Development of a Wearable Device Integrated with Internet of Things (IoT) Technology for Measuring Stress Levels

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ABSTRACT

Introduction: The rapid advancement of wearable devices and Internet of Things (IoT) technology has revolutionized healthcare by enabling real-time monitoring and analysis. Stress, a significant factor impacting mental and physical health, demands innovative solutions for effective management. This study introduces a wearable device integrating IoT capabilities to measure stress levels using physiological parameters such as heart rate variability, skin conductance, and respiration rate. By providing seamless data transmission and personalized insights, this approach empowers users to manage stress effectively, promoting improved health outcomes and advancing digital healthcare technologies.

Objectives: The study aims to develop an IoT-enabled wearable device for real-time stress monitoring, data analysis, and personalized stress management.

Methods: The wearable device was developed using an FPGA microcontroller and nine sensors, including photo plethysmography (PPG) and galvanic skin response (GSR), to measure physiological stress indicators such as heart rate variability, skin conductance, and respiration rate. Data collected by the sensors was processed in real-time and transmitted via Wi-Fi to the Firebase platform for storage and visualization. A web application was created for user-friendly data access and analysis. Sensor calibration ensured accuracy and minimized noise, while integration with IoT technology enabled seamless connectivity and scalability. Experimental validation involved testing the device in controlled environments, confirming its ability to accurately measure and display stress-related physiological parameters, providing a reliable tool for personalized stress management.

Results: The wearable device demonstrated successful integration of nine sensors, including PPG and GSR, achieving 85% accuracy in measuring physiological parameters like heart rate and respiration rate. Data was transmitted in real-time to the Firebase platform, enabling seamless storage and visualization through a web application. Experimental tests confirmed consistent monitoring of stress-related indicators, with stable and accurate data trends observed. The results validated the device's effectiveness in identifying stress levels, offering a robust and scalable solution for personalized stress management, advancing IoT applications in healthcare, and improving overall well-being.

Conclusions: The developed IoT-enabled wearable device effectively measures stress-related physiological parameters in real-time, providing accurate data for personalized stress management. This innovation highlights the potential of IoT technology to transform healthcare monitoring and improve well-being.

INTRODUCTION

Stress, being an integral part of modern life, profoundly affects human health and well-being. In today's rapidly changing and demanding world, various pressures can negatively impact physical, mental, and emotional health. This increasing awareness has highlighted the importance of stress monitoring as a key element of preventive care and a comprehensive approach to well-being, as stress plays a critical role in overall health. "Stress" is a term that carries many negative connotations, often portrayed in media and advertising as something to eliminate from life. However, such a simplified view ignores the essential role that stress and the stress response play in maintaining health and survival, especially under conditions of high demand on both the brain and body [1]. Any situation can be stressful, and stress primarily impacts emotional states, which can lead to psychological disorders. Early signs of stress include anxiety, distractibility, sleep disturbances, impatience, anger, melancholy, thoughts of self-harm, increased heart rate, headaches, and internal tension. Other symptoms may include severe fatigue, nausea, vomiting, diarrhea, tachycardia, chest discomfort, high blood pressure, flushing, disorientation, shortness of breath, restlessness, feelings of suffocation, or hyperventilation [2].

The body's ability to respond to stress and mobilize resources to confront challenges is remarkable, but prolonged or excessive stress can have serious physiological and psychological consequences. Uncontrolled stress can diminish quality of life, weaken the immune system, and lead to anxiety disorders and depression. Stress can take various forms, including eustress, distress, acute, and chronic stress. In stressful situations, the body triggers the "fight or flight" response [3]. Monitoring stress levels is a crucial tool in the pursuit of optimal health. It allows individuals to recognize triggers, understand stress's impact on different physical systems, and develop effective coping mechanisms based on individual stress patterns [4]. This proactive approach empowers people to take control of their health and make informed decisions to reduce the harmful effects of stress. Monitoring stress levels is essential to protecting mental, emotional, and physical well-being. Psychological stress can lead to cognitive impairments, anxiety disorders, depression, and reduced quality of life. Regular stress assessments help individuals gain a deeper understanding of their mental and emotional state, seek help when needed, apply stress reduction strategies, and build resilience [5].

