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Design and Development of a Wearable Biofeedback System for Real-Time Stress Management using ESP32 and MAX30102

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***Abstract*— In today's world, high pressure settings of academics as well as industry, stress has undergone a transformation from being a visible health concern to an unknown one. This paper presented the design, development, and validation of the "Stress Relief Band", a low-cost device that can be worn by the user to relieve stress and induce focus through physiological monitoring. Grounded in an extensive evaluation 15 different research studies, the system consists of MAX30102 Pulse Oximetry Sensor as well as ESP32 Microcontroller to measure Heart Rate Vari- ability (HRV) as well as finding signs of sympathetic overwhelming of the nervous system. Upon the detection of stress, the device automatically causes a Linear Resonant to occur Actuator (LRA) provide rhythmical haptic vibrations; directing the user in a pattern of deep breathing. This project offers to close the gap between the diagnostic monitoring and the therapeutic intervention, offering a discreet and not pharmacological solution for immediate stress relief. The architecture of the hardware is described in more details, signal processing algorithms, as well as the comparative literature analysis which informed the multi-Dimensional approach to the emotional wellbeing. Index Terms--Anxiety management Biofeedback ESP32 Haptic intervention Heart rate variability (HRV) MAX30102 Stress Relief Wearable Technology.**

***Index Terms*— Stress Management, Biofeedback, ESP32, HRV, Wearable Technology.**

I. INTRODUCTION

Stress is an adaptive physiological response which, if chronic, is maladaptive. Stress has become an unavoidable part of modern life, which affects people of all age groups. Academic pressure, work demands, social expectations and anxiety around performance are a major factor in everyday stress levels. Although stress is a natural physiological response that allows the body to adapt to challenging situations, when stress is prolonged or unmanaged, it can have adverse effects. Chronic stress has been linked to cardiovascular disorders, poor cognitive performance, emotional instability, anxiety-related conditions, and a decrease in quality of life. Despite the greater awareness of mental health, access to immediate and effective solutions to stress is less than ideal. Existing interventions like meditation applications, guided breathing exercises or clinical therapy often require the active engagement of the user, active attention, or professional supervision.

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During acute stress like anxiety during examinations, stage fright or performance pressure, these approaches may be impractical or are inaccessible. As a result, individuals often do not receive any timely support during the periods of high stress levels. Major feature of this system are as follows:

- To overcome this shortcoming, the Stress Relief Band has been conceived as a simple, wearable and passive stress management solution. Designed to be a portable and comfortable device, the band provides relaxing sensory feedback when physiological arousal is high.
- The main objective of this project is to design and create a low cost, portable and user-friendly stress relief device that will promote emotion, focus and reduce anxiety with sensory and physical engagement.
- As a part of the design, the system is intended for particular sets of users based on their preliminary identification such as students experiencing academic pressure, sportspeople dealing with performance pressure, individuals suffering from social anxiety issues and patients undergoing various medical treatments.
- In relation to any conventional wearable devices that simply records the parameters like the heart rate and other physiological aspects, the proposed system serves as a virtual fidget object.
- The proposed Stress Relief Band is an innovative and passive system that monitors stress by identifying physiological signs of stress and gives an instantaneous feedback via vibrations.

II. LITERATURE REVIEW

TABLE I: COMPARISON OF EXISTING STUDIES AND PROPOSED SYSTEM

Study	Stress Detection	Intervention	Wearable	Real-Time Response	Low Cost
Villarejo et al.	GSR	No	Yes	Yes	No
Galli et al.	PPG	No	Yes	Yes	No
Doppel Wristband	Partial	Haptic Feedback	Yes	Yes	No
Proposed Stress Relief Band	PPG (MAX30102)	Haptic Feedback	Yes	Yes	No

- A systematic review of 15 research articles on stress detection algorithms, sensor efficiency, and interventions has been performed for the effective system design.
- The importance of personalized AI based solution is stress problem, highlighted by Rebeccal et al. and Saiteja et al., lies in the fact that it provides the basis of adaptivity and individual response to stress.
- The use of physiological sensors based on photoplethysmography (PPG) has been revealed to be effective technique of heart rate measurement when appropriate filters are used. Although stress detection with the help of Galvanic Skin Response (GSR) can achieve upto 90.97% of accuracy (as stated by Villarejo et al.), the use of PPG technique, suggested by Galli et al., proves to be more applicable to wearable wrist mounted devices.
- Concerning techniques of stress interventions, haptics prove to be a reliable means of coping with stress.
- In terms of intervention strategies, haptic feedback has been widely supported in the literature as an effective method for stress reduction. Azevedo et al., through their work on the “Doppel” wristband, demonstrated that heartbeat-like vibrations—approximately 20% slower than the user’s resting heart rate—can significantly reduce skin conductance and anxiety levels.
- Complementing this, Wang et al. found that vibration frequencies in the range of 36–46 Hz are effective in reducing muscle fatigue, which is a common physical manifestation of stress.
- Additionally, minimalist tactile feedback designs proposed in highlight that simple vibration patterns are sufficient to convey calming signals to the brain without imposing cognitive load on the user.
- Together, these findings strongly support the use of low-power, vibration-based haptic feedback as an efficient and practical intervention mechanism in wearable stress management systems.
- While some studies have investigated measures of stress using physiological data like Heart Rate Variability (HRV), Photoplethysmography (PPG) and Galvanic Skin Response (GSR), most of the current systems are mainly focused on stress monitoring and analysis. Stress management devices that are able to detect high stress levels often must be actively used by the person/engaged with mobile apps/external systems to initiate stress-relieving activities.
- Additionally, there are a number of solutions that are more cumbersome, require expensive equipment or complex machine learning models, or require cloud-based processing, which are less accessible for everyday use. Current wearable systems are not always simple and inexpensive to detect stress and to also give immediate feedback without involving the user.

