Biomedical Instrumentation (BM2762)
Mini-Project on Galvanic Skin Sensor

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ABSTRACT

Experiencing stress in everyday life has become quite normal, with it affecting both physical and mental health. Hence preventing the side-effects caused by stress by detecting it early on has been sought out by many. In this project, our goal is to determine if a person is experiencing stress based on four physiological sensors - temperature sensor, heart rate (HR) sensor, saturated oxygen sensor (SpO2) and the galvanic skin response (GSR) sensor, by creating a compact, non-invasive, real-time stress detection system. These biosensors focus on the Autonomic Nervous System, which controls the “fight-or-flight” response.

The data is recorded, processed and calculated using an ESP-32 microcontroller. The GSR sensor measures the electrical conductance of the skin due to perspiration, the heart rate sensor tracks how fast the heart is beating, and SpO2 sensor measures the blood oxygen saturation level, or how much oxygen is being carried by the haemoglobin of the Red Blood Cells (RBCs). These data recordings are then later analyzed to detect if the person is under stress or not, by comparing the readings to the normal average benchmark readings.

This stress-measurement device due to its compact nature and portability could prove to be a useful tool in biomedical engineering and in everyday life to detect stress among individuals for better health monitoring. It would also determine multiple physiological parameters, which would provide a better understanding on how to deal with stress, once we know the source.

INTRODUCTION

Stress has become a major issue in today's fast-paced society due to the rise in hustle culture, work pressure, and competition. It is frequently linked to mental health conditions like eating disorders, depression, panic attacks, etc., as well as physical health conditions like headaches, cardiovascular problems, and hypertension. More often than not, stress is neglected because of one, lack of knowledge on how important this issue is, and two, not knowing what stress exactly looks like. Therefore, proper knowledge, early detection, and continuous monitoring of stress levels are crucial for preventive healthcare.

Traditional methods of stress assessment involve clinical interviews and psychological questionnaires. These are often time-consuming, subject to what the patient is experiencing at the moment, inaccurate, and not suitable for continuous monitoring. This leads to a need for a more reliable, faster, and real-time monitoring device, which is based on physiological parameters.

Objective:

- To develop and design a prototype that integrates Galvanic Skin Response (GSR), SpO2, and Heart Rate (HR) sensors

This project focuses on building a prototype for stress detection using non-invasive biosensors. We use data from GSR, SpO2, and HR sensors to determine the user's stress level. The current scope is limited to data collection and analysis, but in the future, we can integrate it with machine learning models to get personalized stress prediction, along with developing a user-friendly mobile app

This project is particularly important in the field of biomedical engineering, as it integrates multiple physiological signals to provide a prediction and assessment of stress levels, something that was seen as a mental health problem, and which needed a longer time to diagnose, as mentioned earlier. Hence, it has applications in mental health monitoring, wearable tech, and preventive medicine.

LITERATURE REVIEW

According to previous studies, the Autonomic Nervous system (ANS) has two types, the Sympathetic Nervous System and Parasympathetic Nervous System. The Sympathetic Nervous System prepares the body for an action - “fight” or “flight”, whereas the Parasympathetic Nervous System calms down the body. The Sympathetic Nervous System accelerates the heart rate, increases perspiration, pumps blood harder and faster, and increases the rate of breathing. It is these physiological changes in a circumstance that can be measured using non-invasive biosensors to determine one’s stress levels.

Galvanic Skin Response (GSR) sensor measures the electrical conductance of the skin based on the perspiration, due to the activation of the Sympathetic Nervous System. This is measured by placing two electrodes on the surface of the skin and continuously monitoring the electrical conductivity as it changes its value. In a study, a Grove GSR sensor, Arduino UNO and Zolertia Z1 was used to collect data from various participants and then arrive at a mean and standard deviation values of GSR. These studies were conducted for a two-minute relaxation phase.

Another study investigated the effectiveness of heart rate variability (HRV) in detecting mental stress. The researchers conducted experiments where participants were exposed to stress-inducing stimuli, and ECG signals were used to compute HRV metrics. They found that certain HRV parameters showed significant variation under stress conditions, making them reliable indicators for mental stress detection.