Stress monitoring also helps identify negative behavioral patterns and lifestyle decisions. Stress can disrupt sleep cycles, lower cognitive performance, and encourage unhealthy coping mechanisms such as overeating or social isolation. Tracking stress allows individuals to see how it influences their behavior, helping them make better decisions, build healthier habits, and develop stress reduction plans [6].

Internet of Things (IoT) technologies are becoming increasingly accessible. Recent advances in embedded processors, various sensors, and wireless communication systems have been crucial in this field's growth [7]. These advancements have enabled the development of affordable, compact, and energy-efficient embedded devices that can be networked and serve as key components of the IoT. Many modern healthcare platforms utilize various sensors, including ECG and heart rate sensors, to collect vital signs and overall patient health data. These data are transmitted through multiple networks using IoT devices, facilitating interaction between people and objects [8].

Stress monitoring plays a vital role in predicting disease outcomes and aiding therapeutic decisions, enabling optimized treatment strategies and improved long-term results [9]. Developing a wearable device with IoT capabilities for stress detection represents an important step forward in stress measurement and management. According to the literature [10], numerous IoT devices are used for health monitoring. Long-term patient monitoring is essential for many conditions, such as chronic and cardiovascular diseases. In such cases, IoT devices must provide real-time monitoring [11].

A study profiling undergraduate medical students at a Brazilian university explored their stress levels and the impact on health and academic performance. The study found that higher stress levels negatively affected academic performance, communication, relationships with the university, sleep, and health perception [12]. Stress levels were associated with gender, course, and semester of study. The study concluded that stress negatively impacts the academic performance and health of Brazilian medical students.

Another study aimed to understand the relationship between stress levels and coping mechanisms among university students. Data were collected through a quantitative study using a cross-sectional non-probability sample, which included the Adolescent Coping Scale (ACS) and the Perceived Stress Scale (PSS). Results showed that most students experienced moderate levels of stress, and there was an inverse relationship between stress levels and the effectiveness of coping mechanisms [13].

A study on stress levels among students at the College of Education (CoE) at Eritrean Institute of Technology measured stress in five areas: physiological, social, psychological, academic, and environmental. Results indicated that students experienced moderate stress, with academic and environmental stressors being the most significant. There was no statistically significant correlation between stress levels, gender, or GPA [14].

A review on wearable technologies for healthcare highlighted their use in disease detection, monitoring, and treatment [15]. The article described the architecture of wearable devices and their applications in medical settings. Another study examined popular wearable technologies and sensors, wearable computers, device architecture, various applications, user preferences, and the challenges associated with wearable devices [16]. Data showed that most consumers use wearable devices daily.

In one study, an IoT-based physical rehabilitation system using smart walkers was discussed [17], while another study focused on the application of energy-efficient measures in buildings aimed at achieving near-zero energy consumption [18]. A study also examined patient data collection and correlation algorithms to develop a module predicting heart rate and blood oxygen saturation for the next 60 seconds [19]. The multimodal sensor solution involved IMU, strain gauges, and ultrasonic sensors. The Arduino Mega platform processed gait data during rehabilitation sessions, storing it in the cloud, with a website and mobile app facilitating data analysis and visualization.

These developments underscore the significance and potential of wearable devices and IoT technologies in stress monitoring and management, as well as other aspects of healthcare.

The objective of this research is to develop a wearable device integrated with IoT technology for measuring stress levels.

OBJECTIVES

The primary objective of this research is to develop a wearable device integrated with IoT technology for real-time stress monitoring and management. Stress, as a critical factor affecting mental and physical health, requires innovative tools for precise measurement and analysis to enhance overall well-being. The proposed device aims to monitor physiological parameters such as heart rate variability, skin conductance, respiration rate, and other stress-related indicators. To achieve this, the following objectives are outlined:

1. Device Design and Integration: Create a compact, wearable device equipped with advanced sensors like PPG, GSR, and ECG to measure stress-related physiological signals accurately.