- To overcome these problems, the proposed Stress Relief Band combines real-time physiological monitoring with automatic haptic feedback in a wearable compact package. The system integrates the three key factors of affordability, portability and immediate intervention, making it appropriate for students, professionals, athletes and those who experience stress in day-to-day situations.

III. Major Contributions of the Proposed Work

The major contributions of the proposed Stress Relief Band are as under:

- Design and development of a low cost wearable stress management system with the help of ESP32 microcontroller and MAX30102 pulse sensor.
- Continuous heart rate monitoring- real time physiological stress monitoring.
- Stress conditions automatically trigger vibrations haptic feedback.
- Embedding stress detection and intervention in a single wearable platform.
- Portable and battery operated for everyday use.
- Passive stress-relief mechanism (not user dependant).
- Showing of a workable, manageable approach to emotional health and stress reduction..

IV. Methodology

Four main phases comprise the methodology of our system. The first is Sensory - this is where we gather data from the physical world. The second phase of the processing pipeline is Processing - each piece of information is assigned its own unique identifier so that it can easily be retrieved when needed. The third phase is Deciding - in this phase, we make decisions based on the data that we have collected and processed, which result in actions to be taken. The fourth and final phase of the process is Acting where those actions are executed (or put into effect).

Some key hardware components will be built in this building phase. They will include (but are not limited to) the following components:

A. ESP32 Development Module

The ESP32 Development Module has two processing cores that each run at 240MHz (MegaHertz) and have Wi-Fi capability, which allows for data collection and logging (i.e., recording the data) to occur simultaneously. This makes it a great candidate for use in Monitoring Natural Physiological Changes in Real-Time.

B. MAX30102 Pulse Oximeter

The MAX30102 Pulse Oximeter captures (i.e., takes) and records (i.e., saves) high sensitivity PPG (Photoplethysmography) that is the main physiological indicator of whether or not an individual is stressed.

C. LRA Vibration Motor

The LRA Vibration Motors provide reliable and consistent Haptic Feedback (i.e., vibrating) to implement the Intervention (award).

D. Power Subsystem

The power subsystem consists of a Lithium-Ion (Li-Ion) battery with a nominal voltage of 3.7 volts and a TP4056 charging circuit and boost converter (i.e., increases the voltage) that works with the Lithium-Ion Battery to ensure that at all times (i.e., always), when the microcontroller requires 5-V (volts) power, there is enough power available for it to work without interruption; as well as to ensure that the TP4056 charger safely and consistently charges the Li-Ion Battery.

E. Physical Design

The physical design of the device consists of a Velcro strap that can be adjusted to fit snugly around the wrist, helping to keep the sensor in firm contact with the skin to limit motion artifact when collecting PPG signals during activities of daily living and improving the accuracy of these readings.

F. System Configuration

The configuration ensures electrical isolation between sensing element(s) and actuator device(s) by electrically separating low-voltage signal acquisition circuits from actuation stage (high current haptic output).

G. Electrical Noise & Life Safety

Isolation of signal processing circuits from the haptic output reduces the effect of electrical noise on PPG readings, providing both improved life safety and better system performance.

H. Operational Algorithms

Operational algorithms for the device only permit haptic feedback until a measured response has been registered, avoiding habituation/desensitization due to continued vibration.

I. Control Logic Based on Thresholds

The vibration motor is only activated when physiological indicators indicate stress exceeds predetermined limits; therefore, stress relief feedback will continue to be effective and responsive for the duration of use.

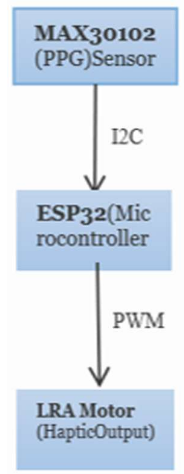


Figure 1

This is a system architecture showing data acquisition from the MAX30102 sensor, processing by the ESP32 microcontroller, and actuation through the vibration motor.

