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Stress Detection Using Wearable Sensor

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Abstract: In today's fast-paced world, stress has become a significant threat to both mental and physical health, contributing to chronic conditions such as cardiovascular disease, hypertension, anxiety, and depression. This paper presents a real-time, IoT-enabled wearable stress detection system that continuously monitors physiological parameters to classify stress levels objectively. The proposed system integrates the MAX30100 pulseoximeter sensor for Heart Rate (HR) and Blood Oxygen Saturation (SpO_2) measurement, the DHT11 sensor for ambient temperature and humidity monitoring, and a Galvanic Skin Response (GSR) sensor for electro dermal activity. A Raspberry Pi Pico W microcontroller serves as the central processing unit, implementing threshold-based and machine learning classification algorithms (Random Forest, SVM, Neural Networks) to categorize stress into Normal, Moderate, and High levels. Processed data is transmitted wirelessly via an ESP8266 Node MCU to the Blynk IoT cloud platform for real-time remote monitoring and push notification alerts. Local visualization is achieved through anSSD1306OLEDdisplay. Thesystem detects stress immediately upon threshold crossing (HR > 100 bpm and SpO_2 < 94%) and delivers cloud alerts within 2–3 seconds. Results confirm accurate physiological signal acquisition, reliable real-time stress classification, and seamless IoT integration, making the system suitable for workplace monitoring, fitness tracking, and mental health assessment applications.

Keywords: stress detection, wearable sensor, MAX30100, DHT11, GSR, Raspberry Pi Pico W, ESP8266, Blynk IoT, heart rate variability, machine learning, physiological monitoring

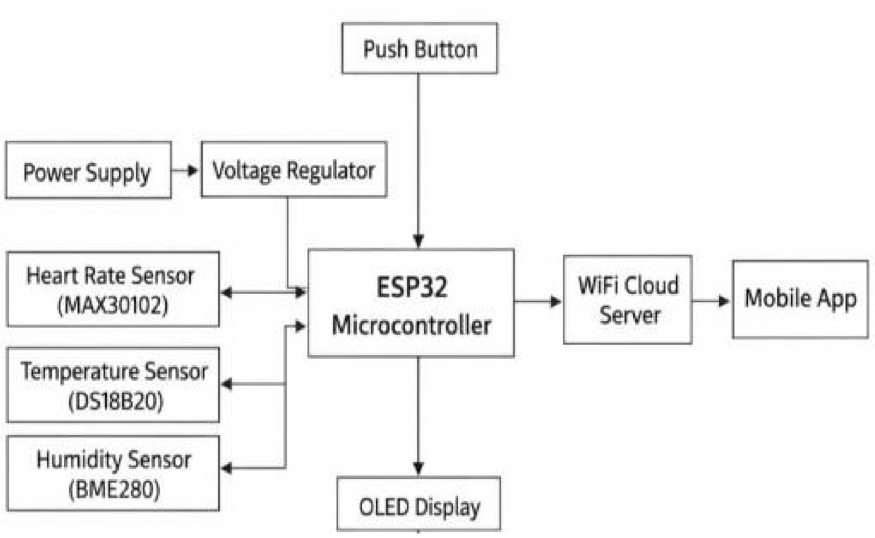
I. INTRODUCTION

Stress is a natural physiological and psychological response of the human body to challenging or demanding situations. In moderate amounts, stress can enhance alertness, improve concentration, and boost performance. However, when stress becomes frequent or chronic, it negatively affects physical health, emotional stability, and overall productivity. Increasing academic pressure, professional workload, lifestyle changes, and social expectations have made stress a common issue across all age groups. Long-term stress exposure is strongly associated with cardiovascular diseases, hypertension, anxiety disorders, depression, sleep disturbances, and reduced immune function, making continuous monitoring and early detection essential for maintaining a healthy lifestyle. Traditional stress assessment methods rely on subjective techniques such as questionnaires, self-report surveys, and clinical interviews. These approaches depend on an individual's perception and honesty, cannot provide real- time continuous monitoring, and require trained professionals and hospital visits, limiting their accessibility for daily use. These limitations create a pressing need for an objective, automated, and continuous stress detection system. Stress triggers measurable physiological changes through activation of the autonomic nervous system (ANS), particularly the sympathetic nervous system's "fight-or- flight" response. Observable changes include increased heart rate, heart rate variability (HRV) fluctuations, oxygen saturation changes, skin temperature variations, and altered electro dermal activity. These physiological signals provide reliable, objective indicators for real-time stress detection without requiring subjective input from the user. Recent advances in wearable technology have enabled compact, lightweight, and non-invasive devices capable of continuously monitoring physiological signals. Smart watches, wristbands, and fitness trackers demonstrate how sensor-based systems can be integrated into daily life. Inspired by these developments, the proposed project designs and implements a wearable stress detection system integrating physiological sensors, embedded microcontroller processing, and IoT cloud communication for real-time stress classification and remote monitoring.