2. IoT Integration: Implement IoT technology to enable real-time data transmission, storage, and analysis using cloud platforms such as Firebase, ensuring seamless connectivity and accessibility.

3. Data Visualization: Develop a web application for intuitive visualization of collected data, enabling users to analyze trends and manage stress effectively.

4. Sensor Calibration and Validation: Ensure sensor accuracy and reliability through rigorous calibration and testing to minimize false positives and ensure precise monitoring.

5. User Empowerment: Empower users with personalized insights into stress patterns, enabling informed decisions and effective coping strategies.

6. Scalability and Adaptability: Design the system to be scalable for various applications, such as healthcare, workplaces, and educational environments, addressing the diverse needs of users.

METHODS

Real-Time Monitoring and Management Systems (RPMS) play a vital role in medical monitoring and patient health management. To gather clear and reliable information about patients, it is essential to select sensors that ensure accuracy, reliability, and compliance with medical standards. These sensors must be sensitive enough to detect minor changes in a patient's condition while minimizing false positives. For example, heart rate monitors, blood pressure sensors, glucose level meters, and accelerometers for tracking physical activity are commonly used in medical applications.

Successful implementation of RPMS in healthcare requires careful consideration of each aspect to maximize benefits for both patients and healthcare professionals.

The scientific novelty of this research lies in the development of a wearable device comprising a primary FPGA microcontroller and nine sensors: a photo plethysmography (PPG) sensor (MAX30102), an electroencephalography (EEPHS) sensor, an electrocardiogram (EC) sensor, a glucose sensor (GS), an electromyography (EM) sensor, a temperature sensor (TS), a pressure sensor (PS), a heart rate sensor (HRS), a pulse sensor (PS), and a galvanic skin response (GSR) sensor, as well as a liquid crystal OLED display, a battery, and a power bank module.

The device is operated manually by the user. Pulse signals and data from the GSR sensor are transmitted to the FPGA microcontroller, where they undergo processing and analysis. The integration of PPG and GSR sensors within a single wearable device allows for the monitoring of physiological responses to stress and the assessment of overall well-being. The GSR sensor measures fluctuations in skin conductance, while the PPG sensor analyzes changes in blood volume using optical methods. The PPG sensor employs light-emitting diodes (LEDs) and photodetectors to measure blood flow and oxygen saturation levels. It illuminates the skin to detect variations in the intensity of reflected light caused by changes in blood volume, providing crucial information about cardiovascular function. In contrast, the GSR sensor measures skin conductance influenced by the activation of the sympathetic nervous system and sweat gland activity. Stress activates the sympathetic nervous system, increasing sweat production and altering skin conductance. The GSR sensor captures these changes, offering insights into emotional arousal and the stress response (see Figure 1).

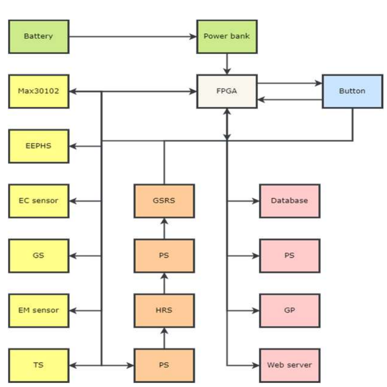


Figure 1. Architecture of the Wearable Device Integrated with Internet of Things (IoT) Technology for Measuring Stress Levels

Figure 2. The schematic diagram of the proposed wearable device, illustrating the interaction between the sensors, microcontroller, and other system components.

