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Design and Development of a Wearable Device for Multi-Parametric Human Health Monitoring

Mukhriddin Arabboev[1 *], Shohruh Begmatov[2], and Khabibullo Nosirov[3]

[1,2,3]Department of Television and Radio Broadcasting Systems, Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, Tashkent 10084, Uzbekistan

Abstract

INTRODUCTION: Wearable technology has emerged as a promising tool for continuous health monitoring, offering potential disease prevention and management benefits. However, existing devices often provide limited physiological data, hindering comprehensive health assessments.
OBJECTIVES: This study aims to design and develop a wearable device capable of multi-parametric human health monitoring, focusing on vital indicators such as heart rate, body temperature, and physical activity.
METHODS: A modular design approach was employed to integrate multiple biosensors into a compact wearable device. The collected data was processed by a microcontroller and transmitted wirelessly to a server.
RESULTS: The developed wearable device demonstrated accurate and reliable measurement of target health parameters, with results comparable to existing prototypes in terms of functional capabilities.
CONCLUSION: The proposed wearable device holds significant potential for enhancing personal health management by providing comprehensive and real-time health data. Future research will focus on expanding the device's capabilities, improving battery life, and conducting long-term user trials.

Keywords: Wearable device, node MCU ESP-32, real-time monitoring, sensing technologies, vital signs.

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1. Introduction

Wearable technology has impacted on starting a new era of personalized healthcare. By enabling continuous monitoring of various physiological parameters (i.e., heart rate, body temperature), these devices have the potential to help disease prevention, early detection, and chronic condition management. However, most existing wearable devices focus on a limited set of parameters (physiological parameters), often neglecting the comprehensive assessment of overall health status [1]-[2].

To address this issue, we design and develop a novel wearable device capable of multi-parametric human health monitoring. By integrating multiple biosensors into a compact and user-friendly platform, the device provides an overview of an individual's physiological state. This approach is expected to enhance the effectiveness of health management strategies and facilitate timely interventions.

The remainder of the paper is organized as follows. In the "Literature Review" section, the existing prototypes of human health monitoring systems are discussed. In the "Proposed Device" section, we describe the main hardware components constituting the design criteria. This section also provides a full explanation of the development procedure of the proposed wearable device. In the "Comparison" section, we discuss the experimental results obtained and compare them with the existing prototypes. Finally, some concluding remarks are formulated in the "Conclusion" section.

*Corresponding author. Email: mukhriddin.9207@gmail.com

2. Literature Review

Several scientists have devoted the last decade to the creation of real-time health monitoring systems. Research on real-time health monitoring systems includes wearable, mobile and remote systems. An IoT-based heartbeat monitoring system is designed in [1]. The proposed system is integrated with the heartbeat detector. The system can automatically update the heartbeat of the patient over the Internet. An IoT-based cardiac monitoring system is developed in [3]. The system uses an Arduino Mega board, ESP8266 Wi-Fi Module, RFID module, pulse sensor and LCD. An energy-efficient wearable smart health system is developed in [4]. The system designed to discreetly track vital signs using a smartphone. The system can identify and predict and/or sudden cardiac arrests. A blood pressure monitoring system is developed in [2]. The proposed system uses a BMP180 sensor, ESP8266-12E, HC-05 Bluetooth module, L293D dual motor driver H bridge module board, KPM27H mini air pump motor, and Arduino Uno. An IoT-based health care monitoring system is developed in [5]. Web-based health monitoring system is presented in [6]. An IoT-based smart patient health monitoring is designed in [7]. This study integrates wireless sensors into an IoT-based health monitor [8]. Wireless sensors are combined with an IoT health terminal for this research. This study outlines a real-time system for tracking and storing patient health data [9]. The authors present a real-time monitor for patient health metrics. A sensor system for measuring and monitoring human body temperature and heart rate is developed in [10]. Finally, a human health monitoring and predicting system is developed in [11].