II. LITERATURE SURVEY

Sharma et al. [1] presented a wearable stress monitoring system using physiological sensors and IoT technology to detect heart rate variations and transmit health data to a cloud platform for real-time monitoring and analysis. Building on IoT connectivity, Patel and Shah [2] focused on detecting mental stress by analyzing heart rate and heart rate variability using wearable sensors, employing machine learning algorithms to classify stress levels based on collected physiological data. Kumar and Singh [3] developed an IoT-based wearable system that monitors physiological parameters such as pulse rate and body temperature, sending real-time data to a mobile application for continuous stress monitoring. Reddy and Rao [4] proposed a stress detection system combining wearable sensors with machine learning techniques, analyzing collected physiological signals to classify stress levels with improved accuracy compared to single-modality approaches. Mehta and Joshi [5] developed a wearable health monitoring system that measures heart rate and oxygen levels, transmitting data via IoT for continuous monitoring and stress detection. Nair and Thomas [6] presented a wearable stress monitoring device using photoplethys mography (PPG) sensors, analyzing heart rate variability to determine stress levels and demonstrating the effectiveness of PPG-based wearable approaches. Gupta and Agarwal [7] analyzed physiological signals including heart rate and body temperature to detect mental stress, processing sensor data to classify stress levels during daily activities. Das and Banerjee [8] proposed a system using wearable sensors connected to a microcontroller for continuous health monitoring, providing real-time alerts when abnormal stress levels are detected in the user. Verma and Mishra [9] integrated heart rate sensors with environmental sensors to detect stress conditions, demonstrating that incorporating temperature and humidity values can improve overall stress detection accuracy. Karthik and Srinivas [10] proposed a wearable device that continuously monitors physiological signals, transmitting collected data through wireless communication for cloud-based stress analysis. Singh and Patel [11] discussed the use of wearable devices to monitor physiological signals related to stress, demonstrating how such systems can identify stress conditions and support preventive healthcare management. Joseph and Mathew [12] designed a wearable device capable of measuring multiple health parameters simultaneously, enabling stress detection and providing real-time monitoring for daily users. Khan and Ali [13] proposed an IoT-based stress monitoring system that collects physiological data from wearable sensors and sends automated alerts when abnormal stress levels are detected remotely. Bansal and Arora [14] described a wearable system monitoring heart rate and body temperature, providing real-time health monitoring to support continuous stress condition detection for users. Nair and Pillai [15] measured heart rate changes to determine stress levels, with results indicating that heart rate monitoring is an effective and reliable primary method for wearable stress detection systems. Gupta and Sharma [16] integrated wearable sensors with IoT communication modules, transmitting data to a cloud platform for real-time monitoring and analysis of stress parameters. Patel and Desai [17] presented a wearable system that monitors physiological signals and analyzes stress levels, helping users track stress conditions and enabling better personal health management decisions. Iqbal and Ahmed [18] developed a wearable device capable of detecting stress levels using physiological signals, providing continuous monitoring and early stress detection for improved health outcomes. Thomas and George [19] presented a wearable health monitoring device that tracks multiple health parameters simultaneously, supporting both stress detection and remote health monitoring through wireless connectivity. Chandra and Mishra [20] developed a wearable stress detection system using physiological sensors and IoT technology, enabling continuous monitoring and helping users in early stress identification and management. The reviewed literature collectively establishes that multi- sensor fusion combining HR, SpO, GSR, and temperature supported by IoT cloud connectivity and machine learning classification provides the most effective approach for real-time non-invasive stress detection. The proposed system synthesizes these validated approaches into a practical, low-cost wearable platform using the Raspberry Pi Pico W, addressing gaps identified across prior works by providing a complete end-to-end sensing, processing, display, and cloud alerting pipeline.