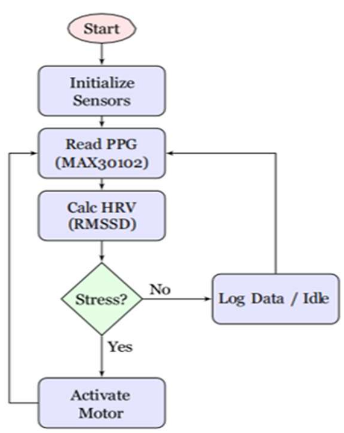
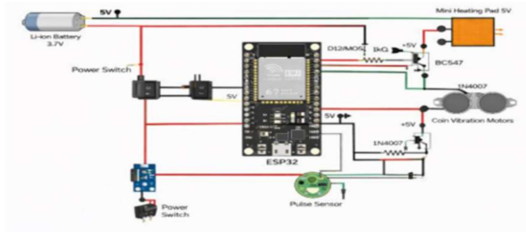


Figure 2. This is an Operational Flowchart of the biofeedback

V. IMPLEMENTATION

Both the circuit boards and power supplies provide stable voltage output and signal quality; however because the MAX30102 Sensor uses a regulated voltage from a transistor driver, it can operate on minimal power even when controlling the vibration motor (i.e., does not use excessive amounts of current from the microcontroller).
To make the device as small, light, and portable as possible while also having the capacity for continuous operation, it will contain a Li-ion rechargeable battery and recharging circuit for continuous use.



Stress Relief Band Circuit Diagram

Table I
Conceptual Circuit Schematic Connections

Component Pin		Destination
MAX30102 VCC	↔	3.3V / 5V Rail
MAX30102 GND	↔	Common Ground
MAX30102 SDA	↔	GPIO 21 (Data)
MAX30102 SCL	↔	GPIO 22 (Clock)
GPIO 18	→	1kΩ Resistor → Base (2N2222)
5V Rail	→	Motor (+)
Motor (-)	→	Collector (2N2222)
Emitter (2N2222)	→	Ground
Diode (1N4007)		Across Motor (Protection)

Figure 3. Circuit Implementation

TABLE II: HARDWARE COMPONENTS USED

Component	Function
ESP32	Data Processing and Control
MAX30102	Heart Rate Monitoring
LRA Motor	Haptic Feedback
Li-ion Battery	Portable Power Supply
TP4056 Module	Battery Charging
2N2222 Transistor	Motor Driver

VI. RESULT AND DISCUSSION

The Stress Relief Band was successfully tested under controlled conditions to assess its ability to detect physiological reactions to stress and act in real-time to provide haptic intervention. The system continuously took heart rate data from MAX30102 sensor and analyzed data with the ESP32 microcontroller.

During the tests, both subjects increased their heart rate when doing stressful activities. If the average heart rate was above the preset value(75bpm), the ESP32 would turn on the vibration motor in around 2 seconds. The vibration continued to work until the heart rate dropped below the threshold value.

The results obtained in this study are that the system is able to detect high physiological arousal and react in real time. Under normal rest conditions, no false activation was observed, to prove the stability of the threshold based activation mechanism.

Also, user feedback was used to assess the effectiveness of the vibration based intervention. There was a significant calming effect experienced by both subjects with vibrations activation. This finding is consistent with the past studies that rhythmic haptic stimulation helps to decrease anxiety and regulate emotions.

The overall system responds actively to stress events as compared with conventional wearable monitoring system which merely provides information regarding the physiology. This combination of sensing and intervening is a big plus as it lessens conscious intervention from the user during stressful situations.

The findings are promising, but there are some drawbacks to the study. The primary data source for evaluating stress detection from the study participants was heart rate, and the range of available methods was limited with respect to participants competing for researcher attention.

Therefore, since physiological sensors can vary widely in the types of physiological response measured (e.g. GSR, skin temp), the possibility for the Stress Relief Band is to utilize other types of sensors as well as create a Machine Learning (ML) component for personalization and/or improve the User Interface (UI) experience.

Overall, as illustrated in this study, the Stress Relief Band provides users with quick feedback for identifying and mitigating stress by incorporating physiological sensors and haptic feedback to recognize signs of stress, as well as ways to alleviate stress.

Figure 4: This is the Subject 1 and Subject 2 device implementation and result evaluation shown in image

VIII. Limitations of Current System

- Study conducted on only two subjects.
- Stress detection based primarily on heart rate.
- Fixed threshold may not suit every user.
- No machine learning based personalization.
- Long term clinical testing not yet performed.

IX. Future Work

- Integration of GSR sensor.
- Adaptive HRV based thresholds.
- Mobile applications connectivity.
- Cloud based data logging.
- AI based stress prediction.

X. Conclusions

The portable Stress Relief Band is an example of how haptic feedback, physiological sensors, and real-time computing can work together in one small package. This unit utilizes an ESP32 microcontroller and the MAX30102 pulse sensor, which monitors heart rate, to notify the user when they are experiencing stress through a vibration whenever the user's heart rate indicates that they might be stressed. The device was shown to reliably and quickly respond to changes in heart rate while consuming low power, providing a comfortable user experience, and "providing an evidence-based and reasonable way to provide instant relief from stress through rhythmically oriented haptic feedback without requiring any effort from users." The Stress Relief Band adds new functionality to wearables by providing another way of detecting and treating stress in a single inexpensive device. This device will help many types of users including students, professionals, high-volume athletes, and anyone working in very stressful environments. Future research will expand the number of users in testing; add more types of physiological sensors to measure additional factors; develop adaptive algorithms for threshold defining; and incorporate more machine learning methods into detection and intervention.

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