Overall, the overview of previous contribution on real-time health monitoring systems witnesses the tremendous attention devoted during the last decade to the development of various technology-based systems. However, none of aforementioned contributions ([x] - [y]) is likely to integrate as many vital signs as the proposed system developed in this work. We investigate the issue of integrating a variety of sensors with Wi-Fi technology by developing a wearable device for multi-parametric human health monitoring. The device presented in this paper has been used to generate patient diagnostic information, which is then transferred to a server wirelessly via Wi-Fi technology. Further, the collected information from a patient on the system is transferred to a web server via Wi-Fi technology. The system can generate emergency alerts and predict probable disease rates based on predefined values by comparing patient's data. This technique is useful as it could help to inform the doctor if there is a requirement for a checkup or investigation.

3. Proposed Device

This section explains the overall structure of developing the proposed wearable device. This section is divided into two subsections. The "Hardware Components" subsection presents all hardware components used to develop the proposed wearable device. The "Design and Development," subsection provides a thorough explanation of the design and the development process.

3.1. Hardware Components

The following hardware components were used to develop the proposed wearable device (see Figures 1-8): NodeMCU ESP32; OLED display; MAX30102 heart rate sensor; AHT10 sensor; BMP280 pressure sensor; MPU-9250; Battery; Battery Charger.

NodeMCU ESP32. The NodeMCU ESP32 is one of the widely used boards that can be integrated with both Wi-Fi and Bluetooth capabilities. The board has a dual-core processor, 240 MHz clock speed, and 520 KB of SRAM. These features of the board allow for efficient multitasking and complex applications. The board includes multiple GPIO pins, ADCs, DACs, and communication protocols like I²C, SPI, and UART. The main purpose of using the ESP32 board in this work, the board can provide wireless connectivity and processing power.

Figure 1. NodeMCU ESP32

OLED display. An I²C bus is used for communication between the Arduino and the OLED display. Several devices can be supported by the I²C bus, and every device has its own location. The Arduino code uses this address to communicate with the OLED display and sets its internal registers and memory to display the data on the screen. The proposed wearable device uses 0.91 inch OLED display. This screen size is large enough to read data coming from sensors. It consumes less energy due to the smaller screen size. The OLED display serves primarily as a means of displaying sensor data on the proposed wearable device.

Figure 2. OLED display

Heart rate sensor. Heart rate is one of the main human physiological parameters (vital signs). Therefore, regular monitoring of heart rate is essential. MAX30102 sensor is a heart rate sensor that helps to determine the health of a person by counting strokes. The MAX30102 is a biosensor module with integrated LEDs, photodetectors, and electronics for measuring SpO2 and heart rate, featuring ambient light rejection and on-chip temperature compensation. The MAX30102 sensor is used in the proposed wearable device to simultaneously measure body temperature, blood oxygen saturation, and heart rate.

Figure 3. MAX30102 sensor

AHT10 sensor. Body temperature is also one of the most important physiological parameters (vital signs) for humans. Because they can cause various diseases due to rapid temperature changes. AHT10 sensor can measure both humidity and temperature simultaneously. The sensor provides calibrated digital outputs in I^2C format, featuring a newly designed ASIC, an improved MEMS capacitive humidity sensor, and a standard on-chip temperature sensor. It is used in many devices for its low cost and multi-functionality. In the proposed device, the sensor serves to obtain patient's body temperature and humidity data.

Figure 4. AHT10 temperature sensor

Pressure sensor. Changes in atmospheric pressure can also lead to various diseases. The BMP280 barometer sensor is a small device that accurately measures air pressure and temperature. It can also estimate altitude based on pressure changes. It can be connected to a microcontroller using I^2C or SPI. In the proposed device, the BMP280 sensor serves to measure barometric pressure.

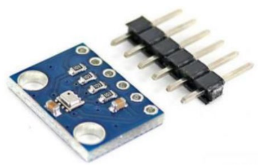


Figure 5. BMP280 pressure sensor

MPU-9250. Monitoring human internal vibrations and environmental vibrations is crucial for assessing human health. The MPU-9250 integrates three sensors—an accelerometer, magnetometer, and gyroscope—which can measure a person's movements (e.g., through positioning) [12]. Communication between these sensors is achieved using I^2C at up to 400 kHz or SPI at 1 MHz. For applications requiring faster data transmission, the sensor and interrupt registers can communicate via SPI at up to 20 MHz.