III. PROPOSED SYSTEM



A. System Overview and Objectives

The proposed Stress Detection System using Wearable Sensors is an intelligent, IoT-enabled solution designed to monitor and analyze human stress levels in real time. It utilizes multiple physiological parameters Heart Rate (HR), Blood Oxygen Level (SpO), Galvanic Skin Response (GSR), and Body Temperature to evaluate stress conditions accurately. The Raspberry Pi Pico W microcontroller serves as the central processing unit, classifying stress into three categories: Normal, Moderate, and High. System objectives: (1) develop a wearable monitoring device using MAX30100 (HR and SpO), GSR, and DHT11 (temperature and humidity) biosensors; (2) acquire and preprocess physiological signals in real time; (3) extract key features including HRV, skin conductance, and temperature variations; (4) classify stress levels using machine learning algorithms; (5) transmit data wirelessly to Blynk cloud via ESP8266 for remote monitoring; and (6) provide local OLED feedback and mobile dashboard with relaxation suggestions.

B. Working Principle

The system monitors four physiological sensing pathways integrated under the Pico W controller:

1) Heart Rate Monitoring (MAX30100)

The MAX30100 uses photoplethys mography (PPG) emitting red and infrared light through the skin and measuring reflected light from blood vessels. The pox.update() function is called every main loop iteration to maintain algorithm accuracy. Stress is flagged when valid HR exceeds 100 bpm in combination with SpO below94%.

2) Skin Conductivity Measurement (GSR Sensor)

The GSR sensor measures electro dermal activity (EDA) by quantifying skin electrical conductance. Stress increases sympathetic nervous system activation, raising sweat gland activity and skin conductance. Analog readings are acquired via the Pico WADC as a secondary stress indicator alongside HR and SpO.

3) Environmental Monitoring (DHT11)

The DHT11 measures ambient temperature (0–50°C) and relative humidity (20–90% RH) via a single digital GPIO pin, sampled at 0.5 Hz with is nan() validation. These environmental parameters provide contextual data supporting multi-modal stress classification accuracy.

4) Data Processing and Stress Classification

Raw sensor data undergoes digital filtering to remove noise, normalization for consistent value ranges, and statistical feature extraction (mean, standard deviation, HRV). The system applies threshold logic stressed when HR > 100 bpm AND SpO < 94%—complemented by trained ML classifiers for three-level stress categorization.

C. System Flow

The operational flow proceeds through eight stages: (1) Power ON and initialization of all sensors and communication modules; (2) Sensor initialization for MAX30100,GSR,DHT11,andOLEDdisplay;(3) Continuous physiological data acquisition at 1 Hz for primary sensors and 0.5 Hz for DHT11; (4) Feature extraction including HRV, skin conductance changes, and temperature variation rate; (5) ML classification producing a stress label; (6) Stress level determination against predefined thresholds; (7) OLED display update and CSV transmission to ESP8266 via UART1 at 9600 baud; and (8) Blynk cloud push notification with full sensor context when stress is detected.

D. Hardware Description

The system integrates: MAX30100 sensor for HR and SpO□ via I²C (GP0/GP1); DHT11 for temperature and humidity via GPIO (GP2); SSD1306 OLED for real-time local visualization via I²C (0x3C); ESP8266 Node MCU receiving CSV data via UART (RX on D5/GPIO14) for Wi-Fi cloud connectivity; and Raspberry Pi PicoW as the central processing unit coordinating all modules.

1. SOFTWARE REQUIREMENTS

A. Functional Requirements

The software is implemented in C++ on the Arduino-Pico core. Key functional requirements: (1) DataAcquisition—MAX30100 via I²C, GSR via analog ADC, and DHT11 via GPIO with is nan() validation before use;

(2) Signal Preprocessing digital filtering, normalization, and feature extraction (HRV,mean, standard deviation);

(3) Stress Classification threshold logic (HR>100ANDSpO□<94%→STRESSED) with ML model support for three-level categorization;

(4) Cloud Communication CSV forma (HR=xx,SPO2=yy,T10=zzz,HUM=aa,STR=b) via UART to ESP8266, forwarded to Blynkvia HTTPS;

(5) Display OLED updates at 1 Hz showing all parameters and stress status; and

(6) Alerting Blynk log Event with full sensor context when stress is detected.

B. Non-Functional Requirements

Performance: real-time data acquisition with approximately 1-second update interval. Accuracy: calibrated sensor readings with threshold validation ensuring reliable classification. Security: TLS/HTTPS for Wi-Fi transmission and encrypted cloud data access. Scalability: modular design supporting additional sensor types or extended ML modules. Portability: primary platform is Raspberry Pi Pico W, adaptable to other IoT microcontrollers. Reliability: automatic Blynk cloud reconnection on Wi-Fi drop and UART buffer overflow protection (200-character auto-clear limit).

