an idea of an integrated mHealth and VIS to predict and notify alarms for long-distance drivers based on real-time parameters of the driver's health condition as well as the road circumstances.

The current healthcare system that we are experiencing today is mostly based on healthcare 3.0 in which we have electronic record keeping and wearable devices for patient tracking. Some researchers presented a health monitoring system for a driver with certain limitations. Authors conducted studies to develop a system to monitor driver health by considering different factors like fatigue, health, comfort, or drowsiness based on image processing techniques for facial expressions and vital signs monitoring by using wired, Bluetooth, or GSM technologies. Some authors consider ECG monitoring, while others presented their studies based on oxygen saturation level, heart rate, body temperature, or respiratory rate by placing sensors in different positions of a vehicle such as steering wheel, seat belt, headrest, earlobe, gearshift lever, dashboard, etc. by providing a user interface on the website, on-board LCD, website, laptop, or smartphone. Up to our best knowledge So we do not have a portable, cost-effective, and user-friendly driver health monitoring system that deals with maximum vital sign reading by using the Internet of Things (IoT) and interactive mobile application with an alert system.

1.4 Proposed system

To develop IoT based non-invasive health monitoring system for biomonitoring of human cognitive process / psychophysiological condition of the car driver to enhance road safety and keep a driver in close observation and monitoring vital signs such as heart rate, ECG, oxygen saturation, body temperature, etc. is a significant phenomenon in the healthcare monitoring system [18]. Furthermore, vital sign data is processed out of biomedical sensors to recommend a drive or not to drive depending on the driver's health condition to avoid an accident at the same time alert system, sends an alert along with the driver's health status to the concerned medical authorities and caretakers if vital signs parameters bounce above its predefined critical threshold values so, they can be informed immediately to take some prevention measures timely to save drive life in case of medical emergencies. The proposed system will read Vital signs such as an electrocardiogram (ECG or EKG), oxygen saturation level, heart rate, and body temperature to detect abnormal behavior (bradycardia, tachycardia, arrhythmia, hypoxia, hypothermia, and hyperthermia) by using biosensors and a controller system Raspberry pi that is a small single-board computer to process data in parallel processing. Whenever the driver will hold the steering wheel DHMS will start reading vital signs and process signs to get required features and the python script will send data to a cloud-hosted real-time database for real-time driver health monitoring these values can be visualized on a Smartphone application remotely and in case of the emergency alert system will trigger alert either automatically or manually by a driver that will bind and send vital sign readings with current location with an emergency message to caretakers and personal physician as shown in Figure 1.2.

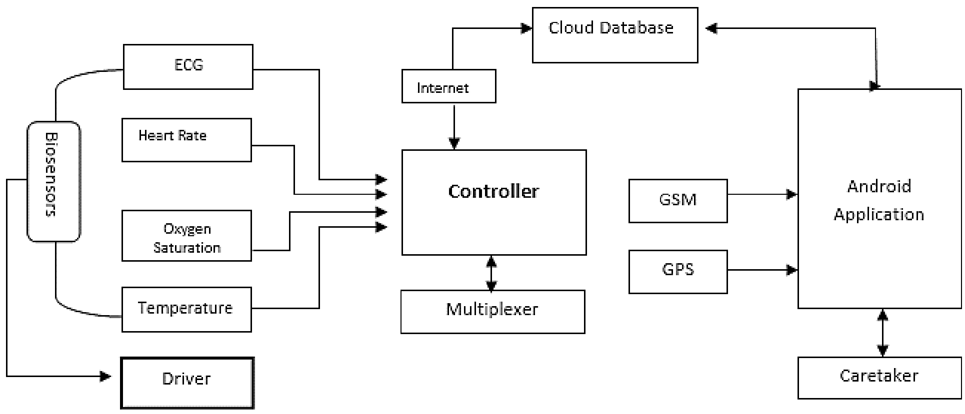

Figure 1.2 Block diagram

The need for a cost-effective and fast-responding alert mechanism is inevitable. Proper implementation of such systems can provide timely warnings to the medical staff and doctors and their service can be activated in case of medical emergencies. Present-day systems use sensors that are hardwired to a PC next to the bed [19]. Presently we do not have an IoT-based in-vehicle sophisticated system for driver health monitoring to enhance road safety. The proposed system will implement biosensors to monitor the vital signs of a driver with real-time cloud-hosted databases and interactive mobile applications to visualize vital signs and alert systems to enhance road safety and seek a timely response in medical emergencies.

1.5 Research methodology

The research focuses on developing a health monitoring system for drivers mainly consisting of two parts DHMS device and an Android application connected through a cloud-hosted real-time database. Initially, the design of hardware architecture will be created by considering controllers, multiplexer compatibility with biosensors that support parallel processing, and performing analysis on the hardware side to send consistent data over the internet to a cloud database. Followed by hardware integration that includes Raspberry pi 4, Arduino nano, multiplexer, and biosensors. After hardware integration, data will be collected from sensors in parallel processing where a dedicated subprocess thread will be allocated to every individual sensor and further models will be implemented for data analysis that includes preprocessing, noise removal, and feature extraction afterward cloud-hosted real-time database will be configured and connected with raspberry pi. At this stage, a device will be developed that reads the vital sign and send data to the cloud database. Furthermore, the Android application design will be created by identifying different activities that include login, authentication, real-time vital sign status, alert system, etc. Based on the aforementioned design, an android application will be developed and integrated with a centralized cloud-hosted real-time database. At this stage, our system will be able to read vital signs and send them to a cloud database and display them on a mobile application in an interactive way. The further alert system will be implemented based on vital sign critical threshold values and abnormal values with both automatic and manual alert trigger systems. Finally, the system will be tested and the results will be analyzed. The research method is as follows:

- Design of hardware
- Hardware Integration
- Data collection from sensor
- Building a model for data analysis
- Real-time cloud-hosted database integration
- Mobile application design and development
- Mobile application integration with cloud-hosted real-time database
- Alert system implementation
- Experiment and analysis

1.6 Vital Signs monitoring significance

Vital signs are an important indicator to monitor the health of a person. It allows to detect dysfunction inside the body that may lead to serious issues or can be used to detect the progress of recovery of a patient. ECG, blood pressure, heart rate, oxygen saturation, respiration rate, and body temperature are the important vital signs to monitor individual health status. More importantly, continuous monitoring of heart rate and respiratory rate can help health teams predict and reduce the occurrence of potential adverse events, such as cardiac arrest, and respiratory failure, even up 6 to 8 hours before the event [20]. A study conducted by Harvard Health Watch shows an average American spends 101 minutes per day driving so it is very important to keep track of driver health through vital signs to enhance road safety. Following are the vital signs that we conducted in our research.

1.6.1 Electrocardiogram (ECG)

An electrocardiogram (ECG) represents the electrical activity of the heart due to the polarization, depolarization, and repolarization of atria and ventricles. An ECG provides information about the basic rhythms of the heart muscles and acts as an indicator for various cardiac abnormalities. Abnormalities include arrhythmia, bradycardia, tachycardia, etc. The use of IoT and machine learning technology has found potential applications in the early detection of heart abnormalities through ECG monitoring. Generally, ECG can be categorized into, normal heart rate (60>=hr<=100), fast (hr>100) tachycardia, slow (hr<60) bradycardia, or irregular heart rate where R-R intervals differ as shown in Figure 1.3 [21]. ECG signal is a combination of P, Q, R, S, T, and sometimes U waves. The p wave is generated at the time of activation (polarization) of atria, the QRS wave is generated (depolarization) at the time of activation of ventricle while the T wave is the recovery (repolarization) wave. The distance between R-R peaks is called the R-R interval which shows how fast or slow the heart is beating. Normally R-R interval is consistent but sometimes there is an irregular R-R interval that shows abnormal behavior of the heart.

Figure 1.3 Normal and abnormal heart rhythm

Abnormal ECG (bradycardia, tachycardia, and arrhythmia) symptoms are chest pain, breathing difficulty, palpitation, fainting, dizziness, weakness, Abrupt temperature changes and fatigue [22] might be caused by stress, drugs intake, electrolyte imbalance, heart structural abnormalities, medication effect, heart attack, food, etc. The aforementioned symptoms might lead to an accident.

1.6.2 Oxygen saturation

Human beings depend on oxygen for life. All organs require oxygen for metabolism but the brain and heart are particularly sensitive to a lack of oxygen. The shortage of oxygen in the body is called hypoxia**.** A serious shortage of oxygen for a few minutes is fatal [23]. Low blood oxygen levels can result in abnormal circulation and cause the following symptoms: shortness of breath, headache, dizziness, confusion, visual disorders, rapid heartbeat, Causes Heart conditions, including heart defects, Lung conditions such as asthma, emphysema, and bronchitis, Sleep apnea (impaired breathing during sleep) Inflammation or scarring of the lung tissue (as in pulmonary fibrosis).