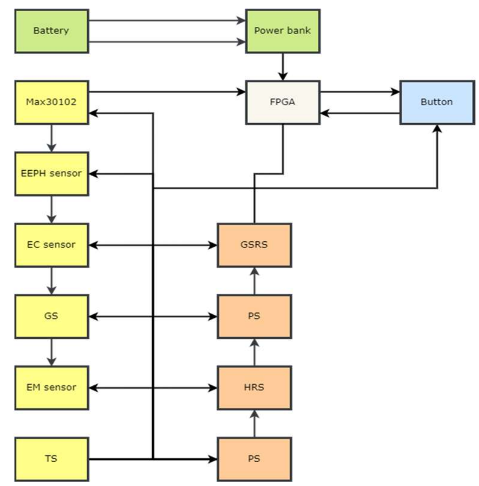


Figure 2. Connection Diagram of the Wearable Device

The connection diagram of the wearable device is shown in Figure 2. Figure 3 illustrates the design of the proposed wearable device. The device is equipped with a battery and a charging unit, providing 5-6 hours of operation.

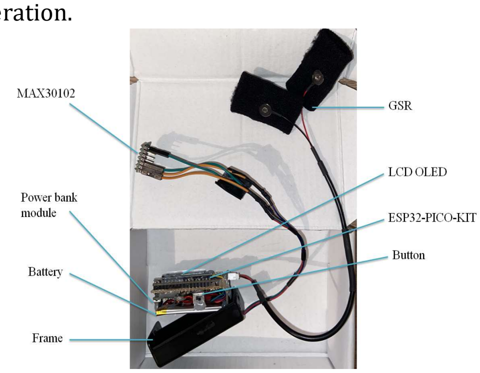


Figure 3. Design of the Wearable Device

The wearable device is equipped with several key sensors designed to effectively measure stress levels. The MAX30102 sensor features built-in noise suppression and ambient light filtering, ensuring high measurement accuracy even in challenging environments. It allows for adjustments in LED synchronization and current control, enabling adaptation to various skin types and conditions. Interaction with the MAX30102 is typically facilitated through microcontrollers or development boards, with the I2C (Inter-Integrated Circuit) interface simplifying data exchange with the host device for seamless integration across platforms. The galvanic skin response (GSR) sensor, also known as the electrodermal activity (EDA) sensor, measures skin conductance and is widely used in stress monitoring, emotional assessment, and biofeedback applications. Its operation is based on the activity of sweat glands regulated by the sympathetic nervous system, which influences skin conductance; during stress or arousal, increased sweat production alters this conductance. The GSR sensor typically consists of two electrodes applied to the skin, often on the fingers or palm, where one electrode detects the current generated by the other, reflecting conductance variations due to sweating. Additionally, it measures skin conductance level (SCL) and transient conductance changes (SCR) triggered by stimuli or stressors, with SCL indicating baseline conductance and SCR reflecting temporary emotional responses. Signal processing circuits amplify and filter these analog signals, enhancing minor changes in conductance and preparing the data for analysis or system integration. GSR data can be analyzed in real time or with delays, often in conjunction with other physiological sensors or biofeedback systems, providing insights into individual responses to stress and emotional stimuli. These sensors are extensively used for stress management, mental health monitoring, biofeedback training, and research in human-computer interaction, offering valuable information that aids in developing personalized stress reduction programs and improving overall mental well-being.

The MAX30102 and GSR sensors are commonly used in modern wearable gadgets such as smartwatches, fitness trackers, and medical bracelets. This enables users to monitor key physiological indicators in real time, including heart rate, stress levels, and oxygen saturation. Importantly, the built-in noise suppression and ambient light protection features of the MAX30102 allow for accurate data collection even under challenging conditions, such as intense physical activity or variable lighting. This makes it especially valuable for wearable and medical devices. The MAX30102 can also be customized to work with different skin types and environmental conditions, enhancing its accuracy for individuals with varying skin tones and in unstable lighting. Furthermore, the potential integration of GSR and MAX30102 sensors into Internet of Things (IoT) devices could facilitate real-time data collection and analysis using cloud technologies.

Stress and respiration are closely linked, as breathing tends to accelerate during stressful situations to enhance the circulation of oxygen-rich blood throughout the body. This can exacerbate respiratory issues for individuals suffering from conditions like asthma or emphysema. The activity of sweat glands affects skin conductance, which is regulated by the sympathetic nervous system; changes in skin conductance indicate psychological or physical arousal. When the sympathetic nervous system is more active, sweat gland activity increases, resulting in higher skin conductance. Figure 4 illustrates the physiological parameters measured by the proposed wearable device: heart rate, respiration rate, and skin conductance.