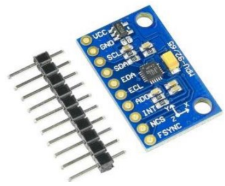


Figure 6. MPU-9250 sensor

Battery. A lithium polymer battery, or Li-Po battery, is a rechargeable lithium-ion battery featuring a polymer electrolyte. These batteries are characterized by their high energy density, thin profile, and light weight. This particular battery (used in this work) has a capacity of 200mAh. The device uses this battery to provide the necessary power. Since the device does not have many sensors and modules, the battery supplied is capable of providing sufficient power.

Figure 7. Battery

Battery Charger. Power Boost 500C is used in the proposed wearable device as a battery charger. This module has a TPS61090 boost converter. The boost converter chip has some extra features such as low battery detection, a 2A internal switch, synchronous conversion, excellent efficiency, and 700 KHz high-frequency operation.

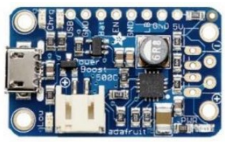


Figure 8. Battery charger

3.2. Design and Development

This section presents the design and development principles for the interconnection and integration of sensors and modules for the proposed wearable human health monitoring device. This section provides an overview of the device's block diagram, circuit board design, and functional specifications. The device's system architecture, circuit board schematic, and capabilities are outlined in this section.

Figure 9 shows the principle of interconnection and integration of sensors and modules used in the proposed wearable device. The proposed wearable consists of the two main blocks: Processor&Power block and Sensors block. The Processor&Power block is on the left in the figure. The Processor&Power block consists of an ESP32 microcontroller, a power block, and a battery. The Sensors block is on the right in the figure. The Sensors block consists of a humidity sensor, a temperature sensor, a heart rate sensor, an accelerometer, an air pressure sensor, and a display.

The ESP32 microcontroller and sensors are connected via the I^2C protocol. The I^2C (Inter-Integrated Circuit) is a serial communication protocol used to connect low-speed devices. It requires only two wires: SDA (Serial Data Line) for transmitting data and SCL (Serial Clock Line) for synchronization.

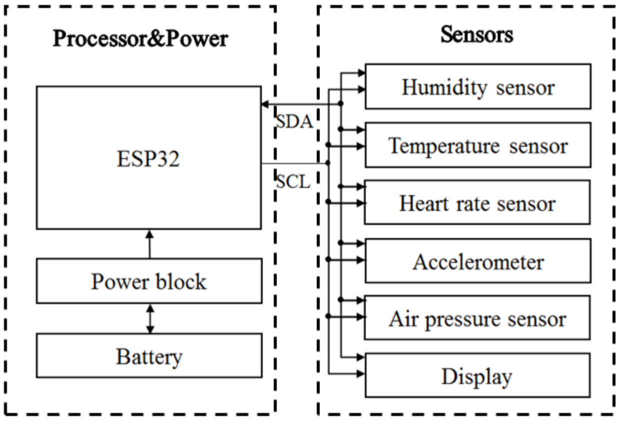


Figure 9. Principle of interconnection and integration of the proposed wearable device for multi-parametric human health monitoring

The circuit board for the proposed device was designed using Sprint Layout 6.0. This software's user-friendly interface and focus on essential tools made it suitable for creating 300x300mm PCBs. Following the digital design, the device components were physically assembled.

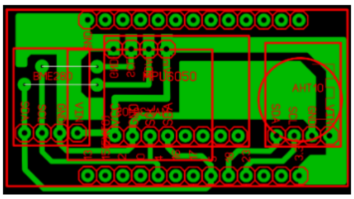


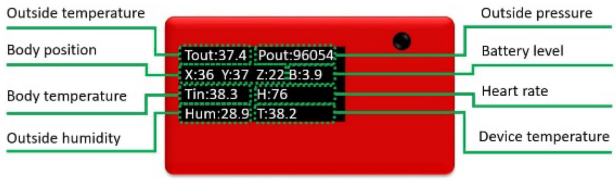
Figure 10. Electronic circuit of the proposed device.

Figure 11 depicts the proposed wearable device from two perspectives: a real-world view (a) and a 3D representation (b). The device is equipped with sensors to measure various human physiological parameters. The collected data is processed and displayed on the device's built-in screen for immediate user reference.

As depicted in Figure 11 (a), the wearable device is worn on the patient's wrist. This image highlights the device's comfortable fit while demonstrating its ability to accurately measure vital signs during real-time use.