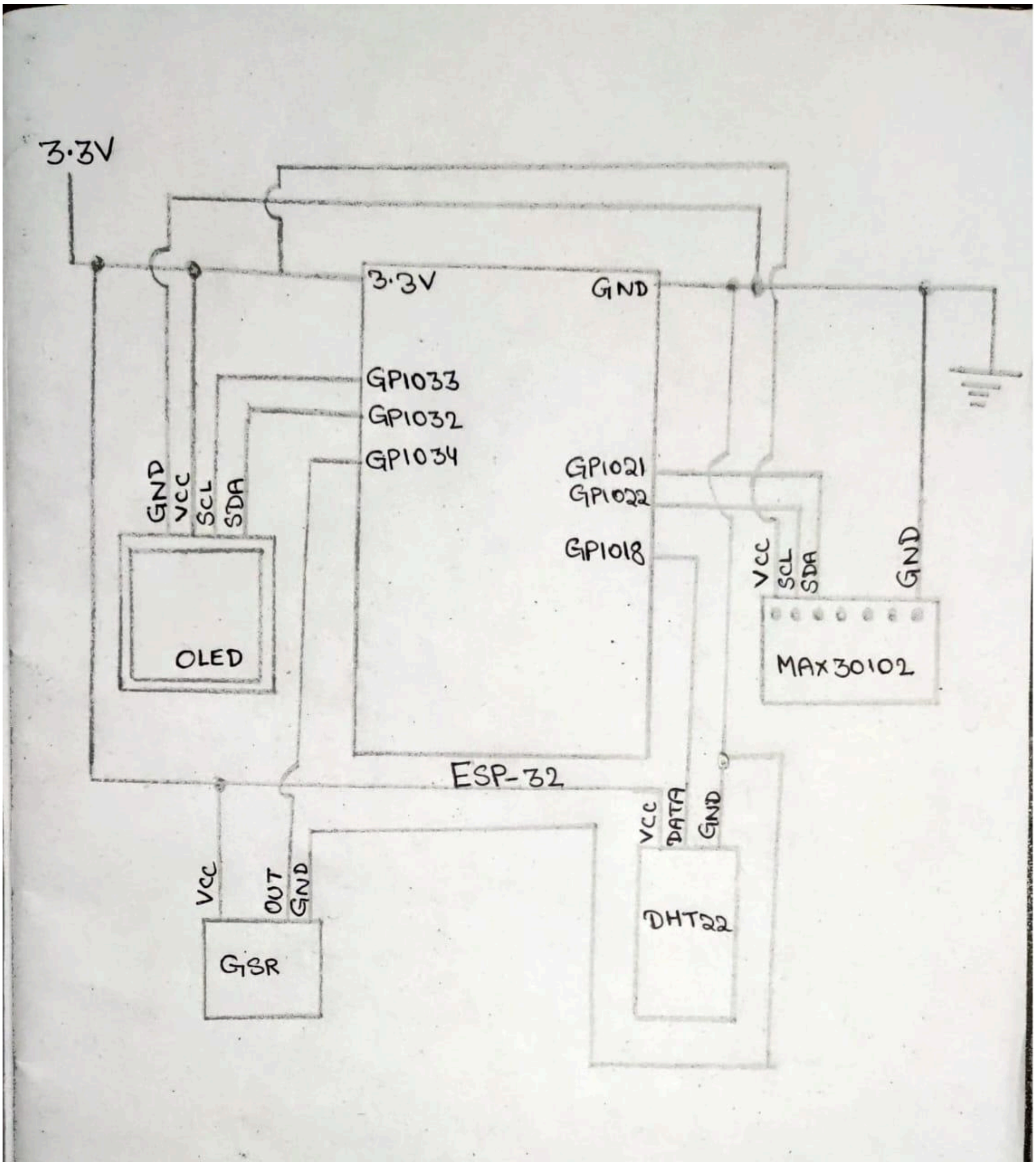
Another study investigated the effects of physical activity and psychological stress on ambulatory blood pressure (BP) and pulse rate variability. While SpO2 was not directly measured, it plays a crucial underlying role in this physiological interplay. Stress and physical exertion can influence breathing patterns and oxygen uptake, potentially affecting SpO2 levels. For instance, stress-induced hyperventilation or shallow breathing may lead to temporary drops in oxygen saturation. Similarly, prolonged physical activity increases oxygen demand, and in individuals with compromised respiratory or cardiovascular function, this can lead to desaturation episodes. Furthermore, increased BP and heart rate during stress are part of the body’s sympathetic response, which can also affect pulmonary function and oxygen exchange efficiency. In this context, monitoring SpO2 alongside BP and heart rate can offer a more comprehensive picture of how the body responds to stress, especially in high-risk individuals. This supports the value of integrating SpO_2 measurement into multisensor stress detection systems for better physiological assessment and early intervention.

The reviewed literature hence shows the correlation between GSR, HR, Temperature, SpO2 and the activation of the sympathetic nervous system during stress. The importance of employing a multisensor strategy for stress detection is highlighted by these findings taken together. The suggested system can take advantage of each parameter's advantages by combining GSR, heart rate, oxygen level sensors and temperature, allowing for a more precise and instantaneous evaluation of stress levels.

SYSTEM DESIGN

Circuit Diagram:

A schematic circuit diagram for the GSR project is given below.



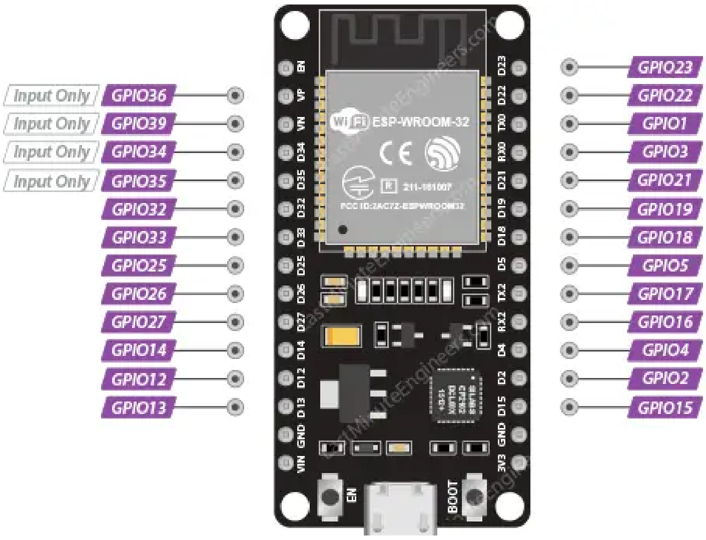
The components being used in the above circuit are:-

1. ESP-32 Development Board
2. Grove GSR(Galvanic Skin Response) Sensor
3. DHT22 Temperature and Humidity Sensor
4. MAX30102 Pulse Oximeter and Heart-Rate Sensor
5. OLED Display 0.96” 128x64

Description of the components used:

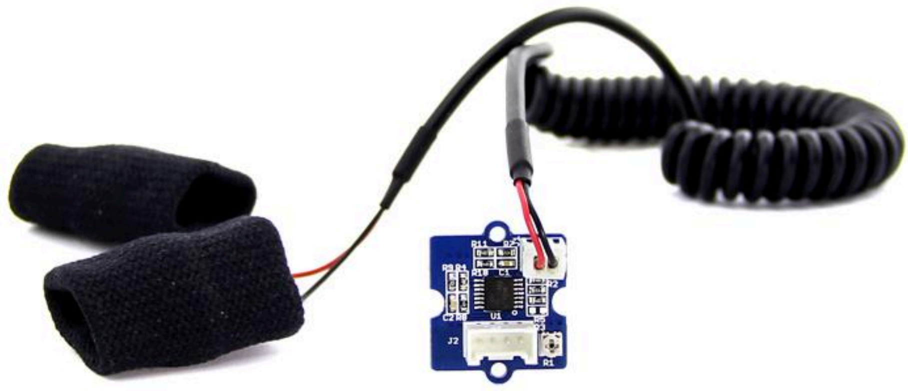
1. **ESP-32 Development Board:** ESP-32 is a powerful, low-cost microcontroller used to integrate input from multiple sensors and perform calculations based on the detections of the said sensors to generate an output. It contains both analog and digital inputs to detect continuous and discrete data simultaneously. Some features of ESP-32, which make it a better microcontroller than others, are the availability of wireless connectivity and Bluetooth, to effortlessly transfer data and output to a PC. The I2C interface makes multiple communication interfaces possible. The dual-core processor and the Real-Time-Clock ensure that the controller will run at high processing speeds (240MHz) throughout the day. The ESP-32 uses Arduino IDE and C++ to upload its code.

   In this project, multiple GPIOs (General Purpose Input Output), including both analog and digital, have been used. These pins connect each sensor to a common voltage and ground, but to specific SDA (Serial Data) or SCL (Serial Clock) pins in an I2C configuration. SDA is the data transfer line between a sensor and a microcontroller. Data could be transferred in either direction depending on the function. SCL synchronizes the data transfer over SDA and ensures that both the microcontroller and the sensor stay in sync over time. The digital pins have been used for sensors like DHT22, OLED, and MAX30102, whereas analog pins have been used for GSR sensor input. This is because temperature and heartbeat are measured and displayed on the LED display as discrete data, and the GSR input is taken in as continuous data. A voltage input of 3.3V is used throughout the entire project and across all the sensors, as it is the most compatible voltage to use in series and to prevent overload of the sensors. Similarly, a common ground has been used to complete the circuit across the sensors.



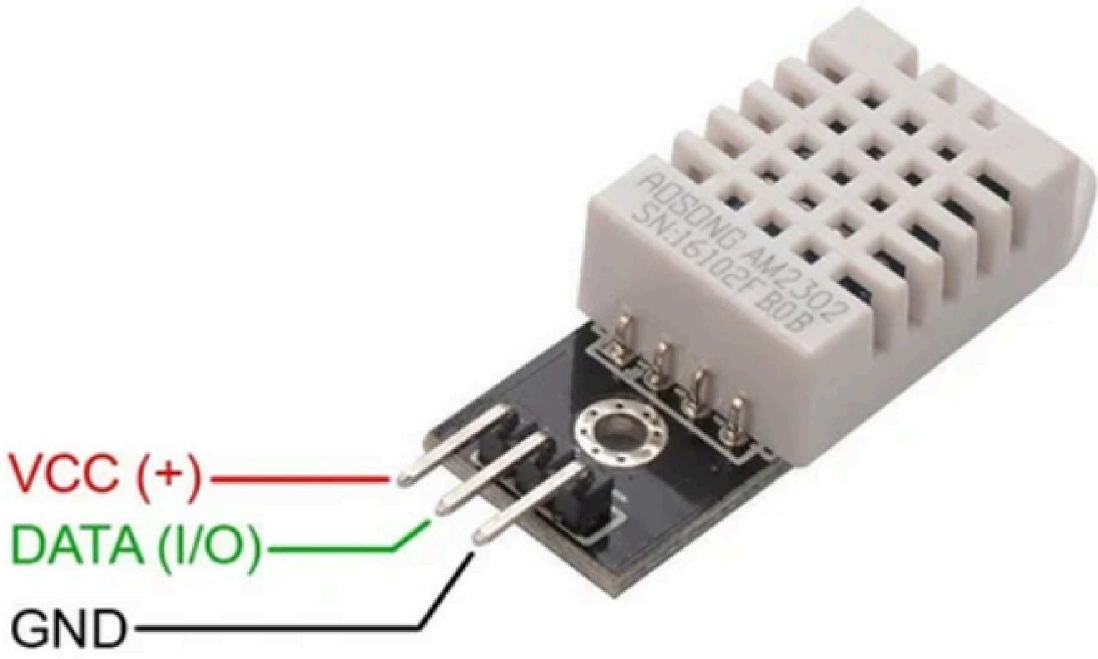
2. **Grove GSR Sensor:** The GSR sensor is the crucial component of the project. This sensor measures the electrical conductance of the skin. This measurement is generally used to determine if a person has been through stress, or any mental/emotional phase. The working principle of the sensor is that the sensor consists of two electrodes, which are usually placed on the palm of one's hand, which is the area where a person sweats the most. Whenever a person sweats, the electrical conductivity of the skin changes, and these changes are then detected by the electrodes placed on the skin of the palm. As the sweating increases, so does the conductivity.

   Since the output changes continuously, it is an analog output, which is read by an inbuilt ADC (Analog-to-Digital-Converter) on the microcontroller. A high conductance indicates that the person has been through more emotional stress, and low conductance levels indicate the opposite. On the ESP-32, the output of the GSR sensor is connected to GPIO34, an analog input, with the Vcc and ground connected to a common link.