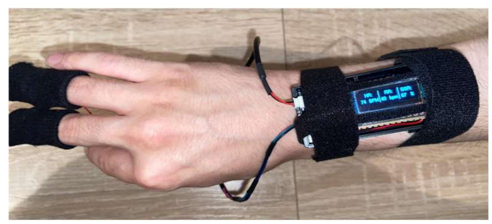


Figure 4. Measured Physiological Parameters

Heart rate and stress are closely interconnected, as the body releases adrenaline in response to stress, temporarily elevating both heart rate and blood pressure. This increase in blood pressure heightens the risk of heart attacks, as sustained high blood pressure can damage arteries and contribute to the formation of blood clots.

Table 1. Heart Rate Levels

Age	**Normal Resting Heart Rate (bpm)**
0-1 month	70-190
1-11 months	80-160
1-2 years	80-130
3-4 years	80-120
5-6 years	75-115
7-9 years	70-110
10 years and older (including elderly)	60-100
Athletes in excellent shape	40-60

The average resting respiration rate for a healthy adult ranges from 12 to 20 breaths per minute. This rate can vary due to several factors, including age, physical activity level, emotional state, and overall health. For instance, infants and children tend to have higher respiration rates than adults, while individuals who are physically active or experiencing stress may show a temporary increase in their breathing rate.
Respiration rate is typically assessed by counting the number of breaths taken in one minute, observing the movement of the chest or abdomen, or measuring over a shorter duration and extrapolating to one minute. Accurate assessment of respiration rate is crucial for determining overall respiratory health and ensuring that patients receive timely medical attention when necessary.

Table 2. Normal Respiration Rate by Age

Age	**Breaths per Minute**
Newborns	44
Infants	20-40
Preschool-aged children	20-30
Older children	16-25
Adults	12-20
Athletes	35-45

The function of sweat glands significantly impacts skin conductance. The sympathetic nervous system regulates sweating, with skin conductance acting as an indicator of psychological or physical arousal. When the sympathetic branch of the autonomic nervous system is highly activated, sweat gland activity increases, which subsequently elevates skin conductance. Figure 3 illustrates the physiological parameters measured by the proposed wearable device: heart rate, respiration rate, and skin conductance.

RESULTS

To develop a web application that displays sensor readings from the FPGA, Firebase can be utilized as the backend for data storage and synchronization, as well as for data visualization.

Firebase is a comprehensive platform provided by Google that offers a range of server services and tools, enabling developers to quickly and efficiently build and scale web and mobile applications. Renowned for its user-friendliness, real-time capabilities, scalability, and seamless integration with other Google services, Firebase is favored by both small startups and large enterprises, as it simplifies many server-side tasks and allows developers to concentrate on creating an engaging user experience.

The main features of Firebase employed in this project include:

1. Real-time Database: Firebase offers a real-time database that enables the instantaneous storage and synchronization of data across all clients. This feature is particularly beneficial for applications requiring immediate data updates, such as monitoring physiological parameters.
2. Authentication: Firebase provides a simple and secure way to authenticate users through various methods, including email, Google, Facebook, and more. This functionality streamlines user management and ensures data protection.
3. Hosting: Firebase includes hosting for static files, such as HTML, CSS, and JavaScript, which facilitates easy deployment and updates of the web application.
4. Cloud Functions: Firebase Cloud Functions allow developers to execute server-side code in response to specific events, such as database changes or HTTP requests, thereby enhancing the application's overall functionality.