Red blood cells contain hemoglobin. One molecule of hemoglobin can carry up to four molecules of oxygen after which it is described as “saturated” with oxygen Normal human SpO2 level is above 95% as shown in Table 1.2. The below 95% oxygen saturation lever is considerable to monitor, if it goes down further there might be a medical emergency and a person could be unconscious. Study shows that while driving a car, if the oxygen rate is lowered, fatigue is felt severely and that in the case of supplying a high rate of oxygen, the feeling of fatigue is lowered to some extent and the reaction time is shortened. It was suggested that the driver's fatigue can be reduced according to the supply of oxygen [24].

Table 1.2 Blood oxygen levels along with their indicators

Oxygen saturation level	Range	Indicator
Normal	96-100 %	Normal
Concerning blood oxygen saturation level	91-95%	Abnormal
Low oxygen saturation level	86-90%	Abnormal
Low oxygen saturation level might affect brain	80-85%	Critical
Cyanosis	<=85	Critical

1.6.3 Body Temperature

Body temperature that’s higher than normal is considered fever also called hyperthermia, high temperature, or pyrexia, and it’s usually a sign that your body is working to keep you healthy from an infection. Normal body temperatures are different for everyone, but they lie within the range of 97 to 99. A temperature of 100.4 or higher is considered a fever. A part of your brain called the hypothalamus controls your body temperature. In response to an infection, illness, or some other cause, the hypothalamus may reset the body to a higher temperature. So when a fever comes on, it’s a sign that something is going on in your body. Fever itself isn’t dangerous, but you should check in with your doctor if you have symptoms like shivering, Fatigue, sweating, headache, being dehydrated, or feeling weak. Causes could be infections, effects of medications, vaccines, immunizations, Blood clots, Hormone disorders such as hyperthyroidism, and Heat exhaustion [25].

Different body parts have a slightly different temperature but in general, a reading that’s 2°F (1.1°C) above your normal temperature is usually a sign of a fever. As shown in Table 1.3 the normal body temperature is 36.5-37.5°C (97.7-99.5°F) with upper and lower threshold values of abnormal body temperature. If the temperature is less than 35°C (95.0°F) is hypothermia and if the temperature exceeds 37.5 or 38.3°C it’s taken as fever/hyperthermia but if the temperature reaches 40.0 or 41.5°C (104.0-106°F) it’s taken as critical and is a medical emergency.

Table 1.3 Body temperature range in Celsius and Fahrenheit

Standard	Celsius	Fahrenheit	Indicator
Hypothermia	<35°C	95.0°F	Abnormal
Normal	36.5-37.5°C	97.7-99.5°F	Normal
Fever/ Hyperthermia	>37.5 or 38.3°C	99.5-100.9°F	Abnormal
Hyperpyrexia	>40.0 or 41.5°C	104.0-106°F	Critical

1.6.4 Heart Rate

Heart rate is usually the number of times the heart is beating in a minute. The normal heart rate of an adult is between 60- 100 beats per minute (bpm) while athletes may find their heart rates lower, between 40 to 60 bpm. Generally, a heart rate lower than 60 and greater than 100 is considered abnormal. Many factors cause abnormal heart rate such as; Cardiovascular conditioning or deconditioning, Psychological stress or anxiety, Endocrine or hormonal abnormalities, Smoking, Medication side effects, emotions, ventricular or supraventricular arrhythmias that might show symptoms like shortness of breath, chest tightness or pain, dizziness, fainting or light-headedness, confusion or memory problems, fatigue. Heart rate may also depend on age factors, sitting position, cardiac issues, emotions, etc. In general for adults, 60-100 is taken as normal while less than 60 is bradycardia and a person should be under consideration if heart rate further drops, it indicates a medical emergency. On the other side, if the heart rate exceeds 100 its tachycardia and should be under monitoring if it exceeds further there might be a medical emergency as shown in Table 1.4.

Table 1.4 Heart rate range and indicators

Heart rate (hr)	Standard	Indicator
60-100	Normal	Normal
55>=hr<=60	Bradycardia	Abnormal
<55	Bradycardia	Critical
100>=hr<=110	Tachycardia	Abnormal
>110	Tachycardia	Critical

1.7 Dissertation Organisation

Chapter 2 presents a literature review of driver health monitoring systems along with a comparative analysis of recent studies based on different methodologies. It also discussed challenges in the existing system. Chapter 3 describe the overall design and implementation of the prototype, Android application, and Firebase database along with their configuration and functionalities. It also describes how different sensors are integrated with Raspberry pi 4. Moreover, it describes the 6-layers model in which data is collected from sensors for further processing and features are extracted to send to the cloud database and shown on the Mobile user interface with an alert system. Chapter 4 includes the analysis and results evaluation of vital signs with medical standard devices along with mobile application and alert system analysis. Chapter 5 provides a brief conclusion of the proposed system along with several ideas for further improvements.

Chapter 2 Literature Review

This chapter includes the literature review of health monitoring systems designed for a driver by using different approaches, technologies, and health factors for monitoring driver health conditions to enhance road safety and timely response in medical emergencies to save lives. The researcher presented their work by focusing on different factors like health, fatigue, drowsiness, comfort, emotions, and gestures by using cameras and biosensors to detect normal and abnormal behavior/ health of the driver. For monitoring driver health status, researchers presented studies on one or a combination of the following vital signs; ECG, oxygen saturation, heart rate, body temperature, respiration rate, weight, etc. By using wired or wireless communication protocols. Such, as; LAN, Bluetooth, Wi-Fi, and GSM, to mount sensors on various locations, such as steering wheel, seat belt, bucket seat, headrest, backrest, gearshift lever, dashboard, that intact with hand palm, finders, earlobe, chest, wrist, back, forehead and tested in a laboratory setting, driving simulator, on-road driving, static vehicle, and prototype by providing interface on a laptop, cloud dashboard, on-board screen, simulators, website or mobile application.

The evolution in the healthcare system brings a lot of opportunities for researchers to develop a sophisticated system to monitor the vital signs of a person. The health monitoring system is used for elderly people with medical conditions, telemonitoring of remote area people, health tracking, patient tracking, etc. By using different wired and wireless technologies such as Bluetooth, GSM, 3G/4G, ZigBee, and wired connection to monitor health status on connected LCD, mobile application, web portal, serial monitor, etc. Initially, the health care system was manual and paper-based with no record tracing (1970-1990). With the advancement of Information and Communication Technology (ICT) computers were used in the early 90s for digital reports and data sharing over the network. Further advancements in healthcare are more efficient ways to record vital signs by wearable devices with real-time patient tracking and a web interface for monitoring health status. Healthcare 4.0 that we are experiencing today has revolutionized the healthcare system with state-of-the-art technologies. Today wearable devices read vital signs in real-time and it’s a great opportunity to develop a health monitoring system for drivers to enhance road safety.

2.1 Internet of things (IoT) based vital sign monitoring model

Healthcare monitoring based on Internet of Things infrastructure is the latest trend in health care evolution 4.0 that provides a new dimension to improve quality, productivity, cost-effectiveness, flexibility, and dependability of healthcare services. IoT infrastructure enables a physician to monitor patent data remotely which is a promising technology for telemedicine and patient remote monitoring. Shaily *et al.* (2021) [26] presented real-time drowsiness and fatigue detection system based on an image processing technique in which the camera is mounted on the dashboard and it works on vehicle OBD-II details along with image processing data with sound alert. Raspberry Pi communicates with Android App via MQTT Protocol and triggers alerts when drowsiness or fatigue is detected. Rachakonda *et al.* (2020) [27] proposed IoMT-Device to monitor blood alcohol concentration level and physiological data as the driver touches the steering wheel and data sent over the internet to be crosschecked with regular baseline information. If a driver is clearheaded, he is allowed to drive else vehicle engine is automatically locked and blood alcohol concentration data is displayed on the infotainment. The data is sent to an Internet of things analytic tool which can be accessed by the user later. The blood alcohol prediction accuracy is approximately 93% achieved. Ali *et al.* (2020) [28] developed non-invasive vital signs (oxygen saturation, heart rate, and body temperature) using IoT and Bluetooth-based communication that allows visualizing vital sign data on web portals and mobile applications respectively. The system heart rate and body temperature with high accuracy while in pulse oximeter 2% deviation is observed. The system was specifically developed for elderly people by using an ESP8266 Wi-Fi shield for internet connectivity and updating real-time values on a web portal. Moreover, the HC-05 Bluetooth module is used for android application interfacing. While Tran *et al.* (2019) [29] used K-band non-invasive vital signs monitoring and values of vital signs are stored on an open-source server using the internet for future correspondence. The proposed system is tested with 5 different subjects with the error of heart rate and respiratory rate at 8.6% and 2.3% respectively. For automatic alerts, GSM and buzzer are being used for alert notification in case of abnormal heart rate and respiration rate.

