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Design And Development Of An Esp32-Enabled Iot Wearable For Stress Classification And Vital Sign Monitoring

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***Abstract*— Stress has become a major health concern in modern society, contributing to cardiovascular disorders, metabolic imbalance, behavioral changes, and long-term psychological complications. Continuous monitoring of physiological indicators is essential for early stress awareness and preventive healthcare. This work presents the design and implementation of an IoT-based wearable health monitoring system capable of stress classification and vital sign tracking in real time. The proposed system integrates a heart rate sensor, body temperature sensor, and sweat sensor with an ESP32 microcontroller for data acquisition and wireless communication. Physiological readings are analyzed using threshold-based decision rules to infer stress state, and abnormal conditions trigger buzzer alerts to notify the wearer. A mobile application developed using the Blynk IoT platform provides remote visualization and cloud-based health logging, enabling continuous monitoring beyond clinical environments. Experimental validation confirms that the device operates reliably during varying physical and environmental conditions and provides consistent vital sign information in real time. Due to its low cost, mobility, and continuous operation, the system demonstrates strong suitability for personal healthcare, stress awareness, and preventive monitoring applications.**

***Index Terms*— Vital sign monitoring, IoT wearable, ESP32 microcontroller, stress classification, physiological sensing, Blynk cloud, remote health monitoring, threshold-based detection, preventive healthcare, biosensing.**

I. INTRODUCTION

Stress has become a pervasive condition affecting individuals across diverse work environments, socio-economic settings, and lifestyle habits. Prolonged stress exposure is associated with adverse physiological responses that alter cardiovascular performance, thermal regulation, and sweat gland activation. These responses, if unmonitored, can contribute to long-term complications such as hypertension, metabolic disorders, psychological dysfunction, and reduced productivity. Early stress detection combined with routine vital sign monitoring has therefore become an important strategy in preventive healthcare and digital health management.

Conventional monitoring techniques rely heavily on periodic assessments conducted within hospitals and clinical laboratories. Such evaluations fail to account for dynamic physiological fluctuations during daily activities and offer no real-time stress insight to the user. Moreover, the instruments used in clinical settings are not designed for mobile or continuous use, limiting their applicability outside medical environments. The growth of wearable biomedical sensing technologies offers a pathway to overcome these limitations through non-invasive monitoring, low power consumption, and sustained user mobility.

Parallel advancements in the Internet of Things (IoT) have transformed bio signal acquisition and health telemetry systems. IoT platforms support remote physiological data transmission, cloud-based storage, and mobile visualization, enabling decentralized workflows in healthcare ecosystems. Wearable IoT devices incorporating microcontrollers and sensor modules are now capable of measuring heart rate, temperature, perspiration, oxygen saturation, and physical movement. Remote access to such parameters enables early intervention, longitudinal health tracking, and the development of preventive health models.

Stress manifests through measurable bio signals that are detectable using non- invasive sensors. Heart rate is a key biomarker modulated by the sympathetic nervous system during stress responses, typically observed as an increase in beats per minute. Body temperature variations also occur due to metabolic alterations and heat dissipation processes. Sweat production through eccrine glands, particularly in the palms and forehead, increases during cognitive and emotional stress, providing an additional physiological indicator. Integrating these parameters allows basic stress-level inference without the need for complex biomedical instrumentation.

This paper presents the development of a wearable IoT-based system designed to monitor vital signs and provide stress classification through threshold-based analysis. The proposed system integrates commercially available sensors with an ESP32 microcontroller, enabling both local data display and remote mobile visualization through the Blynk IoT platform. A buzzer alert mechanism is included to notify the user in real time when abnormal physiological parameters are detected. The device is intended for everyday usage scenarios, offering a compact, low-cost, and energy- efficient architecture suitable for consumer health monitoring and stress awareness.

The key contributions of this work are as follows:

- A wearable sensing platform combining heart rate, temperature, and sweat sensing to monitor multiple stress-related physiological parameters simultaneously.
- Integration of IoT functionality using the ESP32 microcontroller and Blynk platform to provide real-time data access through mobile devices.
- Threshold-based stress classification implemented without computationally expensive machine learning models, improving deployment feasibility for embedded systems.