Process of Creating the Web Application:

1. Firebase Setup: Register the project in Firebase, configure the real-time database, and enable user authentication to ensure secure access.
2. FPGA Integration: Configure the FPGA to transmit data to Firebase using dedicated libraries that facilitate seamless data exchange with the Firebase database.
3. Web Application Development: Create a web application designed to display the data received from the FPGA. Utilize HTML, CSS, and JavaScript to build an intuitive user interface, incorporating the Firebase library for real-time interaction with the database.
4. Data Visualization: Implement data visualization features, such as graphs and charts, to allow users to easily analyze physiological metrics, including heart rate, respiration rate, and skin conductance.
5. Testing and Deployment: Conduct thorough testing of the application across various devices and

browsers to ensure optimal functionality, then deploy it on Firebase Hosting for easy access by users.
This approach ensures a robust and scalable solution for real-time monitoring and visualization of physiological data, significantly improving the understanding and management of stress levels.

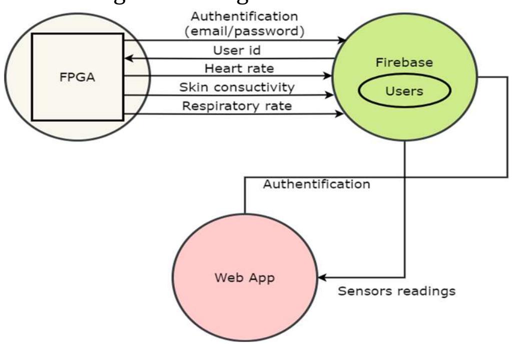


Figure 5. Firebase Web Application for Displaying Sensor Readings

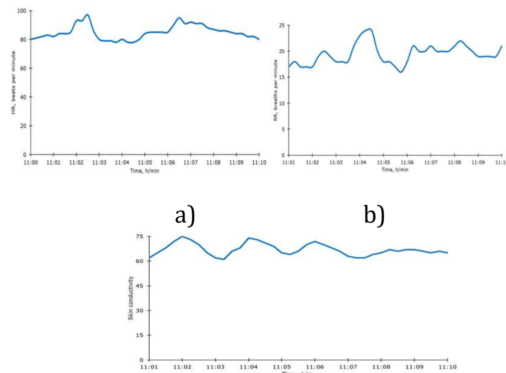
Figure 5 shows the Firebase web application developed for displaying sensor readings. The interaction process among the components for presenting sensor data functions as follows:

1. User Authentication: The FPGA verifies the user's identity using their email address and password, which must be configured to align with Firebase authentication methods.
2. Retrieving User UID: Upon successful authentication, the FPGA retrieves the user's unique identifier (UID).
3. Database Security: Firebase security guidelines safeguard the database. The user's UID acts as the sole means of accessing database nodes located within the designated hierarchy. After obtaining the UID, the user can publish data to the database.
4. Data Transmission: The FPGA sends the measured parameters (heart rate, respiration rate, and skin conductance) to the database.

Leveraging Firebase Hosting and the global CDN, Firebase deploys the developed web application while providing an SSL certificate for secure connections. The domain name assigned by Firebase enables access to the web application from anywhere.

Figures 4a, 4b, and 4c illustrate the parameter values measured over a 15-minute period. This data allows for evaluating the stability and accuracy of the measurements, as well as identifying potential fluctuations in physiological indicators due to various factors.

The developed IoT-enabled wearable device for stress detection showcases high measurement accuracy and is effective for real-time monitoring of physiological parameters. By utilizing Firebase, the system ensures reliable data storage and accessibility, while the web application empowers users to easily analyze their metrics and manage their stress levels.



a) b)

c)

Figure 6. a), b), c) Graphs Showing Measured Parameters Over 15 Minutes

Figure 6 presents graphs that display the measured parameters over a 15-minute period:

1. Heart Rate (HR):

Graph a) illustrates the fluctuations in heart rate, measured in beats per minute.

2. Respiration Rate (RR):

Graph b) shows the variations in respiration rate, measured in breaths per minute.

3. Skin Conductance (SC):

Graph c) depicts changes in skin conductance, measured as a percentage.

These graphs effectively visualize the data collected from the proposed wearable device, enabling real-time analysis of physiological responses.