2.2 Bluetooth based vital sign monitoring model

Bluetooth Low Energy (BLE) based communication model is widely used in health monitoring wearable sensors/gadgets that allow short-range communication to visualize vital signs data on a small screen or mobile application. Babusiak *et al.* (2021) [30]describe the design of a smart steering wheel proposed for drowsiness and health monitoring. The important vital signs such as heart rate variability, heart rate, and oxygen saturation are measured using an ECG signal and pulse oximeter mounted on the steering wheel to record and analyze the data by Bluetooth communication with a laptop (C# application). Ali *et al.* (2020) [28] developed a non-invasive hybrid model for vital signs (oxygen saturation, heart rate, and body temperature) monitoring by using IoT and Bluetooth-based communication for vital sign data visualization on mobile applications and websites portals respectively. The interactive interface for mobile applications is achieved by using Bluetooth (HC-05) communication between biosensors and smartphones. Cherif *et al.* (2020) [31] focused on designing a new practical system for monitoring two vital physiological signals (ECG and PPG) to detect a driver's abnormal health status during driving such as heart rate, oxygen saturation level, and certain respiratory and cardiac dysfunctions with an alert system to warned immediately to react and consult a doctor. The ultimate goal is to monitor the driver’s health condition by using Bluetooth technology to visualize vital sign data on a mobile application. Choi *et al.* (2014) [32] propose a smart steering wheel system based on Bluetooth communication with an emergency alert system using SMS. ECG, PPG, and pressure sensors are used for driver health monitoring and steering wheel touch detection (to detect drivers). The mobile communication (Bluetooth-based) system for driver’s emergency using a smartphone and automatic emergency location alarm system based on google map are also presented. Kavitha *et al.* (2014) [33] used Body Sensor Network (BSN) to a present health monitoring system for monitoring driver health status periodically and abnormal behavior is informed to both transport office and healthcare provider. The proposed system monitors a driver's physiological parameters such as pulse rate, and body temperature, using sensors and is transferred to a smartphone using Bluetooth communication.

2.3 GSM based vital sign monitoring model

GSM model can be used to send data over long-range through SMS. Studies were conducted to use GSM technology for getting alerts if certain vital sign values bounce over the threshold value. This methodology does not provides real-time visualization of health status instead only trigger alert on abnormal vital signs values or send health status data to physician or caretakers as requested. Hyder *et al.* (2020) [34] presented an application based on alcohol detection, drowsiness detection, and vital sign monitoring (ECG, and heart rate) along with the lane-based auto drive to avoid an accident with certain limitations that include lack of judgment of drowsiness/ inattentiveness by Eye Aspect Ratio (EAR) only, which can be improved drastically by the addition of EEG observations of the driver. Raspberry pi board is used along with GSM/GPRS for long-range communication and SMS is triggered upon detection of any abnormality and the car shifted to auto-drive mode. Abu-Faraj *et al.* (2018) [35] presented the design and development of a smart steering wheel for heart attack detection. The Arduino board is used for real-time monitoring along with the GSM module. On abnormal heart rhythm of a driver, an emergency SMS along with the current location send automatically within 30 seconds. In addition, a warning alert triggers when abnormal behavior is detected to warn the driver to park at the shoulder of the road and take a vasodilation pill from a built-in compartment. Choi *et al.* (2014) [32] presented a smart steering wheel that uses Bluetooth communication to visualize ECG and PPG data on smart mobile with the emergency alert system by using GSM communication (SMS) for the driver's emergency using a smartphone and automatic emergency location alarm system based on google map is also presented.

2.4 On-board vital sign monitoring model by using different techniques

Besides wireless communication-based driver health monitoring system, researchers proposed a board display system for visualization of vital signs with the alert system. Moreover, machine learning and deep learning methodologies are used for detecting abnormalities and results are analyzed on laptops through wired connectivity. McConnell *et al.* (2020) [36] investigated several machine learning algorithms that we're able to detect the number of electrode contacts on specially constructed steering wheels to measure the ECG signal of the driver. The system automatically categorizes sections of the ECG into classes of hand contact by using machine learning and deep learning methodologies, which utilized the raw signal data rather than hand-crafted features, was the best performing algorithm (>99%), though it was also the most computationally expensive. Nita *et al.* (2019) [37] proposed a systematic approach for the detection of AF rhythms in ECG hand-held devices. A set of 150 highest-ranked features is selected and fed into a random forest classifier to detect AF rhythms in addition to three other ECG rhythms/types for stress detection. Guede-Fernández *et al.* (2019) [38] use respiratory signal analysis for drowsiness detection. The respiratory signal, which has been obtained using an inductive plethysmography belt, has been processed in real-time to classify the driver's state of alertness as drowsy or awake. The proposed algorithm is based on the analysis of the respiratory rate variability (RRV) to detect the fight against falling asleep. Performance of drowsiness detection has been assessed achieving a specificity of 96.6% ± 3.6%, and a sensitivity of 90.3% ± 14.3%.

Park *et al.* (2019) [39] presented a novel heart rate and breath rate detection simultaneously based on a switchable Phase-Locked Loop circuit-based architecture for the continuous non-contact monitoring of driver health status. Sensors can be either mounted on the steering wheel or attached to the seatbelt to detect vital signs. Hui *et al.* (2019) [40] demonstrated the near-field coherent sensing system integrated into the seat to monitor respiration, heartbeats, femoral pulses, and PTT-based blood pressures. The system is entirely embedded and invisible to the user. The new balancing bridge design at the RF transceiver front end can significantly improve the signal quality. Variations of sensor placement to account for different body sizes and postures are briefly investigated. Yang *et al.* (2018) [41] presented a location-based Variation Mode Decomposition (VMD) algorithm for in-car multiple subjects' vital sign monitoring. Firstly, the received radar signals are divided into several intervals based on the prior knowledge of seat locations, considering the invariance of the position of each fixed seat in the car. Secondly, by performing VMD on each interval, vital signals are obtained, which contain the body movement signals caused by the pumping action of the heart and chest movements. Lastly, the correlation coefficients between the vital signals are calculated to select the vital signs including the HR and RR. Mühlbacher-Karrer *et al.* (2018) [42] used a deep learning-based algorithm for a driver state detection system to monitor the stress level of a driver. It combines the input of both the physiological sensors and a novel touch detection sensor. First, the Capacitive Hand Detection Sensor (CHDS) for steering wheels with wireless and energy-efficient data transmissions is evaluated. Second, the proposed driver state detection system is evaluated through a driving simulator platform with 22 participants. The classification results of the CNN show a significant improvement in the accuracy, whenever the physiological sensor(s) are combined with information of the CHDS. In the case of taking all available sensor inputs into account, the CHDS improves the accuracy by 10%.

Choi *et al.* (2017) [43] proposed a conductive fabric-based dry electrode utilizing an electroplating method and employed a conductive fabric-shaping procedure as a steering wheel cover to measure the ECG signals of a driver. Comparing the measured ECG signals of a driver in a normal condition to those in a drowsy condition, and showed that the proposed ECG measuring system is useful for detecting drowsy drivers. Vetter *et al.* (2017) [44] demonstrated a system to detect the respiratory activity of the driver in a resting position. The estimated breath time was evaluated and an average error of 5% for the reference signal was achieved. For heart rate estimation, he presented the spectrum of the apnea phase with the measured signal. The results show a match in the estimated frequency in the apnea phase and suggest that heart activity is present in the signal, but needs some further investigation and development of sophisticated algorithms and sensor fusion to be extracted while breathing. Vavrinsky *et al.* (2013) [45] presented a design of the car driver health monitoring system with a novel IDAT microsensor applied. A new thin-film multipurpose microsensor (IDAT) consists of an impedance sensor based on the interdigital array of microelectrodes which is integrated with a temperature resistive sensor on a single chip. The developed microsensors allow monitoring of psychogalvanic reflex, heart pulse, and skin temperature using depth impedance analysis of different skin layers by choosing the appropriate size of microelectrodes.