- Development of a local alerting mechanism using a buzzer to enhance user awareness during abnormal conditions.

II. LITERATURE REVIEW

Wearable electronics and IoT-based biomedical systems have become major research focus areas within digital healthcare due to the increasing need for continuous and remote monitoring capabilities. Research studies have demonstrated that wearable sensors can provide reliable measurements of physiological parameters related to cardiovascular performance, thermal regulation, and autonomic stress indicators. These wearable platforms are commonly employed photoplethysmography (PPG) or optical sensors for pulse detection, resistive or thermistor-based elements for temperature tracking, and capacitive or resistive films for sweat analysis.

Heart rate monitoring forms a core component of many wearable systems due to its strong correlation with physical exertion, emotional stress, and cardiovascular health. Optical heart rate sensors offer advantages in terms of compact form factors and low cost, making them suitable for wristbands, adhesive patches, and finger-based sensing devices. Recent commercial devices have incorporated heart rate sensing primarily for fitness assessment and cardiac tracking, although their data has also been used for stress inference.

Temperature monitoring through wearable thermistors and analog temperature sensors has been explored for fever detection, sleep analysis, and metabolic studies. The ability to integrate temperature sensors on microcontroller-based embedded platforms makes them useful in preventive healthcare applications. Sweat sensors, although less common compared to heart rate and temperature sensors, are gaining research attention due to their direct link to emotional stress and hydration. Recent literature identifies sweat analysis as an emerging diagnostic channel for stress detection, as sweat gland activation is directly controlled by sympathetic neural pathways.

IoT technologies have further advanced physiological monitoring by enabling bidirectional communication between sensing devices and cloud platforms. Studies report that the use of IoT in healthcare can reduce clinical staff workload, enhance real-time health tracking, and support decentralized telemedicine models. Experimental systems utilizing Wi-Fi, Bluetooth Low Energy (BLE), and cellular networks have demonstrated the feasibility of remote monitoring for chronic diseases, elder care, rehabilitation, and stress awareness.

Existing wearable devices available commercially, such as fitness trackers and smart watches, provide partial monitoring capabilities but often lack open hardware interfaces, multi-parameter sensing integration, or detailed stress-level interpretation. Many commercial solutions rely on proprietary algorithms and closed ecosystems, limiting customization and broader research applicability.

In contrast, the system developed in this work integrates open microcontroller hardware, multi-sensor capability, and IoT-based remote monitoring within a single low-cost platform. By utilizing threshold-based classification, the system avoids heavy computational requirements, making it suitable for low- power embedded applications and extended wearability.

III. METHODOLOGY

The methodology adopted for this work involves the extraction of physiological parameters associated with stress and vital signs, followed by classification using predefined threshold rules and communication of these parameters through both local and remote interfaces. The system operates continuously while worn by the user and acquires data from three independent sensing units: heart rate, body temperature, and sweat level. The acquired signals are conditioned, digitized, processed, and transmitted through an IoT communication pipeline for visualization and alert generation.

3.1 Physiological Parameter Selection

Stress manifests through changes in autonomic nervous system behavior, with notable alterations in heart rate, thermoregulatory function, and sweat gland activity. The following physiological parameters were selected due to their relevance and ability to be monitored using non-invasive sensors:

- Heart rate (beats per minute): increases during emotional and physiological stress.
- Body temperature (°C): reflects metabolic changes and thermal regulation.
- Sweat level: indicates eccrine gland activation associated with stress and hydration status.

These metrics are well supported in biomedical literature and are compatible with embedded sensing technologies.

3.2 Data Acquisition

Data acquisition is performed through analog and digital sensor channels interfaced with the ESP32 microcontroller. The heart rate sensor utilizes an optical detection method, providing a digital pulse waveform corresponding to cardiac cycles. The temperature sensor outputs an analog voltage proportional to surface temperature, which is digitized through the ADC channels of the ESP32. The sweat sensor outputs an analog signal whose magnitude varies with the moisture content detected on the sensor surface.

3.3 Threshold-Based Classification

Unlike machine learning-based stress recognition systems, which require training datasets and feature extraction, the proposed wearableapplies threshold-based classification to infer stress conditions. This approach reduces computational burden and enables operation on low-power embedded platforms without external processing support.