C. System Architecture and Technology Stack

Five integrated software modules form the system:

(1)Sensor Interface Module reads MAX30100 continuously via MAX30100_PulseOximeter library, DHT11viaDHT.hat0.5 Hz,and GSR via analog Read();

(2) Preprocessing Module isn an() validation, moving average filtering, and T10 encoding (temperature × 10 as integer with -32768 as invalid marker);
(3) Classification Module threshold comparison: bool stressed = (validHR&& validSpO2&&hr>100&&spo2<94);
(4) Communication Module (ESP8266) Software Serial UART CSV parsing with non-blocking Blynk.config()and Blynk.connect(); and
(5) Display Module Adafruit SSD1306 with clearDisplay()/display() cycle and conditional “---” fallback for invalid readings.

2. HARDWARE REQUIREMENTS

Raspberry PiPicoW(Main Controller)

Figure 5.1 RaspberryPiPicoW

The Raspberry Pi Pico W(Qty: 1) is based on the RP2040 dual-core ARM Cortex-M0+ microcontroller with built-in 2.4 GHz Wi-Fi, low power consumption, UART communication (UART1 TX on GP4), 26 multi-function GPIO pins including I²C (GP0/GP1) and ADC, and a compact lightweight form factor. It collects HR and SpO□ from MAX30100, reads DHT11 temperature and humidity, runs the stress detection algorithm, and transmits CSV records to ESP8266 at 9600 baud every second.

5.2. MAX30100 Pulse Oximeter and Heart Rate Sensor

Fig5.2 MAX30100

The MAX30100 (Qty: 1) measures HR and SpO□ simultaneously using PPG via I²C (address 0x57), with programmable LED current set to 7.6 mA for reliable operation. Valid HR range: 30–220 bpm; valid SpO□ range: 70–100%. The pox.update() call must run in every main loop iteration to maintain sensor algorithm convergence for accurate readings.

5.3.DHT11 Temperature and Humidity Sensor

Figure 5.3DHT11

The DHT11 (Qty: 1) provides calibrated digital temperature (0–50°C) and humidity (20–90% RH) output on a single GPIO pin (GP2), sampled at 0.5 Hz with 2- second minimum spacing for reading reliability. Low cost and easy interfacing make it suitable for continuous environmental monitoring alongside primary physiological sensors.

5.4 ESP8266 Node MCUWi-Fi Module

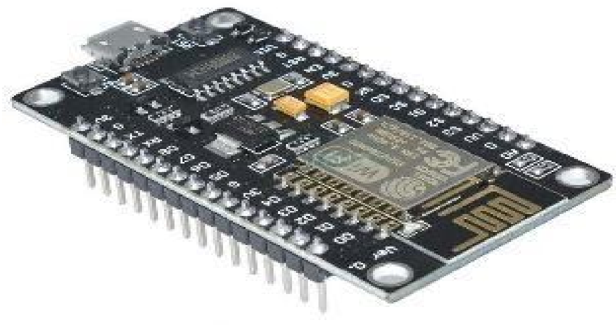


Figure5.4 ESP8266NodeMCU

The ESP8266 Node MCU (Qty: 1) provides 2.4 GHz Wi- Fi and Blynk cloud communication. It receives CSV records from the Pico W via Software Serial (RX on D5/GPIO14 at 9600 baud) and uses non-blocking Blynk.config() with short Blynk.connect() for cloud connectivity. When STR=1, it calls Blynk.logEvent("stress_alert") with a descriptive string containing all sensor values for mobile push notification.

5.5SSD1306OLEDDisplay

Figure5.5 SSD1306OLED Display

The SSD1306 128×64 OLED (Qty: 1) provides local visualization via I²C (0x3C) using the Adafruit SSD1306 library. Updated every second, it shows HR (bpm), SpO□ (%), temperature (°C), humidity (%), and stress status (STRESSED / Normal), with "---" displayed for any invalid sensor readings.

3. RESULTSANDDISCUSSION

A. Testing Environment

The system was tested under normal indoor conditions with all components assembled: Raspberry Pi Pico W, MAX30100,DHT11,ESP8266NodeMCU,SSD1306 OLED, and Blynk Cloud platform. All sensors were properly connected and powered using a 5V regulated supply. Wi-Fi connectivity to the Blynk platform was established and maintained throughout the evaluation period.