2.5 Comparative analysis of existing driver health monitoring system

The review is conducted on 20 most relevant and recent studies that show in the year 2021 authors [26], [30] presented Bluetooth-based vital sign monitoring for health and drowsiness detection another presented study for drowsiness and fatigue detection based on facial expression using IoT and mobile application. In the year 2020 authors [27], [28], [31], [34], [36] presented studies on multiple factors to monitor health, fatigue, drowsiness, and Alcohol detection using Bluetooth, GSM, or IoT by considering one or more vital signs with certain limitations like if author worked on 4 vital signs he didn't use IoT and Mobile application interface. Another used Bluetooth and a mobile interface but a pulse oximeter is mounted on the ear lobe that causing discomfort for the driver. In most of the scenarios, the authors used a laptop to visualize vital signs with Bluetooth-based communication in a close loop without having an alert system as shown in Table 2.1. In the year 2019; health, stress, and drowsiness are taken into consideration by authors [29], [46]–[49]to focus on ECG and respiration rate by using a wired network with a laptop to monitor health and stress with an alarm system (beep, vibration, SMS). In the year 2018 proposed studies [35], [41]focus on heart rate, ECG, and skin temperature by using wired communication with a laptop and an alert system using GSM. In the year 2017 authors [42]–[44]conducted a study using ECG signals to detect health and stress by placing ECG electrodes and radar sensor technology on the seat backrest and steering wheel and used wired and Bluetooth connectivity with a laptop to monitor data. In 2013 and 2014 authors [32], [33], [45]conducted studies on ECG oxygen saturation and temperature using Bluetooth and wired communication for visualization and sending alerts through SMS in case of abnormal vital sign values to enhance road safety.

Table 2.1 Comparative analysis of existing methodologies for driver health monitoring by using different techniques

Research Year	Factors	Parameter/ Vital signs	Communication Technology	Test setting	Sensor Placement	Interface
2021	Drowsiness Fatigue	• Facial expression	IoT	Static Vehicle	Dashboard	Mobile app
2021	Health Drowsiness	• Electrocardiogram (ECG) • Oxygen saturation (PPG)	Bluetooth	On-Road driving & Static Vehicle	Steering wheel	Laptop
2020	Fatigue	• ECG	Wired	Machine learning model	--	Laptop
2020	Health	• Temperature • Respiration Rate • Heart Rate	IoT	Laboratory setting	Prototype	Database dashboard
2020	Health	• Oxygen saturation	IoT Bluetooth	Laboratory setting	Prototype	Database dashboard,

		• Body temperature • Heartbeat				On-board LCD
2020	Drowsiness Alcohol Health	• ECG • Heartbeat	GSM	Laboratory setting, On-Road driving	Steering wheel	Laptop Mobile
2020	Health	• ECG • Oxygen saturation	Bluetooth	Laboratory setting	Steering wheel Ear lobe	Mobile Application
2019	Health	• Respiration • Heartbeat	IoT	Laboratory setting	Steering wheel	Website
2019	Stress Monitoring	• ECG	Wired	Laboratory setting	Seat backrest	Laptop
2019	Drowsiness	• Respiratory signal	Wired	Simulator	Seat belt	Laptop
2019	Heath	• ECG	Wired	Laboratory setting	Steering wheel	Laptop
2019	Health	• ECG	Wired	Laboratory setting	Seat back rest	Laptop
2018	Health	• Heart beat	Wired	Static Vehicle	Front mirror	Laptop
2018	Health	• Heart rate • Body temperature • Skin impedance	GSM	Laboratory setting	Steering wheel	SMS
2017	Stress level	• ECG	Wired	Driving simulator	Steering wheel, head and chest	LCD
2017	Health	• ECG	Wired	Laboratory setting , On-Road driving	Steering wheel	Laptop
2017	Health	• ECG	Wired	Laboratory setting	Seat back rest	Laptop
2014	Health	• ECG • Oxygen saturation • Pressure	Bluetooth GSM	Laboratory setting	Steering wheel	Mobile SMS
2014	Health	• Pulse rate • Body temperature	Bluetooth	Laboratory setting	Prototype	Mobile
2013	Health	• ECG • Pressure sensor • Skin temperature	Wired	Laboratory setting	Seat backrest Steering wheel	Laptop

2.6 Existing system challenges

Recently, wireless healthcare monitoring systems are being implemented in luxurious cars like Mercedes Benz. Further, up to our best knowledge, no such system exist that provides a complete solution to monitor and detect abnormal health status (bradycardia, tachycardia, arrhythmia, hypoxia, hypothermia, and hyperthermia) of the driver through physiological information based on IoT and alert system that work in real-time to enhance road safety and health tracking. Researchers presented different solutions over time that have certain limitations from different prospective such as communication technology (Bluetooth, IoT, wired), sensors type, sensor placement, user interface, number of vital signs, alert system, and accuracy. Recent studies do not cover four primary vital signs, it does not have clear ECG (noisy), mostly based on wired, GSM, and Bluetooth technologies that cover short and medium range.

However, one way to improve the traditional design of driver monitoring systems is to consider the important vital signs, including driver's characteristics, user interface, sensor placement, signal processing methodologies, and preferences in the design process. Therefore recent studies covered health, fatigue, drowsiness, comfort, emotions, and gestures for driver monitoring and an effective solution is vital signs monitoring that gives a batter approach to monitoring driver state and covers limitations with state-of-the-art technologies. Therefore our proposed DHMS is a well-defined model that covers four primary vital signs(ECG, oxygen saturation, heart rate, temperature), IoT wireless communication approach, sensors placement to consider comfort, the accuracy of data, user interface, and dual(automatic, manual) alert system. The proposed system will be having great significance to enhance road safety and allowing quick emergency response to avoid implications in medical emergency scenarios.

Chapter 3 Design and Implementation

This chapter presents the general architecture and implementation of the proposed Driver Health Monitoring System (DHMS) based on IoT. The design, integration, configuration, and implementation of a prototype are presented along with the Android application and IoT Infrastructure. This chapter also defines the functionality of different units of the proposed system and communication protocols among them. The systems consist of 3 main parts as shown in Figure 3.1, application biosensors, Android, and a cloud database that works together in real-time for vital sign monitoring of drivers to identify normal and abnormal health conditions. The structure will proceed as follow: First and foremost DHMS abstract view is presented followed by the proposed 6 layers model that defines how data is collected from sensors, processed, analyzed, send to a cloud database, stored, and fetched on a mobile interface in different layers. Followed by sensor connectivity, configuration, and flows diagrams. Moreover, modules of Mobile applications and designs are presented. Finally, the prototype model is presented by specifying its different sensor positions on the steering wheel.

Figure 3.1 Design of DHMS

3.1 Driver Health Monitoring System (DHMS) Abstract View

The abstract view is the high-level design view of DHMS that includes three main modules as shown in Figure 3.2. Such as hardware part that includes controllers and sensors to read and process vital sign data, a cloud database for remote access/ cloud storage, and a mobile application for the interactive user interface. Four biomedical sensors are mounted with the steering wheel at different locations to monitor important vital signs such as ECG/EKG, Oxygen saturation level, heart rate, and body temperature. (1)Biomedical sensors are used for monitoring the aforementioned vital signs along with Arduino Nano and 16-bit ADS1115 multiplexer (analog to digital converter) all together connected with a Raspberry pi 4 model B, a credit card size computer. It read raw data from sensors to process and analyze data to generate valuable information in parallel processing using sub-processes and acts as a gateway for internet connectivity and sends data to a cloud-hosted real-time database (Firebase). (2) Firebase is a cloud-hosted hybrid database that can be configured and linked with embedded systems and Android application. In this research, authentication, real-time database, and storage features of Firebase databased are used for user authentication (registration, login), vital sign real-time value, and media storage respectively. (3) The interface to visualize vital signs is provided on a mobile application that can be wirelessly accessible to monitor health status remotely. Android application has been developed and configured with a centralized database (Firebase) that provides several features for real-time monitoring of driver health, based on vital sign readings such as data retrieval from Firebase, an emergency alert system that inform caretakers and doctors about abnormal /critical condition along with vital signs readings and current location through SMS. GPS and GSM of the android smartphone are used for location retrieval and SMS sending in an emergency. So, hardware devices, cloud databases, and mobile applications work together for real-time driver primary vital sign monitoring to enhance road safety.