Thresholds were selected based on common physiological ranges reported in biomedical literature and preliminary observations. For instance:

- Resting heart rate values exceeding typical baseline ranges may indicate stress.
- Temperature values above normal body thresholds may reflect metabolic activation.
- Elevated sweat levels correspond to sympathetic nervous system activity.

Abnormal readings detected across one or more physiological channels trigger classification into a stressed state, while normal readings correspond to a relaxed or unstressed state.

3.4 IoT Communication Pipeline

The system supports remote visualization through the Blynk platform using Wi-Fi communication provided by the ESP32. Sensor readings are formatted and transmitted at fixed intervals to the cloud, where they are displayed on a mobile dashboard. Users may observe trends, instantaneous values, and alert states from any remote location with network access.

3.5 User Alert Mechanism

A buzzer is employed as the local alerting mechanism to notify users when parameter values exceed predefined thresholds. This modality supports immediate awareness without the need to observe the mobile interface continuously. Alerts serve as preventive feedback encouraging rest, hydration, or medical consultation depending on severity and persistence.

3.6 System Workflow

The operational workflow can be summarized as follows:

1. Sensors acquire physiological signals.
2. Signals are conditioned and digitized.
3. ESP32 processes-values and applies threshold rules.
4. Results are forwarded to:
    a) LCD for local display
    b) Blynk cloud platform for remote visualization
    c) Buzzer for local alerting (if abnormal)
5. Process repeats continuously during wear.

This workflow enables continuous monitoring with minimal user intervention.

IV. DESIGN AND HARDWARE IMPLEMENTATION

The system architecture consists of hardware subsystems responsible for sensing, processing, communication, power regulation, and user notification. The physical and electrical design utilize commercially available components assembled into a compact wearable prototype.

4.1 Hardware Architecture Overview

The overall hardware configuration illustrates the interconnection between the sensing modules, microcontroller, power supply, display interface, buzzer, and communication subsystem. The ESP32 serves as the central unit responsible for data acquisition and system coordination. Key hardware modules include:

- Sensory Unit
- ESP32 Microcontroller Unit
- IoT Communication Interface
- Local Display Module
- Alerting System
- Power Regulation Unit

Each module is described in detail in subsequent subsections.

4.2 Sensory Unit

The sensory unit comprises the following biomedical sensors:

4.2.1 Heart Rate Sensor

The heart rate sensor employs an optical technique based on the principle of photoplethysmography. Light emitted from an LED is partially absorbed and reflected by blood flowing through vascular tissues in the finger. Variations in reflected intensity during systolic and diastolic phases generate a pulsatile waveform detectable by a photodiode. A conditioned digital output representing each heartbeat is delivered to the ESP32 for beat counting and BPM estimation.

4.2.2 Temperature Sensor

Body temperature monitoring is achieved using an analog temperature sensor (e.g., LM35), which provides a linear voltage output proportional to temperature in Celsius. This sensor offers low self-heating characteristics, high signal stability, and compatibility with embedded ADC inputs.

4.2.3 Sweat Sensor

The sweat sensor functions as a moisture- sensitive element whose resistive output varies with perspiration levels. This technique enables qualitative estimation of stress-related sweat activity.

4.3 Processing and Communication Unit

4.3.1 ESP32 Microcontroller

The ESP32 microcontroller is selected due to its integrated Wi-Fi module, dual-core processing capabilities, and rich peripheral interfaces including ADC channels, GPIO pins, and serial buses. The device offers low power consumption and is well-suited for wearable systems.

4.3.2 IoT Integration via Blynk

The Blynk platform enables cloud-based data visualization and remote access. The ESP32 transmits sensor values to the Blynk server through Wi-Fi, and the user retrieves data through a mobile application. This integration enables telemetric health monitoring outside clinical environments.

4.4 Power Regulation Unit

A 12 V rechargeable battery serves as the main power source. Voltage regulation is achieved using IC7805 and IC7812 regulators. These regulators ensure stable voltage levels for sensor modules and microcontroller operation, eliminating ripple and preventing damage to low-voltage components.

4.5 Display and Alert Interfaces

4.5.1 LCD Display

A 16×2 LCD is employed to display real-time physiological values for local user awareness. The display’s pin arrangement and interfacing protocols. The LCD enables standalone operation without continuous reliance on the mobile application.