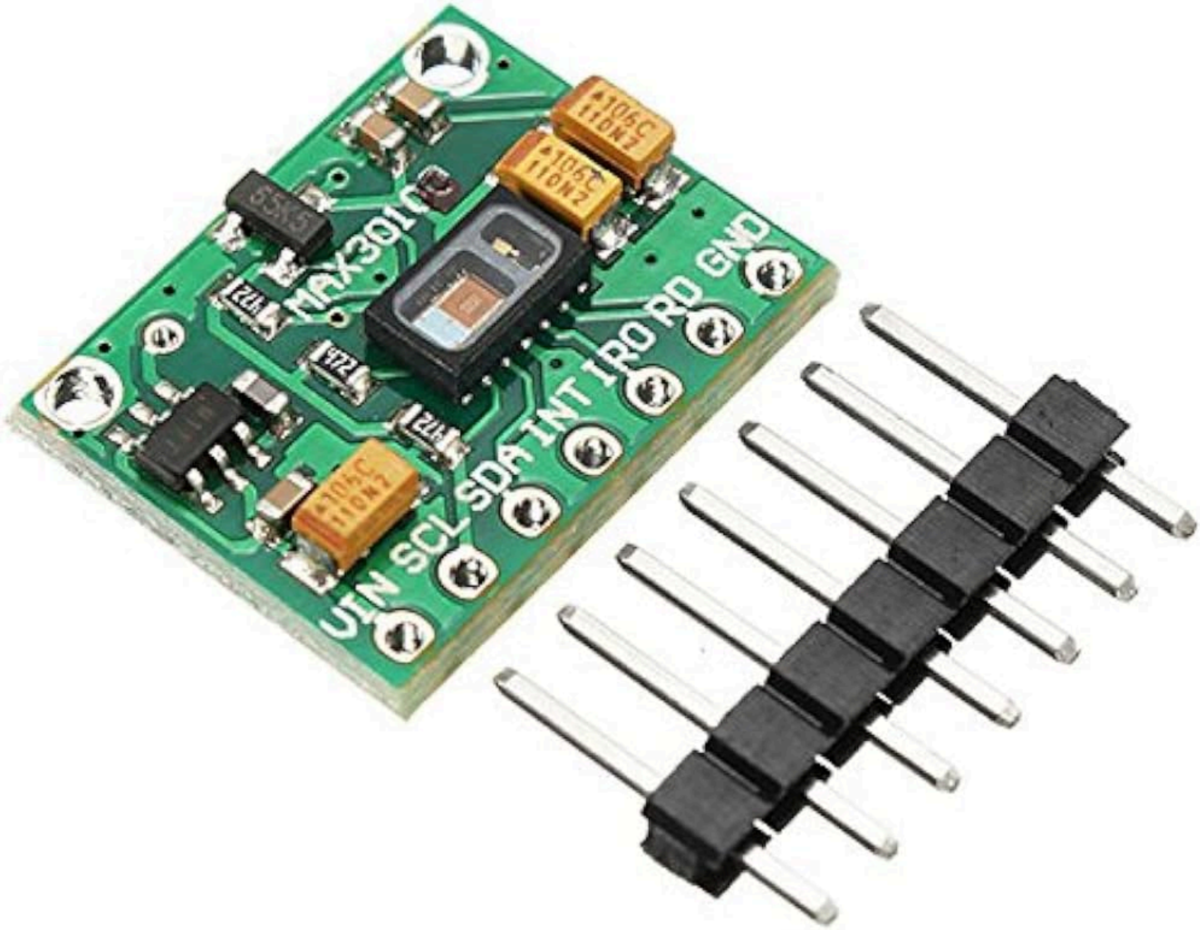
3. **DHT22 Temperature and Humidity Sensor:** The DHT22 sensor acts as a marker for more accurate predictions for the GSR sensor. The DHT22 is a digital temperature and humidity sensor, which is used to measure the temperature of the subject whose emotional stress is being measured. The working principle for measuring temperature is the usage of a thermistor, which is a type of resistor that changes its value based on the external temperature. The internal circuit consists of an ADC, which converts the change in analog resistance to a digital value. A higher temperature would produce a lower resistance, whereas a lower temperature would produce a higher resistance. The humidity of the atmosphere is measured using a capacitive sensor, which would change its dielectric constant based on the presence of water vapour in the atmosphere. A dry atmosphere would have a low dielectric constant, whereas a humid environment would have a high dielectric constant. The capacitor would then measure the capacitance with a base ground value to determine the humidity in the atmosphere. The combined result from the thermistor and the capacitor would produce a digital output of temperature and humidity.

   Since the output is discrete, the data pin of DHT22 is connected to GPIO18, with common voltage and ground



4. **MAX30102 Pulse Oximeter and Heart Rate sensor:** The MAX30102 sensor is used to measure the Heart Rate and the SpO2 (Blood Oxygen Saturation) of the patient. The sensor uses a photodetector, a red light of 660 nm and an infrared light of 800 nm, which passes through the finger of the patient, placed on top of the light source, which then outputs the heart rate and SpO2 level. The working principle for both the pulse oximeter and the heart rate sensor is Beer-Lambert's law, which relates the amount of light absorbed by a substance and the distance light travels.

   Heart rate is measured by the technique of photoplethysmography. This technique is non-invasive, which uses red light and IR light to pass through the skin, which are absorbed by oxygen-rich haemoglobin and deoxygenated haemoglobin respectively. The photodetector detects the light intensity over time as the heart pumps the blood, and the volume of blood in the finger changes over time. As the blood pumps, the volume in a specific concentrated area increases briefly, which creates a peak in the infrared signal. The heart rate is measured by measuring the time between two peaks. Saturated oxygen in blood is also measured in a similar way. Blood rich in oxygen absorbs more IR radiation compared to red light, and blood low in oxygen absorbs more red light compared to IR radiation. The photodiode measures the ratio of red light absorption to IR absorption to calculate the oxygen saturation. The analog output is passed through an ADC to obtain a discrete digital output. On the ESP-32 microcontroller, the SDA is connected to GPIO21 and the SCL is connected to GPIO22.