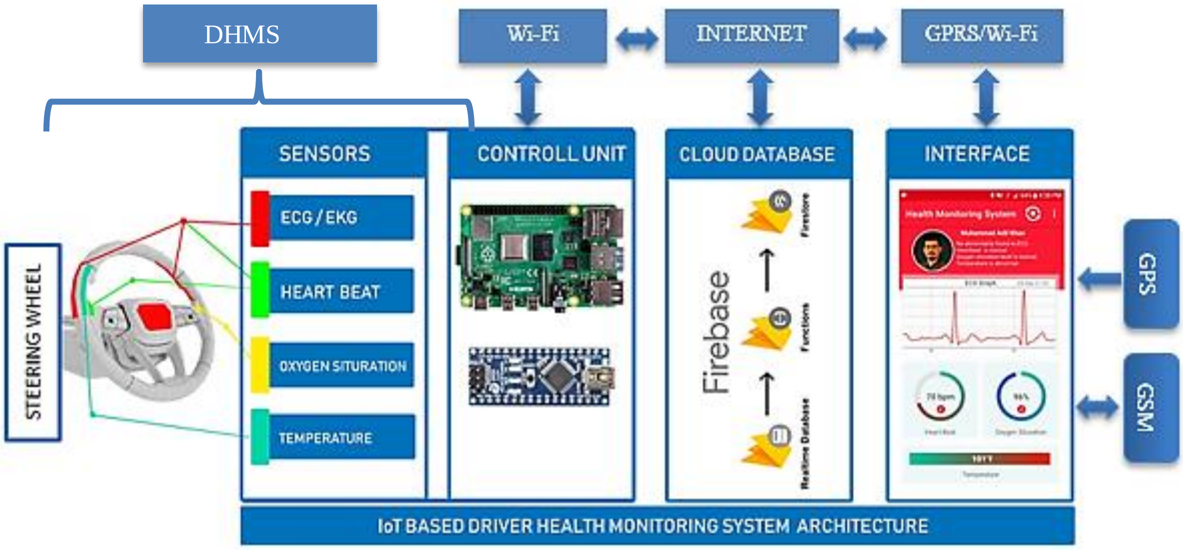

Figure 3.2 Architectural view of the proposed system

3.2 The layered architecture of DHMS

The implementation of the proposed system is defined into 6 different layers as shown in Table 3.1. Each layer performs a set of operations and invokes an adjacent layer for further operations. Bottom to up the first layer is the sensors layer in which biomedical sensors, multiplexer, and the controller are, connected with Raspberry pi 4 .to read raw data based on i2c, analog, and serial communication. The second layer is the processing layer that processes raw data by using multiple algorithms, libraries, and filters to de-noise raw data. Followed by a modeling and analysis layer for data analysis to get meaningful information and pass it to the network layer that uses TCP/IP protocol to send data over the network and further storage layer stores data in a cloud-hosted real-time database. Finally, the application layer provides an interactive interface on an android mobile application to visualize data to the user with an alert system that triggers on abnormal/critical health conditions.

Table 3.1 Proposed layered architecture of driver health monitoring system

Application Layer			**Interface**
User authentication	Data visualization	Alert system	Android Smart Phone
Storage Layer			**Cloud Database**
Authentication	Real-time database	Firebase storage	Firebase
Network Layer			**IEEE Standard**
Wi-Fi			IEEE 802.11b
Modeling and Analysis layer			**Model**

Feature Extraction	⇨ Analysis			Heartpy
Processing layer				**Libraries**
Data acquisition	⇨ Data sampling Normalization	⇨ Noise removal		Numpy Pandas Matplotlib Scipy Heartpy MAX30102
Sensors Layer				**Hardware**
Serial Sensor	i2c sensor	Analog sensor		Raspberry pi 4 Arduino Nano ADS1115
ECG (AD8232)	**Oxygen saturation** (MAX30102)	**Heartbeat** (Heart sensor)	**Body temperature** (LM35)	
Arduino Nano		Analog to digital converter **ADS1115** (i2c module)		
Raspberry pi 4				

3.2.1 Sensor layer

The sensor layer consists of four biomedical sensors to read the vital signs of the driver. Such as ECG/EKG, oxygen saturation, heart rate, and body temperature. These sensors are mounted on the steering wheel in different locations and connected with Raspberry pi 4 model B. For ECG a single lead AD8232 (analog) sensor with Ag/AgCl or stainless steel electrodes is used to record the pathway of electrical impulses through the heart muscle. The AD8232 sensor is connected with Arduino Nano to read analog values and further Arduino Nano is connected with Raspberry pi 4 through a serial port that collects and processes analog data. To determine oxygen saturation level MAX30102 integrated pulse oximeter sensor is used. It has an i2c output signal and interfaced interface with Raspberry pi 4. For heart rate, a pulse sensor is an analog output sensor attached with a 16-bit ADS1115 multiplexer that interprets analog signal to digital signal for Raspberry pi 4. For temperature reading a 1-wire analog LM35 temperature sensor is used with a 16-bit ADS1115 multiplexer, it operates from 3V to 30V, and measures from -55°C to +150°C range. Less than 60Ma current drain calibrated directly in centigrade with an accuracy of 0.75ºC.

3.2.2 Processing layer

The processing layer is followed by the sensor layer that processes acquired data in parallel sub-process instead of sequential processing. So, every sub-process executes individual sensor data with specific algorithms and libraries in real-time to perform data acquisition, sampling, normalization, and noise removal. Moreover, ECG signal is processed by using python data science packages(NumPy, pandas, scipy, matplotlib) for pre-processing with 3rd order bandpass filter for noise removal with the configuration of 1Hz low cut, 40Hz high cut, and 500 sampling frequency. While Oxygen saturation sensor data is processed by using the MAX30102 library uses 100 samples to calculate the SpO2 value in a single loop. Moreover, pulse sensor and temperature sensor data are stored in an array for further processing.

3.2.3 Modeling and Analysis

This layer analyses the pre-processed data of the temperature sensor, oxygen saturation sensor, and heartbeat sensor to calculate mean values from processed samples and store them in variables while ECG R peaks are extracted and mark valid and invalid R peaks by using the heartpy library. This library also allows us to calculate R-R interval and heart rate. We further implement our model to determine irregular heart rhythm based on the R-R interval we have by using the heartpy library. After extracting the required features, data is prepared to send to the cloud database by using the network layer.

3.2.4 Network layer

As the proposed system is based on IoT infrastructure. In which both hardware device and mobile application are connected with a cloud database for real-time communication by using a Wi-Fi router. So, the network layer is a gateway that uses IEEE 802.11b standard to send vital sign data to cloud-hosted real-time databases (Firebase). On the other side mobile application also use the internet to send and receive data for visualization and user authentication.

3.2.5 Storage Layer

The storage layer is used to store and sync incoming data from both the DHMS device and mobile application. For this purpose, a cloud-hosted NoSQL real-time database (Firebase) is used to store, query, and sync incoming data over the network in Jason format. Moreover, authentication, real-time database, and storage features of Firebase databased are used for user authentication, vital sign real-time value storage/sync, and media storage respectively.

3.2.6 Application layer

Provides an interactive interface where a user interacts to visualize vital sign data fetched from a cloud database, Moreover, a driver can register themselves on the Android application by creating an account, and by using the same credentials he can login to the application, where he can configure settings to activate/ deactivate alert, warning, GPS, GSM and can add doctor and caretakers emergency contact. In case of a medical emergency, an emergency SMS will be sent to the caretaker and doctor for timely action.

3.3 Electrocardiogram (ECG/EKG) sensor implementation

Getting smooth ECG is challenging, there might be signal interference by other circuits attached or power line interference (50Hz/60Hz) that makes the signal noisy. In the proposed system the components used for ECG implementation are; AD8232, Arduino Nano, Raspberry pi 4, and electrodes. For ECG reading a single lead AD8232 ECG sensor integrated with AD8232 IC from analog devices is used with Arduino Nano and Raspberry pi 4. Pin configuration includes (AD8232- Arduino Nano) GND to GND, 3.3v to 3.3v, output to A0, LO- to digital pin 11, L0+ to digital pin 10, and USB serial port is used for connectivity of Arduino Nano with Raspberry pi 4 as shown in Figure 3.3. As the AD8232 ECG sensor is very sensitive and its processing speed could be compromised. So, a dedicated Arduino Nano is attached with AD8232 to overcome this issue. Arduino Nano starts reading electrical impulses in the form of analog signals from AD8232 when RL (ground), RA (+ve), and LA (-ve) electrodes are attached to the human body at specific locations. Arduino Nano is further connected with Raspberry pi 4 through a serial USB port in which incoming ECG raw data is received in Raspberry pi 4 and stored in a .csv file for further processing. To avoid discontinuity of ECG signal we have placed a push-button that activate the ECG sensor. When a driver is on a smooth road and he properly holds the steering wheel with both hands and sensors are in good contact with palm/ fingers. He presses the ECG button that starts reading heart electrical impulses for 15 to 20 seconds to generate results. Even ECG sensor is activated the discontinuity of the signal is also analyzed by our algorithm to avoid garbage values.