4.5.2 Buzzer Alert System

The buzzer generates alert tones when abnormal readings are detected. This feature supports preventive user notification, particularly during exercise, work-related stress, or overheating.

4.6 Circuit Integration

The complete circuit implementation is routing between the sensor unit, ESP32, regulators, and output modules. Secure wiring and isolation are essential for minimizing noise in sensor readings and ensuring system durability during prolonged wear.

V. RESULTS AND DISCUSSION

Prototype evaluation was conducted to assess sensing performance, response consistency, alert behavior, and IoT communication capability under practical usage conditions. The device was tested in indoor environmental settings under varying user activities including resting, mild physical movement, and cognitive work tasks. The parameters observed include heart rate, body temperature, sweat level, and system alert events.

5.1 Sensor Behavior and Measurement Consistency

The heart rate sensor generated a stable pulse waveform allowing accurate counting of beats per minute (BPM). At resting conditions, test observations showed BPM values within accepted physiological ranges (typically 65–85 BPM for healthy adults). During cognitive stress tasks, a noticeable increase in BPM was observed, consistent with sympathetic nervous system activation. These patterns demonstrate the sensor’s ability to detect stress-related variations without requiring invasive measurement techniques. The temperature sensor responded to surface temperature changes typically within 0.2– 0.5°C resolution. Although skin temperature is known to differ from core body temperature, relative increases are sufficient for stress inference when combined with additional physiological indicators. The sweat sensing module exhibited increased conductance readings during elevated stress and heat exposure. While this module does not quantify sweat composition, qualitative moisture detection was sufficient for threshold-based classification.

5.2 Stress Classification via Threshold Rules

Threshold parameters were applied to categorize physiological states into normal and stress levels. Table 1 presents representative threshold values used for classification.

S.NO	***Parameter***	***Normal Range***	***Stressed Condition Indicator***
1	Heart Rate	65–95 BPM	> 100 BPM
2	Temperature	36.0–37.0°C	> 37.5°C
3	Sweat Level	Dry-Moderate	High Moisture

The system classifies stress conditions when one or more parameters exceed their respective thresholds. This rule-based logic is computationally lightweight and suited to embedded platforms.

5.3 IoT Data Visualization and Remote Monitoring

IoT capability was verified through successful data transmission to the Blynk platform via Wi-Fi. Sensor values were displayed on a mobile dashboard featuring real-time graphs and numerical indicators. This remote visualization supports preventive health awareness without requiring dedicated medical equipment. The ability to access physiological data off-body through mobile devices expands the application scope to workplace environments, exercise, and routine daily activities.

5.4 Alert Mechanism and User Interaction

The buzzer-based alert mechanism activated consistently when stress thresholds were exceeded. Audible alerts served as immediate notifications, prompting users to rest, hydrate, or reduce stress-inducing activity. From a usability perspective, the combination of mobile visualization and local alerts provides multi-channel feedback, increasing system practicality during prolonged wear.

5.5 Discussion of Strengths and Limitations

The proposed wearable system demonstrates several strengths:

- Non-invasive measurement of multiple stress-related physiological parameters
- Integration with IoT for remote access and visualization.
- Lightweight rule-based classification suitable for embedded use.
- Low-cost and modular design using off-the-shelf components.
- Real-time alerting for preventive awareness.

VI. CONCLUSION

This paper presented the design and implementation of a wearable IoT health monitoring system capable of stress classification and vital sign tracking using the ESP32 microcontroller. The system integrates heart rate, temperature, and sweat sensing modules with a dual-feedback interface consisting of a mobile dashboard and buzzer alert signals. IoT connectivity through the Blynk platform enables remote visualization and supports preventive health monitoring outside clinical environments.

Experimental evaluation demonstrated that the proposed system reliably detects changes in physiological parameters associated with stress and provides real-time feedback to the user. The adoption of threshold-based classification enables a low-power, computationally efficient solution suitable for embedded wearable devices. The developed prototype highlights the feasibility of integrating affordable biosensing and IoT technologies for everyday stress awareness, making it suitable for consumer health, occupational monitoring, and fitness-related applications.

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