Figure 11(b) is a logical continuation of Figure 11(a). Figure 11(b) shows the results obtained by measuring the patient's physiological parameters, as shown in Figure 11(a). It can be seen from Figure 11(b) that the device performed 8 different measurements. The four measurement parameters are depicted on the right of this figure. From top to bottom: outside pressure, battery level, heart rate and device temperature. The readings from the device were as follows: outside pressure: 96054 Pa, heart rate: 76 bpm, and device temperature: 38.2°C. Another four measurement parameters are depicted on the left of this figure. From top to bottom: outside temperature, body position, body temperature and outside humidity. The readings from the device were as follows: outside temperature: 37.4°C, body position: (X: 36, Y: 37, Z: 22), body temperature: 38.3°C, and outside humidity: 28.9 %.

(a)



(b)

Figure 11. Proposed wearable device: (a) Real view; (b) 3D view

A key contribution of this work is the development of an algorithm for human health monitoring and prediction.

Figure 12 depicts the developed algorithm for human health monitoring and prediction. The number of incoming data is determined and a loop with number k is opened by assigning it to a variable named k. Parameters are measured. In order to increase the accuracy of the measurements, the measured value is normalized with the previous ones. Based on all the data, the patient’s condition is predicted. If a deviation is noted, voice information is generated and an alarm is sent to the server. Otherwise, the measurement results are sent to the server. In both cases, the data is displayed to the user (patient).

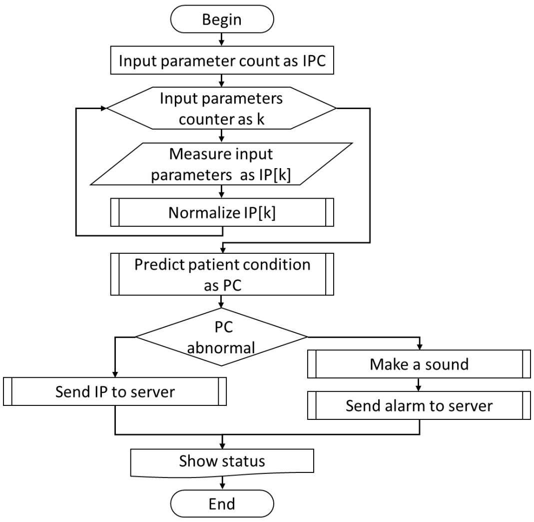


Figure 12. Algorithm for human health monitoring and prediction. IPC: Input parameter counter; IP: input parameter.

4. Comparison

A comparative evaluation of the proposed device against existing prototypes is presented in this section. The comparison highlights the functional differences and similarities between the devices.

Table 1 explains the comparison of the developed device with existing prototypes in terms of functionality: monitored parameters, applied network topology, and used microcontroller.

In Table 1, the proposed wearable device is compared with 10 existing prototypes according to their functional capabilities (technical specifications). More than half of the existing prototypes compared in this table used an Arduino microcontroller as the main processor of their device/system. 8 of the existing prototypes compared in this table applied Wi-Fi as the network technology of their device/system. The works where only one physiological parameter was monitored are: heart rate ([1], [3], [11]), body temperature ([13], [6]), and blood pressure [2]. The studies where two physiological parameters such as heart rate and body temperature were monitored in [4], [5], [8], [7].

The proposed wearable device uses an ESP32 as the main processor. The device supports Wi-Fi network technology. With the help of this device, along with physiological parameters such as heart rate, body temperature, and and body position, environmental parameters such as outside temperature, humidity, air pressure, which affect human health, are monitored.

Table 1. Functional comparison of the proposed device and existing prototypes based on parameters, network, and microcontroller