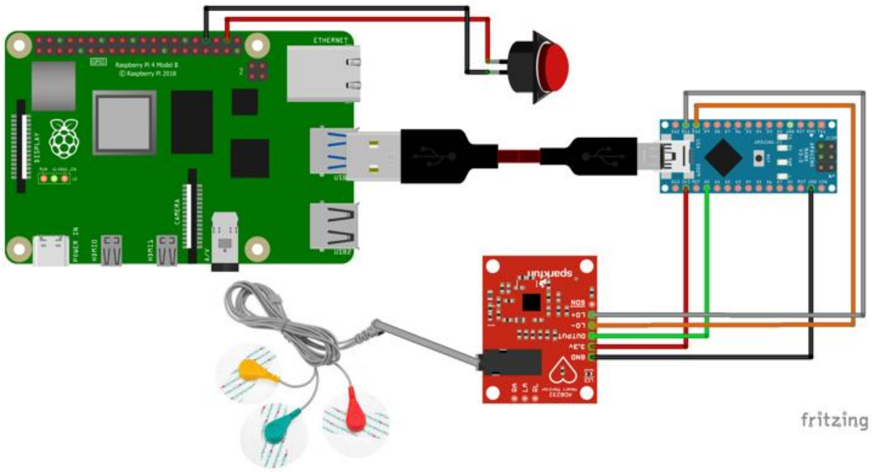

Figure 3.3 ECG sensor circuit diagram

Electrodes used in this project are made-up of Silver-Silver Chloride (Ag/AgCl) that have the best conductivity and the low resistivity. The resistivity of silver is 1.58 µΩ-cm which is best as compared to other conductive metals like Copper, Gold, and Aluminium as shown in Table 3.2. The temperature coefficient of resistance of Ag is 0.0038 and solid conductive and adhesive Hydrogen-gel have very low impedance and it’s non-irritating, non-sensitizing, and non-cytotoxic to skin. Further silver-based fabric dry electrodes can be used to enhance driver comfort.

Table 3.2 Metals with high conductivity and low resistivity

Metals	Chemical Symbol	Resistivity (µΩ -cm)	Temperature Coefficients of Resistance (/oC)
Silver	Ag	1.58	0.0038
Copper	Cu	1.68	0.00386
Gold	Au	2.21	0.0034
Aluminium	Al	2.65	0.00429

After receiving electrical impulses in the form of analog values through a USB port in Raspberry pi 4. The python script starts writing analog values in the .csv file in the local directory with a condition that checks whether incoming data is valid or not. If electrodes are not intact with a body, it gives “0” as output through a serial port that is ignored by our script to write in a .csv file. Moreover, if an electrode is attached to the body, it always gives values more than “0” that are logged into the .csv file in a local directory of Raspberry pi for further processing as shown in Figure 3.4. Furthermore, python script store 10,000 valid data points in

.csv file. As we get 10,000 points, the infinite loop is terminated and the control is passed to the signal filtering function after 3 seconds delay. In this stage, the data is loaded in a NumPy array and passes through a bandpass filter for noise removal with 1Hz low cut, 40Hz high cut, and 400 sampling frequency. This filter configuration removes power-line and circuit noise and gives us clean ECG as shown in Figures 3.5(a, b) and a picture of a plotted graph is saved in the current directory along with a filtered ECG signal into a CSV file and ECG picture sent to the cloud database. Furthermore, Filtered ECG data is loaded from CSV fie and R-R peaks are extracted by using a heartpy library that marked valid and invalid R peaks and stores valid peaks in an array, based on R-R valid peaks the threshold values are determined to find an irregular rhythm of the heart if any along with heart rate calculation, and the final results are sent to the cloud databases storage that can be fetched on a mobile application.

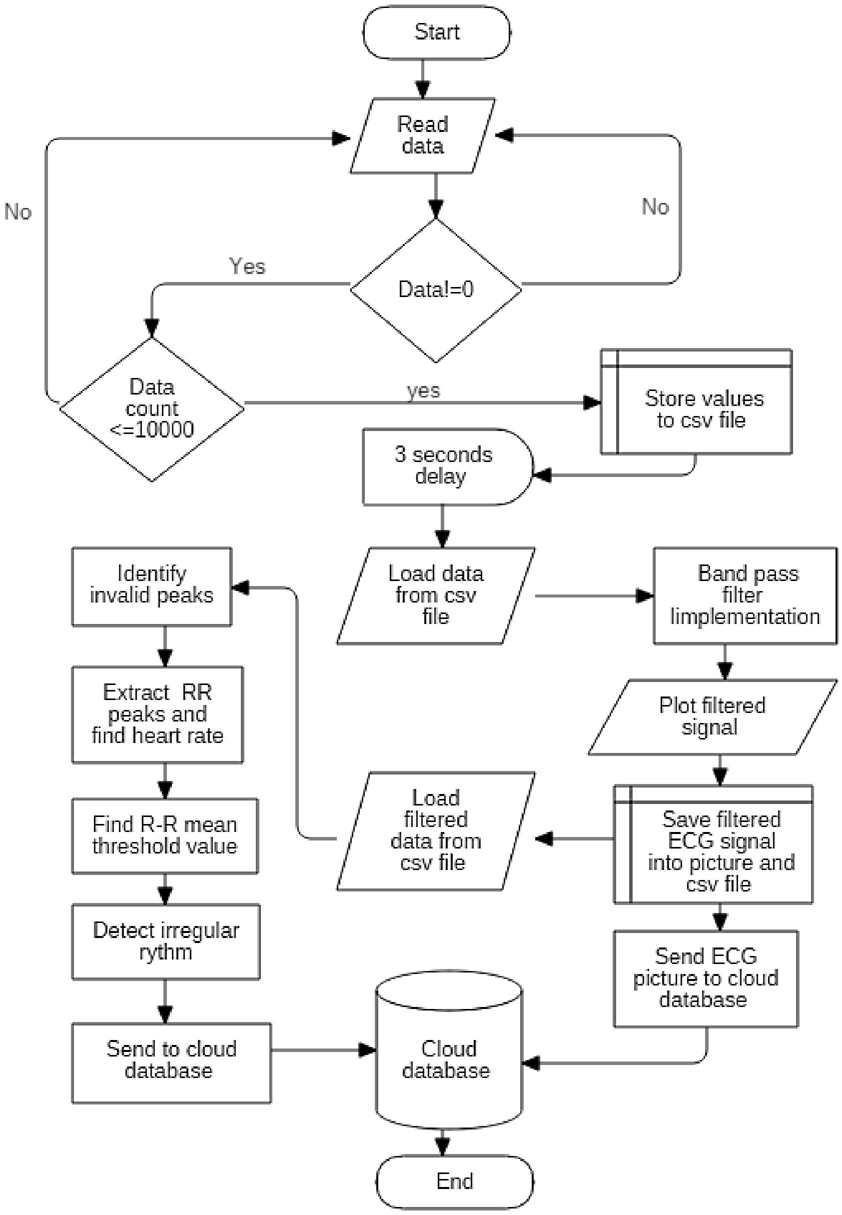

Figure 3.4 ECG data acquisition and processing flowchart

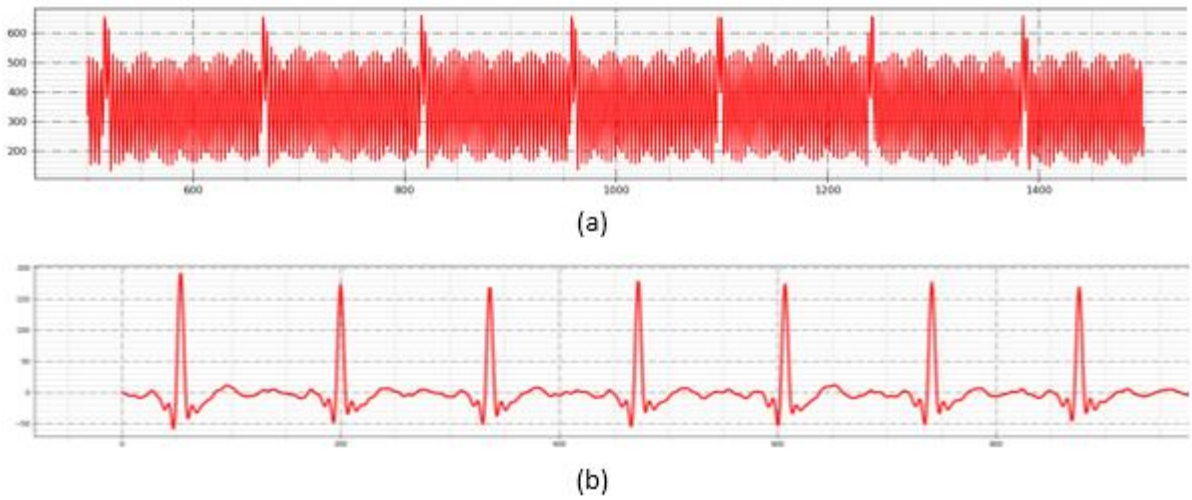

Figure 3.5 ECG signal pre-processing. (a) Raw signal, (b) Filtered signal

3.4 Oxygen Saturation sensor implementation and working principal

Pulse oximetry is a non-invasive technique to determine the oxygen saturation of blood-based on a beam of light. It is widely used in-home care and clinical applications. Typically attached with earlobe or fingertips. This research used MAX30102 an integrated pulse oximeter and heart rate sensor that has two LEDs, a photodetector, low-noise analog signal processing, and, optimized optics to detect pulse oximetry and heart-rate signals [50]. The sensor is directly connected to Raspberry pi and the pin configuration (MAX30102-Raspberry pi) is; VIN to 3.3V, GND to GND, SCL to GPIO 23, and SDA to GPIO 22 as shown in Figure 3.6.