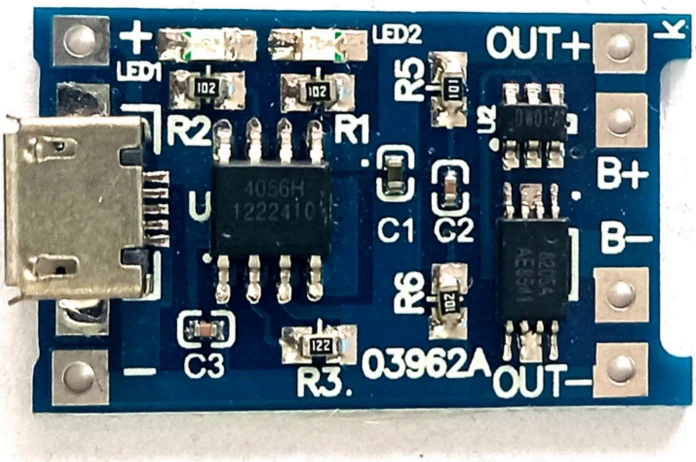


5. **OLED Display:** The LED display is used to display the outputs from the sensors and the prediction after taking in the inputs from the sensors. It provides a user-friendly method of analysing the results across all the sensors. The OLED display is 0.96 inches across its diagonal, with a resolution of 128x64 pixels. The operating voltage is between 3.3V and 5V, but for the safety of the components, the voltage is set to 3.3V.

   On the ESP-32 microcontroller, the SDA pin of the OLED display is connected to GPIO32 and the SCL pin is connected to GPIO33, to display a digital signal.

Power Supply Details: A common voltage supply of 3.3 V is supplied to all the components from the ESP-32, which has its source from a 3.7V Li-Po Rechargeable Battery, mounted to a 03962A charging module. The battery would produce a current of 500mAh, which is ideal for the proper functioning of all the sensors. Li-Po battery was used due to its being lightweight, rechargeable, and portable. It is estimated that a 500mAh battery would run the sensor for 2-5 hours alone, on a single charge.

The B+ and the B- terminals would be connected to the positive and negative terminals of the battery, respectively. The OUT+ and OUT- would be connected to the VIN and GND pins of the ESP32. The other sensors of the circuit would then be connected to the 3.3V pin of the ESP32.



METHODOLOGY

The first step in the implementation of the project is to acquire the different signals from all the different sensors. The GSR sensor is used to check the conductance of the skin to determine the level of sweating a person has undergone. A larger GSR value would indicate a large amount of emotional stress or heat. But it clearly could not be determined if the person suffered a heavy emotional phase, or if the surrounding temperature is just too high, that sweating was induced to cool the body. This issue is taken care of by the DHT22 and MAX30102 sensors. The DHT22 temperature sensor would determine the local temperature and humidity levels surrounding the patient, acting as a first marker to help determine if the sweating was due to heat or emotional stress. The MAX30102 sensor would help determine the heart rate and oxygen levels of the person. Heat-induced sweating would not affect the heart rate and oxygen levels to a great extent, but emotional stress-induced sweating would show the results immediately, as the heart rate would be elevated and the oxygen levels would be lower than usual, suggesting rapid breathing.

The next step would be to filter the signals to make accurate predictions. The GSR signal is processed through an ADC channel to better work with the already digitally acquired temperature and heart rate signals. Signal noises are smoothed out by the sensor, if required.

Stress Classification Logic

The threshold values for classification of the data are based on experimentally obtained values, and need to be changed multiple times through trial and error methods to reduce errors, but a good starting point would be as such.

Sensor	**What is means**	**Threshold**
GSR	Sweating	> 1800
Temp	Heat-induced sweating	>37.5 C
Heart Rate	Stress-induced	>90 bpm
SpO2	Low Oxygen	<95%

In simple words, the marker threshold parameters would be:

- If the value of GSR is greater than 1800, then sweating is confirmed, but the cause is not
- If the temperature of the human is more than the average temperature of 37.5 C, then it could be ruled as heat sweating, else the sweating could indicate stress sweating

- If both the heart rate is more than that of an average human of 90 bpm and if the SpO2 levels are less than 95%, then the sweating is due to emotions and it is ruled that the person is under stress.

Arduino Code for the Working Mechanism

The ESP-32 custom code was coded in Arduino IDE under C++. Some required libraries from the Arduino Library manager were installed. The libraries were:

- MAX30100_PulseOximeter by OXullo Intersecans (for measuring heart rate and pulse oxygen saturation)
- DHT sensor library by Adafruit (for measuring temperature and humidity)
- ADafruit SSD1306 and Adafruit GFX (for displaying output on an OLED screen)
- BluetoothSerial (allows for wireless transfer of data through Bluetooth)