Reference	System	Monitored parameters	Applied Network Technology	Microcontroller
[1]	Heartbeat Monitoring and Detection system	Heart rate	Wi-Fi	Arduino and ESP8266
[3]	IoT-based Cardiac Monitoring System	Heart rate	Wi-Fi	Arduino Mega and ESP8266
[4]	Wearable Smart IoT System to Predict Cardiac Arrest	Heart rate and body temperature	Bluetooth	Arduino Uno
[2]	Blood Pressure Monitoring System	Blood pressure	Wi-Fi	NodeMCU
[5]	Health Care Monitoring System	Heart rate and body temperature	Wi-Fi	Arduino
[13]	IoT-enabled Network for Real-Time Safety and Health Monitoring	Body temperature	LoRa	ARM Cortex M0
[6]	Web-Based Health Monitoring System	Body temperature	N/A	Arduino
[8]	Human Health Monitoring System	Heart rate and body temperature	Wi-Fi	ESP32
[11]	Health Monitoring and Prediction System	Heart rate	Wi-Fi	Arduino and ESP8266
[7]	Smart Patient Health Monitoring System	Heart rate and body temperature	Wi-Fi	ESP32
Proposed	Wearable Device for Multi-Parametric Human Health Monitoring	Heart rate, body temperature, body position additionally environmental parameters such as outside temperature, humidity and air pressure	Wi-Fi	ESP32

Table 2 presents a comprehensive comparison of the developed device against existing prototypes. The comparison highlights the devices' cost-effectiveness, wearability, and capability to monitor multiple physiological parameters (three or more). According to these three evaluation criteria, the proposed wearable device met all the requirements and showed superiority over its compared counterparts ([14], [11], [15], [16], [17], [18]).

Table 2. Comparison of the proposed device and existing prototypes based on cost-effectiveness, wearability and multiple physiological parameters monitoring (three or more)

Title	Cost Effective	Wearable	Multi-parametric monitoring (3 or more parameters)
Wearable 2.0: Enabling Human-Cloud Integration in Next Generation Healthcare Systems [14]	No	Yes	Yes
Health Monitoring and Predicting System using Internet of Things & Machine Learning [11]	Yes	No	No
Exploiting smart e-Health gateways at the edge of healthcare Internet-of-Things: A fog computing approach [15]	No	No	Yes
Towards fog-driven IoT eHealth: Promises and challenges of IoT in medicine and healthcare [16]	No	Yes	No
Integrated IoT Medical Platform for Remote Healthcare and Assisted Living [17]	No	Yes	Yes
IoT-Based Low-Cost Smart Health Monitoring System using Raspberry Pi Pico W and Blynk Application [18]	Yes	No	Yes
Proposed	**Yes**	**Yes**	**Yes**

Table 3 compares the developed device to existing prototypes based on storage modality and feedback typology. Moustafa et al. [19] developed a human health monitoring system that employs both local and central databases for data storage. This system provides insights into the user's health and wellness status. Chen et al. [14] also created a human health monitoring system, but it relies solely on a central database. Their system offers additional feature emergency alerts to family members. Rahmani et al. [15] developed a multi-parametric health monitoring system that utilizes both local and central databases for data storage. Their system provides emergency alerts to family members. Farahani et al. [16] proposed a human health monitoring system that employs local and central databases. Their system offers the following features: medical advice and family notifications. Rashed et al. [17] developed a medical monitoring system equipped with emergency medical aid, medical advice, and family alerts. Hala Jassim Mohammed [18] created an affordable device that monitors vital signs. It uses both local and central databases to store data. This device tracks body temperature, heart rate, and blood oxygen levels. If any of these numbers suddenly change, it sends a warning message to the patient's caregivers.

The proposed system employs both local and central databases for data storage. It predicts heart and body temperature-related diseases by analyzing sensor data and employing a predictive algorithm. Upon detecting deviations from normal physiological parameters, the system generates a voice alert and transmits an alarm signal to the server.

Table 3. Functional comparison of the proposed device and existing prototypes based on storage modality and feedback typology

Reference	Storage Modality	Feedback Typology
[19]	Local and Central DB	Information about health and wellness of user's status
[14]	Central DB	Emergency alarm to family members
[15]	Local and Central DB	Emergency alarm to family members
[16]	Local and Central DB	Medical advisor; Emergency alarm to family members
[17]	Local and Central DB	Medical advisor; Information about health and wellness of user's status
[18]	Central DB	The developed system monitors for patient vital signs observation wirelessly in real-time
Proposed	Local and Central DB	The proposed wearable device detects abnormal heart and body temperatures and triggers emergency alerts

Table 4 compares the proposed device to existing prototypes, focusing on sensor types, communication methods, and data visualization.