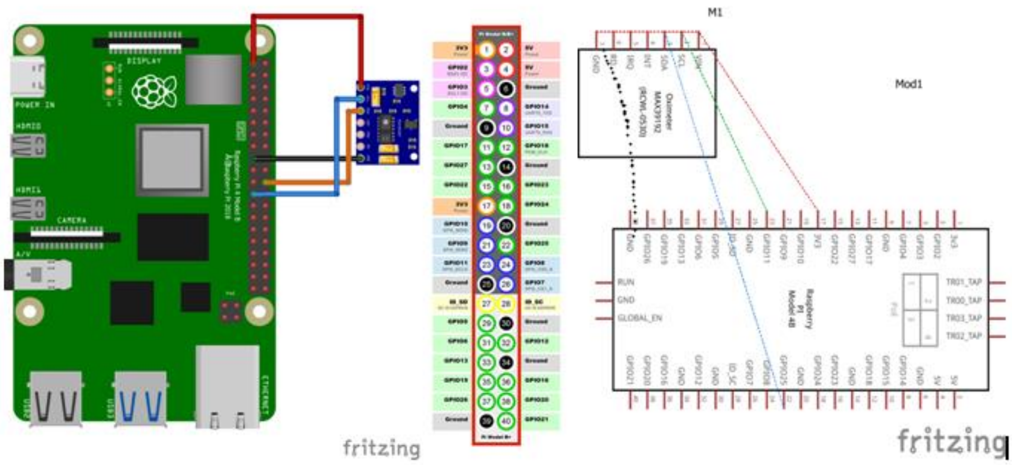

Figure 3.6 MAX30102 sensor circuit diagram

When the python script is executed, the MAX30102 photodetector and LED light are turned on. Where the optical signal is converted into an electrical signal that generates analog values to be stored in an array and processed by the MAX20102 library [51]. The script initializes the sensor to record raw values from an infrared and red LED. 100 values are recorded for each sensor and processed to generate the average SpO2 level that is sent to the cloud database as shown in Figure 3.7 followed by a delay of 2 seconds. Moreover, the script read the next 100 values to calculate the average SpO2 level. This process goes on for continuous monitoring of oxygen saturation until the finger is placed on sensors. If a finger is removed from the sensor, it is detected by an INT pin (GPIO) for checking the value availability the script will freeze unless the finger is placed again on a sensor.

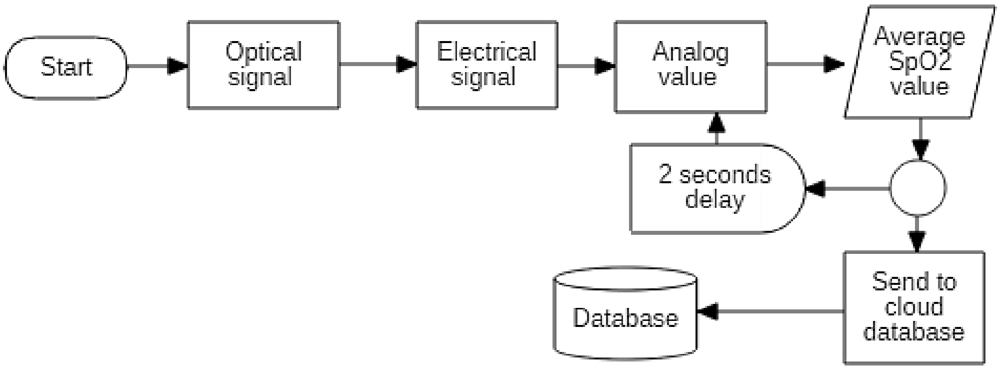

Figure 3.7 Oxygen saturation processing flow chart diagram

3.4.1 Working Principle of the PPG Sensor

Photoplethysmograph is widely used in pulse oximetry for SpO2 and heart rate measurements [52]. Pulse oximeters have two modes of operation: transmittance mode and reflectance mode. In transmission mode, the tissue sample is placed between the source light and the photodetector, while, in reflection mode, the LED and photodetectors are placed side-by-side. This work uses reflection mode pulse oximetry because of its flexibility and suitability for wearable sensors. In Figure 3.8, the working principle of a reflection-type PPG sensor is illustrated. For SpO2 measurements, a PPG optical sensor utilizes two types of light sources (LED) to illuminate the tissue. The two commonly used light sources are red and infrared (IR), with respective wavelengths of 660 nm and 940 nm. The red and IR wavelengths give different absorption properties for oxygenated hemoglobin (HbO2) and hemoglobin (Hb). The captured light at the photodetector is subsequently analyzed to estimate the blood volume changes, based on the difference in the absorption of red and IR wavelength [53].

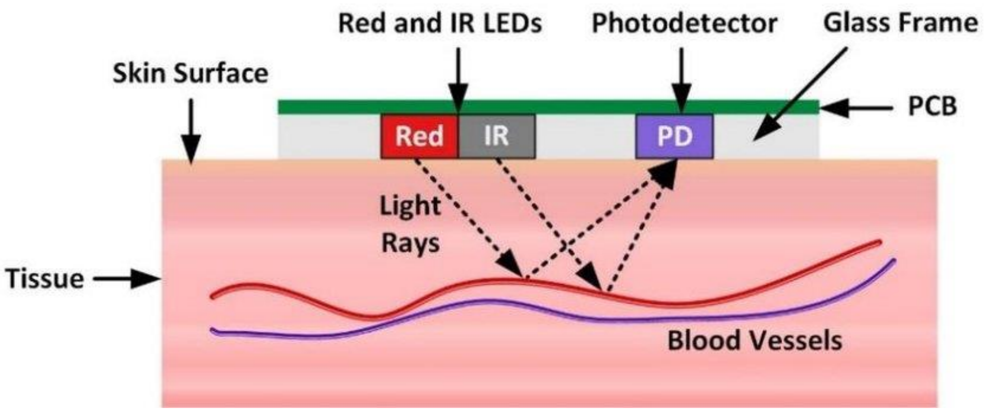

Figure 3.8 Reflection-type PPG sensor

Oxygen saturation in arterials is determined as the ratio of the total Hb, and HbO2 available in the Arteries. The comparison can be seen in the following equation (3.1):

$$SpO2 = [HbO2]/[HbO2] + [HB] \quad \textbf{3.1)}$$

Where: SpO2= Percentage of oxygen saturation, HbO2 = Haemoglobin containing oxygen, and HB= Haemoglobin that doesn't contain oxygen

The value of oximetry can be calculated by finding the value of R by formula (3.2). R is a comparison of the absorption of red and infrared light which produces AC and DC components: [54].

$$R = (ACred/DCred)/(ACired/DCired) \quad \textbf{(3.2)}$$

After R-value is known, then the value of SpO2 can be determined by entering the R-value into the following linear equation (3.3).

$$SpO2 = 110 - 25R \quad \textbf{(3.3)}$$

Where:

R= Voltage ratio results from the absorption of red and infrared light.

ACred = Value of AC voltage from absorption of red light.

DCred = Value of DC voltage from absorption of red light.

ACired =Value of AC voltage from infrared light absorption.

DCired =Value of DC voltage from infrared light absorption.

3.5 Heart rate sensor implementation

The normal heart rate of a person is between 60-100 beats per minute. For heart rate measurement, a pulse sensor is used in a proposed system that can be attached to the ear lobe or fingertip. It can be classified into two types based on the measurement technique of photoelectric pulse waves like transmission & reflection. This sensor has 3 pins; VCC, GND, and analog signal output pin. As there is no analog GPIO pin in Raspberry pi, so additional ADS1115 higher-precision ADC analog to digital converter is used between the heart rate sensor and raspberry pi. ADS1115 can be configured as 4 single-ended input channels with a programmable Gain Amplifier. It provides 16-bit precision at 860 samples/second over I2C. Pin configuration includes; (Heart rate sensor- Raspberry pi) GND to GND, 3.3v to 3.3v. (Heart rate sensor- ADS1115) signal pin to A0. (ADS1115 – Raspberry pi) GND to GND, VDD to 3.3v, SCL to GPIO3, and SDA to GPIO2 as shown in Figure 3.9. Heart rate can be obtained from both ECG sensor and pulse sensor. But the ECG sensor is not activated all the time and we want to measure heart rate continuously that' is why we used a dedicated pulse sensor.