The code using logic detection from data from the sensors, and processing them is given as follows:

```
#include <Wire.h>
#include <Adafruit_GFX.h>
#include <Adafruit_SSD1306.h>
#include <DHT.h>

// OLED Config
#define SCREEN_WIDTH 128
#define SCREEN_HEIGHT 64
#define OLED_RESET -1
Adafruit_SSD1306 display(SCREEN_WIDTH, SCREEN_HEIGHT, &Wire,
OLED_RESET);

// Pins
#define GSR_PIN 34
#define DHT_PIN 18
#define PRESSURE_PIN 21

// DHT Config
#define DHTTYPE DHT22
DHT dht(DHT_PIN, DHTTYPE);

// Thresholds (tweak based on calibration/testing)
const int GSR_THRESHOLD = 1800;       // Analog value (0–4095)
const float TEMP_THRESHOLD = 37.5;    // Degrees Celsius
const float BP_THRESHOLD = 17.0;      // Approximate kPa for elevated BP

void setup() {
```

```
  Serial.begin(115200);

  // Display setup
  if (!display.begin(SSD1306_SWITCHCAPVCC, 0x3C)) {
    Serial.println("OLED init failed");
    while (1);
  }

  display.clearDisplay();
  display.setTextSize(1);
  display.setTextColor(SSD1306_WHITE);

  // DHT Init
  dht.begin();
}

void loop() {
  // Read sensors
  int gsrValue = analogRead(GSR_PIN);

  float temperature = dht.readTemperature();
  float humidity = dht.readHumidity();

  int pressureRaw = analogRead(PRESSURE_PIN);
  float voltage = (pressureRaw / 4095.0) * 3.3;
  float pressure_kPa = (voltage - 0.2) * (50.0 / 4.5); // MPX5050GP formula

  // Stress Detection Logic
  String state = "Normal";

  if (gsrValue > GSR_THRESHOLD) {
            if (temperature > TEMP_THRESHOLD && pressure_kPa <=
BP_THRESHOLD) {
      state = "Sweat from heat";
        } else if (temperature <= TEMP_THRESHOLD && pressure_kPa >
BP_THRESHOLD) {
      state = "Emotional stress";
    } else {
      state = "Possible stress/heat";
    }
  }

  // Serial Debug
  Serial.print("GSR: "); Serial.print(gsrValue);
```

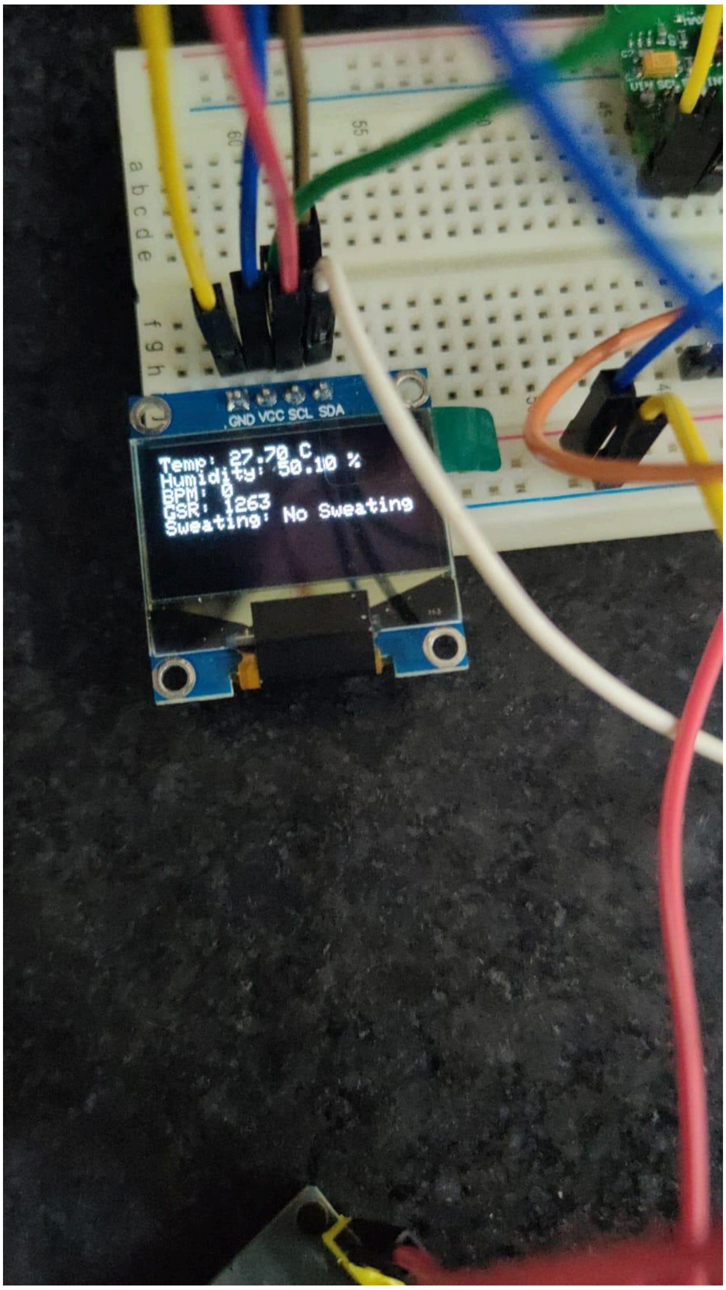
```
  Serial.print(" | Temp: "); Serial.print(temperature);
  Serial.print(" | Hum: "); Serial.print(humidity);
  Serial.print(" | BP: "); Serial.print(pressure_kPa);
  Serial.print(" | State: "); Serial.println(state);

  // Display Output
  display.clearDisplay();
  display.setCursor(0, 0);
  display.print("GSR: "); display.println(gsrValue);
  display.print("Temp: "); display.print(temperature); display.println(" C");
  display.print("BP: "); display.print(pressure_kPa); display.println(" kPa");
  display.setCursor(0, 48);
  display.print("State: "); display.println(state);
  display.display();

  delay(2000);  // 2s delay
}
```