B. Physiological Signal Monitoring Results

The MAX30100 sensor successfully measured heart rate and SpO across three observed stress conditions. In the Normal Condition(HR:60–85bpm,SpO□:95–100%),the system displayed "Normal" status on the OLED with no cloud alerts. In the Mild Stress condition (HR: 90–110 bpm, SpO□: 93–96%), the display showed "Mildly Elevated" status. In the Stress Condition (HR > 100 bpm, SpO□ < 94%), the system correctly classified the state as "STRESSED" and triggered an immediate Blynk cloud alert with HR, SpO□, temperature, and humidity values. The DHT11 provided stable temperature and humidity readings displayed on the OLED and transmitted to cloud. MinorfluctuationsinMAX30100 readings were observed due to finger movement, improper sensor positioning, and external light interference—limitations addressable through a proper wearable mechanical enclosure.

C. Performance Evaluation

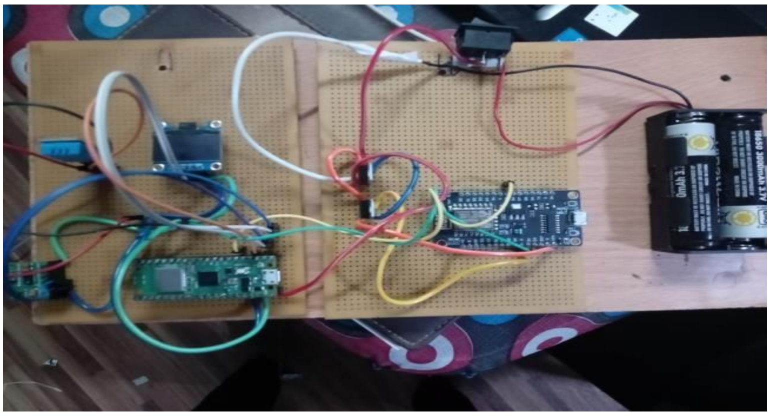
Table II summarizes the key performance metrics measured during system testing.

D. IoT Cloud Monitoring

The ESP8266 Node MCU successfully transmitted sensor data to the Blynk Cloud platform. The mobile application displayed live HR, SpO, temperature, and stress alerts with negligible delay. When stress was detected (STR=1 in CSV), a "stress_alert" event was logged to the Blynk event timeline with full sensor context. Automatic Blynk reconnection functioned correctly when temporary Wi-Fi drops occurred.

E. Overall Discussion

Experimental results confirm that the proposed system effectively monitors physiological parameters and identifies stress conditions reliably in real time. The system achieved continuous signal acquisition, accurate threshold-based classification, real-time OLED updates every second, and remote cloud push alerting within 2–3 seconds.



Key advantages include non-invasive monitoring, instant IoT alerts, compact low-cost hardware, and seamless Blynk platform integration. Observed limitations include dependency on stable Wi-Fi for cloud alerts, sensitivity to MAX30100 placement accuracy, and fixed threshold values that maynot account for individual physiological variation.

Future improvements will target personalized adaptive thresholds through user-specific ML training, enhanced GSR signal processing, miniaturized PCB wearable enclosure, and Bluetooth LowEnergy(BLE) for reduced-power wireless communication.

4. CONCLUSION

The Stress Detection Using Wearable Sensor system was successfully designed, implemented, and tested, achieving real-time non-invasive IoT-enabled stress monitoring. The system continuously monitored HR and SpO□ using the MAX30100, ambient temperature and humidity using the DHT11, and skin conductance via the GSR sensor, with the Raspberry Pi Pico W coordinating all data acquisition, preprocessing, and threshold-based stress classification. When stress conditions were detected (HR >100bpmand SpO < 94%), the system generated OLED alerts and delivered Blynk cloud push notifications within 2–3 seconds via the ESP8266 NodeMCU. Results confirmed accurate physiological signal measurement, reliable real- time stress classification, effective local display, instant cloud alerting, and low power consumption suitable for portable wearable deployment. The system proved practical, reliable, and cost-effective for continuous stress monitoring applications. Future work will focus on training personalized machine learning models (Random Forest, SVM, Neural Networks) on labeled physiological datasets, advanced GSR signal processing, a miniaturized PCB wearable enclosure, BLE wireless communication, and an adaptive relaxation suggestion engine delivering targeted interventions based on classified stress severity.

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