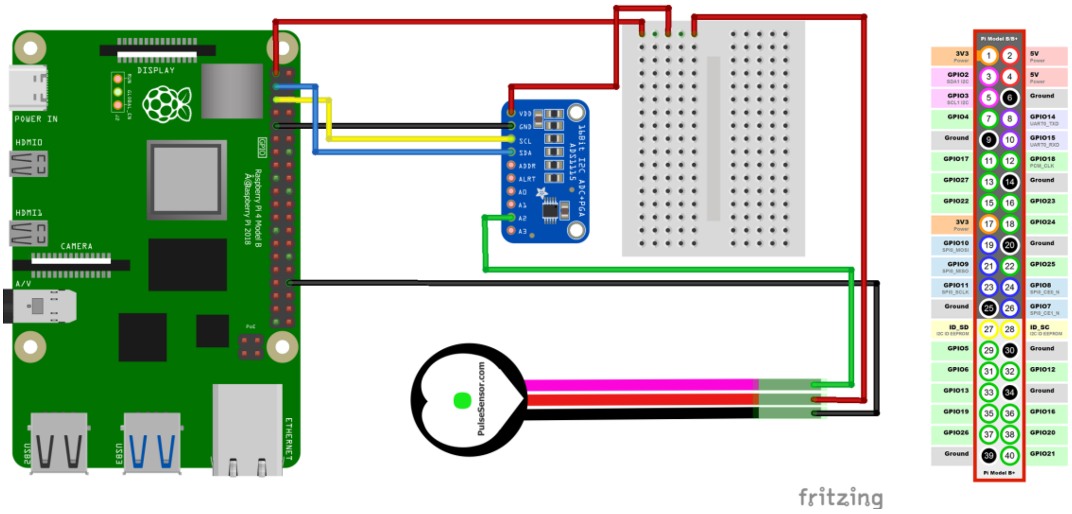

Figure 3.9 Circuit diagram and pin configuration of heart rate sensor

As the python script is executed the green light starts illuminating that indicating the sensor is ready to read heart rate to get accurate BPM data from the Pulse Sensor, it is important to have a fast and regular reading of the pulse sensor. By fast, we mean 500Hz (1 sample every 2 milliseconds) [55]. A dedicated subprocess is used in raspberry pi for pulse sensor processing using the PulseSensor playground library by Joel murphy. When a person places his finger on a sensor the optical signal is converted to an electrical signal and we get an analog value. Based on analog value heartbeat is calculated continuously to evaluate the average heart rate. As we get the average heart rate, the script sends the heart rate value to a cloud database that can be visualized on a mobile application as shown in Figure 3.10. Moreover, the sensor continuously reads analog values to calculate heart rate, and the process is continuous in a loop for real-time monitoring.

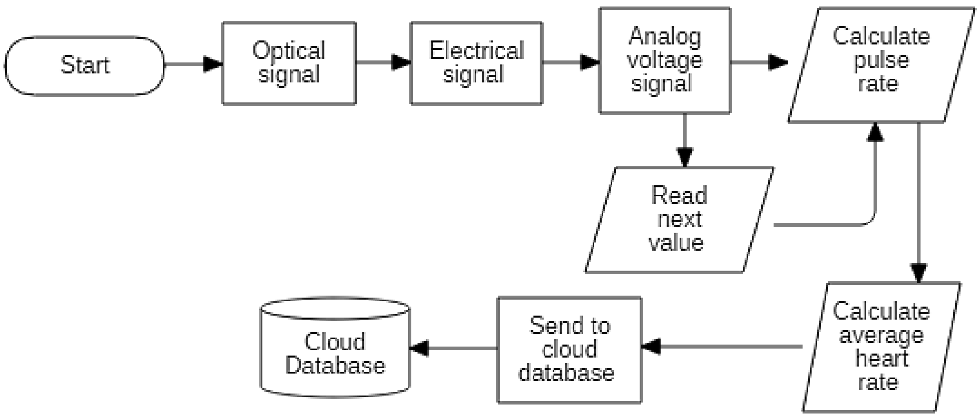

Figure 3.10 Heart rate sensor flowchart diagram

The optical pulse sensor works by shining a green light (~ 550nm) on the finger and measuring the amount of reflected light using a photosensor called a Photoplethysmogram. The front of the sensor is the side with the heart logo. This is where you place your finger. On the front side, you will see a small round hole, from where the Kingbright's reverse-mounted green LED shines. Just below the LED is a small ambient light photo sensor – APDS-9008 from Avago, similar to that used in cell phones, tablets, and laptops, to adjust the screen brightness in different light conditions as shown in Figure 3.11. On the back of the module, you will find the rest of the components including a microchip's MCP6001 Op-Amp and a bunch of resistors and capacitors that make up the R/C filter network. There is also a reverse protection diode to prevent damage if the power leads are accidentally reversed [56].

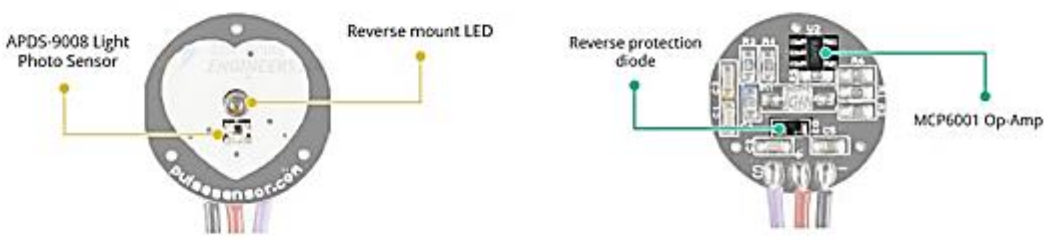

Figure 3.11 Pulse sensor top and bottom view

3.6 Temperature sensor implementation

Body temperature is an indicator that shows the behavior of the human body to respond to infection, inflammation, and trauma. [57] . LM35 sensor is used for getting body temperature. LM35 series are precision integrated-circuit temperature devices with an output voltage linearly proportional to the Centigrade temperature. As the output of the LM35 sensor is analog value and Raspberry pi does not have analog pins. So, ADS1115 analog to digital converter is used with pin configuration (LM35- ADS1115) GND to GND, VCC to 3.5v, DATA to A3, and (ADS1115- Raspberry pi) GND to GND, VDD to 3.3v, SCL to GPIO3, SDA to GPIO2 as shown in Figure 3.12. Specifications of LM35 are: Linear + 10-mV/°C Scale Factor, Rated for Full −55°C to 150°C Range, Less than 60-µA Current Drain, Non-Linearity Only ±¼°C Typical, Operates from 4 V to 30 V, Low-Impedance Output, 0.1 Ω for 1-mA Load, Low Self-Heating, 0.08°C in Still Air.

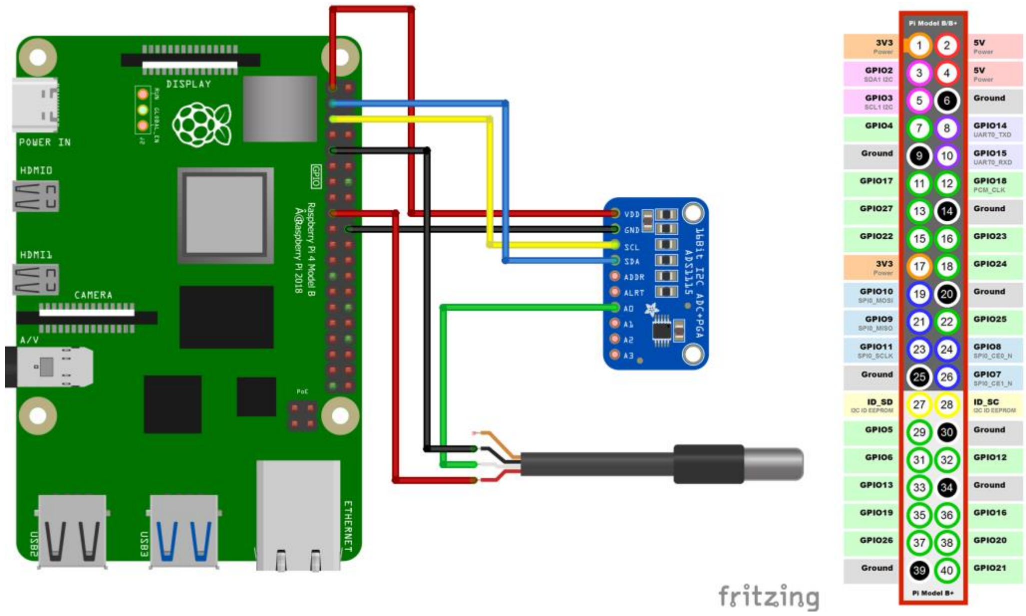

Figure 3.12 Temperature sensor circuit diagram and pin configuration

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