The proposed wearable device [4] with pulse and temperature sensors enables real-time health monitoring. Bluetooth syncs data to a mobile app for tracking and insights. The study focuses on optimizing energy consumption for longer battery life. This study [5] uses pulse, temperature sensors, and an LCD to track health in real time. Wi-Fi, instead of costly Zigbee, connects the device for practical data transmission. The proposed device [18] features sensors for temperature, heart rate, and oxygen levels, with Wi-Fi for data transmission to a web app. While it offers local data on an LCD, further development is needed to improve wearability. The system [9] integrates blood pressure, heartbeat, and body temperature sensors, using Wi-Fi and MQTT protocols for data transmission to a web application. However, the Wi-Fi communication channel exhibits noticeable latency, which may affect the real-time accuracy of the health monitoring data. The system [20] is equipped with sensors for monitoring body temperature, pulse, blood oxygen, and blood glucose levels, with data transmitted via the Bluetooth HC-06 module to a web application. In the study, data analytics tools are not used for automated decision-making. The system [10] uses heartbeat and body temperature sensors with Wi-Fi and HTTP to transmit data to a web application. However, the limited number of sensors currently employed is insufficient for comprehensive patient monitoring, potentially leaving gaps in the overall assessment of the patient's health status. The system [11] utilizes heartbeat and pulse sensors connected via Wi-Fi to a web application for data transmission. However, the study lacks experimental results, which limits the ability to evaluate the effectiveness and accuracy of the system in real-world scenarios. The prototype [21] includes heartbeat, blood pressure, and body temperature sensors, with data transmitted via Wi-Fi and HTTP to a web application and displayed on an LCD. However, it does not address emergency cases in its current design.

The proposed wearable device in this work is equipped with sensors to monitor heart rate, body temperature, body position, as well as external factors like temperature, humidity, and air pressure. This comprehensive data is transmitted wirelessly via Wi-Fi/HTTP to a web-based application, where it is analyzed to predict potential health issues. An LCD screen provides real-time feedback on the device's measurements.

Table 4. Comparison of the proposed device with existing prototypes, considering their sensor usage, communication methods, and data presentation

Reference	Sensors	Communication Media/Protocol	Visualization	Comments
[4]	Pulse and body temperature sensors	Bluetooth	Mobile application	The study mainly focuses on energy efficiency issues for the developed wearable device.
[5]	Pulse and body temperature sensors	Wi-Fi	LCD	This study uses Wi-Fi due to Zigbee's high cost.
[18]	Body temperature, heart rate and blood oxygen sensors	Wi-Fi	Web application, LCD	The proposed prototype is not currently suitable for wearability.
[9]	Blood pressure, heartbeat, and body temperature sensors	Wi-Fi/ MQTT	Web application	There is a noticeable amount of latency in the Wi-Fi communication channel.
[20]	Body temperature, pulse, blood oxygen, and blood glucose sensors	Bluetooth HC-06	Web application	Data analytics tools are not employed in automated decision-making.
[10]	Heartbeat and body temperature sensors	Wi-Fi/ HTTP	Web application	A limited number of sensors is insufficient to fully monitor the patient's status.
[11]	Heartbeat and pulse sensors	Wi-Fi	Web application	The study lacks experimental results
[21]	Heartbeat, blood pressure, and body temperature sensors	Wi-Fi/ HTTP	Web application, LCD	Emergency cases were not addressed in the developed prototype.
Proposed	Heart rate, body temperature, body position, outside temperature, humidity and air pressure sensors	Wi-Fi/HTTP	Web application, LCD	The device measures vital signs and environmental factors to predict patient health

4. Conclusion

In this work, a wearable device for comprehensive health monitoring and prediction is developed. The developed device features sensors that track heart rate, body temperature, and environmental factors like temperature, humidity, and air pressure. The device wirelessly transmits data to a web application where advanced algorithms analyze and predict health risks.

A major breakthrough is the creation of a novel algorithm for health monitoring and prediction, enhancing the device's ability to provide valuable health insights. According to the comparison, the device surpasses existing prototypes by offering a wider range of parameters, a robust network topology, and a powerful microcontroller. Further emphasize its cost-effectiveness, wearability, storage, feedback mechanisms, sensor types, communication methods, and data visualization.

Overall, this wearable device marks a significant advancement in personal health monitoring, with potential benefits for preventative care and overall well-being. Future research should refine the algorithm, add more sensors, and explore real-time health interventions.

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