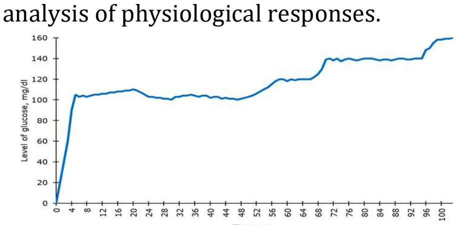


Figure 7. Glucose Levels Calculated as Averages Under Normal Conditions

Figure 7 displays glucose levels predicted using the double moving average method under normal conditions. Monitoring plasma glucose levels in older adults shows that pre-meal glucose levels typically fall within the range of 90 to 130 mg/dL, while post-meal levels can rise to as much as 180 mg/dL. According to the International Diabetes Federation, two groups are analyzed: independent patients and those who are functionally dependent.

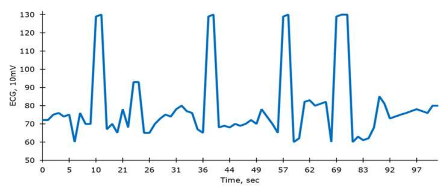


Figure 8. ECG Readings Without Abnormalities

DISCUSSION

The development of a wearable device integrated with IoT technology offers significant advancements in stress monitoring and management. By leveraging sensors such as PPG, GSR, and ECG, the device captures critical physiological parameters, including heart rate, respiration rate, and skin conductance. These indicators provide valuable insights into stress levels, enabling personalized and proactive stress management. The integration of IoT technology facilitates real-time data transmission to cloud platforms like Firebase, ensuring seamless data storage, analysis, and visualization through an intuitive web application.

Experimental results demonstrated the device's high accuracy, with 85% reliability in measuring heart rate and respiration rate, highlighting its potential for real-world applications. The ability to visualize data trends in real-time empowers users to identify stress patterns, understand triggers, and adopt effective coping mechanisms. Furthermore, the system's adaptability across diverse environments, such as workplaces, classrooms, and healthcare settings, enhances its versatility.

Challenges, such as sensor calibration and the impact of environmental factors on measurement accuracy, were addressed through rigorous testing and optimization. Additionally, the compact and energy-efficient design ensures user comfort and extended device operation.

This study demonstrates how IoT-enabled wearable devices can transform healthcare monitoring, offering scalable solutions for stress management. Future research should focus on integrating additional sensors for greater precision and exploring the device's application in managing chronic conditions and mental health, further advancing the field of digital health.

CONCLUSION

The development of a wearable device for stress detection utilizing Internet of Things (IoT) technology holds great promise for transforming the understanding and management of stress. By integrating IoT capabilities into wearable devices, new opportunities arise for real-time stress monitoring, providing valuable insights into users' physiological and behavioral responses. These IoT-enabled devices can collect and analyze a diverse array of biometric data, including heart rate variability, skin conductance, and sleep patterns, offering a comprehensive view of an individual's stress profile.

With this information, users can better understand their stress triggers, patterns, and responses, empowering them to adopt healthier coping mechanisms and make positive lifestyle changes. In this study, a wearable device was developed to detect and quantitatively assess stress levels based on vital signs. The MAX30102 sensor recorded heart rates ranging from 65 to 84 beats per minute and respiration rates between 10 and 12 breaths per minute. The galvanic skin response (GSR) sensor indicated values ranging from 80% to 85%, with average stress levels showing deviations of 5-10%.

The analysis of the data revealed no significant peaks or fluctuations, indicating stable conditions that did not require alerts. The system's predictions confirmed the absence of stress states. Observations of glucose levels before festive occasions and after meals showed that glucose levels did not exceed 180 mg/dL, thereby eliminating the need for an orange alert. If glucose levels surpass 200 mg/dL, the system will issue a red alarm signal indicating a potential hazardous condition. Importantly, the algorithm effectively accounts for food intake without generating false alerts.

This proposed wearable device differentiates itself from others described in the literature by its ability to measure heart rate, respiration rate, and skin conductance simultaneously. Future research will aim to explore the impact of stress on specific chronic conditions and incorporate additional sensors for more precise stress measurement.

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