RESULTS AND OBSERVATIONS

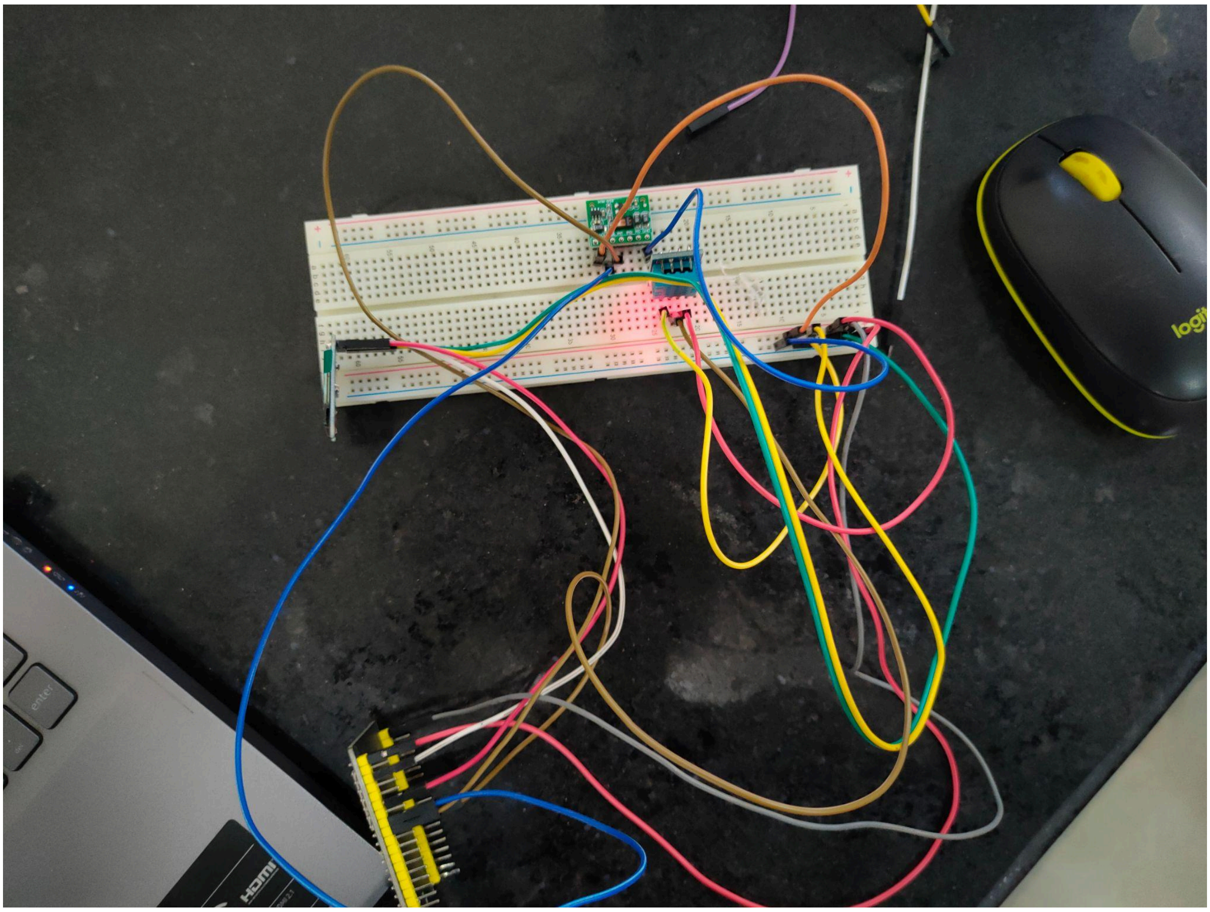
Here are some results of the circuit detecting the temperature and humidity and displaying it on the Serial Monitor and the OLED screen.

Result on Serial Monitor

Result on OLED screen



The working circuit containing the DHT22 sensor



The GSR readings of multiple people have been recorded with varying temperature and stress levels, and given below are the outputs of different situations.

1. **Subject is Calm and Relaxed**

```
GSR: 1120
Temp: 36.5 C
HR: 72 bpm
SpO2: 98 %
State: Normal
```

2. **The subject is emotionally stressed**

```
GSR: 2090
Temp: 36.4 C
HR: 102 bpm
SpO2: 97 %
State: Emotional stress
```

3. **The subject is sweating due to the heat**

```
GSR: 1980
Temp: 38.2 C
HR: 84 bpm
SpO2: 96 %
State: Sweat from heat
```

Tabular Representation of the observations

S.No	GSR	Temp (in C)	HR (bpm)	SpO2 (%)	State
1	1120	36.5	72	98	Normal
2	2090	36.4	102	97	Emotional Stress
3	1980	38.2	84	96	Heat Sweat

From the above observations, we can conclude that the circuit provides an accurate prediction of whether the person is under stress or not.

APPLICATIONS

Galvanic Skin Response (GSR) also known as EDA (electrodermal activity) has a vast area of application working on the conductance due to sweat gland activity, making it useful in a range of disciplines:

Physiotherapy:

- During physiotherapy, patients get to be aware and have control over physiological processes to reduce stress and chronic pain using **GSR.**
- In pain management and neuromuscular disorders, it is used to assess stress levels during therapy sessions.
- In autonomic dysfunction, it helps in the diagnosis and tracking of the disorders.

Sports science:

- Identifying psychological stress before and during performance can affect concentration and physical output.
- Coaches and sports psychologists use GSR data to tailor training sessions, balancing stress and recovery to avoid overtraining.
- Insights into an athlete's engagement and mental state during performance or training. Real-time GSR monitoring can be provided.

Rehabilitation:

GSR serves as a tool to understand patient responses and promote recovery in rehabilitation, especially in neurorehabilitation and post-trauma recovery.

- Therapists can adjust treatment accordingly to track emotional responses in patients undergoing therapy.
- During tasks, GSR is employed in brain injury rehab to assess cognitive workload and attention levels.
- In patients with PTSD, GSR helps detect triggers and monitor therapy progress by indicating stress levels during exposure therapy or VR-based interventions.

Education:

GSR is an innovative tool in educational research, especially in the realm of emotional and cognitive engagement.

- During learning activities, educators can identify which materials or methods generate the most engagement by measuring arousal .

- With the help of GSR data, adaptive learning systems that adjust content difficulty based on the learner's stress or arousal can be identified.
- Research has used GSR to study test anxiety, helping educators develop more supportive testing environments.
- **I**n children with autism or ADHD, GSR can help in a great way that it can monitor emotional states during learning, supporting more personalized interventions.

Limitations

Though GSR has a vast area of application, it has some limitations which are still to be considered.

Noise Sensitivity

GSR signals are highly sensitive to external and internal noise, which can lead to data inaccuracy or misinterpretation which makes it challenging to collect clean data in real-world scenarios like sports fields, classrooms, or therapy sessions without careful calibration and filtering techniques.

- Factors like ambient temperature, humidity, and skin hydration levels can significantly affect GSR readings. As an example, warmer environments increase sweating, which may artificially elevate the signal, and thus we don't get proper data as the temperature factor is working as a noise here.
- Physical movements or skin-electrode displacement can introduce signal fluctuations unrelated to emotional or physiological changes. So any displacement of the electrode may result in unwanted data collection.
- Other electrical devices or poor shielding in sensor circuits can also distort the signals.

Muscle-Specific Tuning

Electromyography (EMG), which targets specific muscle groups, on the other hand, GSR does not provide localized muscle activity data. This limits its use in applications where muscle-specific biofeedback is needed, such as motor rehabilitation or detailed motion analysis in sports science.

- GSR reflects general autonomic arousal, not the activity of a specific body part or muscle, which is a barrier to getting specific data.
- Electrodes placed on fingers or palms can't distinguish between different sources of arousal—be it emotional stress, physical exertion, or thermoregulatory sweating we can't get specific data.

Basic Threshold Logic vs AI Methods

GSR systems (traditional) often rely on simple threshold-based interpretations of skin conductance changes, which can be crude and unreliable. That's why we have to take the help of AI. Without AI-driven data analysis, GSR interpretations may lack precision, leading to false positives/negatives in detecting stress, engagement, or fatigue.

- Many basic systems interpret emotional states based on fixed cutoff points (e.g., “if conductance > x, user is stressed”), without accounting for individual variability.
- Skin conductance response can vary widely based on individuals based on skin type, hydration, or baseline anxiety levels.
- Most off-the-shelf GSR systems still use basic logic. Modern AI/ML algorithms can offer deeper insights by learning patterns over time, which can give better accuracy.

Future Scope of GSR Technology

As GSR technology is continuously evolving, it presents promising opportunities for more advanced, accessible, and intelligent physiological monitoring systems. The advancements given below are expected to enhance its usability and integration across various fields:

Wireless Integration

The GSR technology is continuously developing and is showing promising effects in wireless, wearable solutions, which eliminate the need for bulky setups and cables. On top of that, GSR sensors can be embedded into smartwatches, wristbands, or fitness trackers using compact Bluetooth- or Wi-Fi-enabled systems.

- Wireless systems allow continuous data collection during daily activities like sports training or therapeutic sessions.
- Enables clinicians, coaches, or educators can monitor users' stress or engagement levels remotely, which is useful in telehealth and e-learning environments.

Visual Interfaces

Improvement in GSR data representation will make it more accessible to both professionals and users which will enhance usability, especially in education, rehabilitation, or at-home physiotherapy.

- Future systems may feature intuitive visualization like stress graphs, arousal maps that help users understand their physiological states.

- self-awareness and behavioral change can be created and supported by Live visuals during therapy, learning, or workouts.
- Visual elements like progress bars or animated avatars can be used to gamify biofeedback therapy for children or patients with cognitive challenges.

AI or ML for Pattern Recognition

Getting better accuracy and personalization of data interpretation will be possible by integrating **Artificial Intelligence (AI)** and **Machine Learning (ML)** with GSR systems .

- ML (machine learning) algorithms can learn user-specific patterns and distinguish between different types of arousal (e.g., stress vs excitement).
- For holistic emotional and physiological profiling AI can integrate GSR with other biosignals (heart rate, EEG, EMG) .
- ML can detect unusual patterns in autonomic response, which may aid in early diagnosis of mental health or neurological disorders.
  In sports, AI-enhanced GSR data could predict mental fatigue or burnout risk before performance declines.

Mobile App Synchronization

In future Mobile platforms will play a key role in democratizing GSR-based insights and making them available to the average user.Smartphone integration,Daily wellness tracking,Therapy support tools will be improved using GRS system .

- Apps would be used to sync with wearable GSR devices to provide personalized feedback, alerts, and history tracking which will be very helpful to individuals .
- Based on their GSR data Users could receive stress management tips, breathing exercises, or focus alerts.
- real-time GSR data to guide sessions can be used for Apps, designed for cognitive behavioral therapy (CBT) or mindfulness .

CONCLUSION

This stress detector project demonstrated the integration of a GSR sensor, heart rate sensor, SpO2 sensor and a temperature sensor into a unified, non-invasive system for real-time stress detection. The results obtained match with the expected results during the testing phase. The physiological changes governed by the sympathetic nervous system are effectively captured by stress-induced changes in skin conductance, heart rate variability, and blood oxygen levels. The use of an ESP32 microcontroller for data collection and analysis ensures that the system is both affordable and accessible.

The multisensor approach has significantly enhanced the accuracy and the reliability of stress detection compared to a single sensor circuit. Its practical implementation using low-cost components highlights the potential of it being cost effective. It can be used in scalable applications in wearable health devices, continuous clinical monitoring, and personal stress management tools. The GSR project not only meets the growing need for continuous monitoring of stress in modern healthcare but also sets the stage for future advancements. In smart biomedical systems and AI-assisted wellness technologies this will grow more faster because of its need.

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