

Original Article

Design of a Low-Cost Galvanic Skin Response Stress Monitoring System Using PIC16F688

S.A. Harge¹, R.C. Pawar², C.A. Rajoba³, S.R. Patil⁴

Department of Electronics, Smt. Kasturba Walchand College of Arts and Science, Sangli, Maharashtra

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Correspondence Address:

S.A. Harge, Department of Electronics,
Smt. Kasturba Walchand College of Arts
and Science, Sangli, Maharashtra
Email: sahilharge710@gmail.com

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Abstract

Mental stress has become a major health problem, directly linked to cardiovascular disease, chronic anxiety, and immune system issues [1]. Catching acute stress early allows people to intervene before it impacts their health [2]. This paper covers the design and practical build of an ultra-low-cost, non-invasive Galvanic Skin Response stress monitoring device built around the Microchip PIC16F688 8 bit microcontroller [3]. The system works by reading tiny changes in skin conductance caused by sweat gland activity, which is directly controlled by the sympathetic nervous system [1][4]. An analog signal conditioning circuit converts high impedance skin resistance changes into a clean voltage range given as input for the PIC16F688 internal 10 bit Analog to Digital Converter [3]. The microcontroller runs moving average filtering and threshold-based classification right on the chip. Testing shows the prototype reliably tells the difference between relaxed, baseline, and high stress states in real time, keeping power consumption minimal and the total component cost extremely low.

Keywords-Galvanic Skin Response, PIC16F688, Stress Monitoring, Embedded Systems.

Introduction

Psychological and physiological stress has emerged as one of the most critical health challenges of the modern era [1]. Prolonged or unmanaged stress is directly linked to chronic physical and mental health conditions, including cardiovascular disease, hypertension, impaired immune function, clinical anxiety, and major depressive disorders [1][2]. From an epidemiological perspective, early detection and real-time monitoring of acute stress states offer a proactive avenue for biofeedback, clinical intervention, and lifestyle management before transient stress triggers devolve into chronic physiological damage [2]. At a biological level, the human response to stress is mediated by the Autonomic Nervous System, which regulates involuntary physiological functions [4]. The Automatic Nervous System operates through two antagonistic branches, one of them is the parasympathetic nervous system, responsible for vegetative rest and digest processes, and another one is the sympathetic nervous system, which drives the immediate fight or flight survival mechanism [1][4]. When an individual encounters a physical, cognitive, or emotional stressor, the Sympathetic Nervous System is activated. This activation triggers a cascade of rapid somatic adjustments, including accelerated heart rate, elevated blood pressure, peripheral vasoconstriction, and increased sweat gland activity [1]. Among the various physiological biomarkers used to measure sympathetic arousal, Electrodermal Activity historically termed Galvanic Skin Response is uniquely valuable [1][4]. Unlike heart rate variability or respiratory rate, which receive dual innervation from both the sympathetic and parasympathetic pathways, the sweat glands located primarily on the palmar and plantar skin surfaces are exclusively innervated by the sympathetic nervous system [1]. As a result, changes in skin electrical conductance serve as a direct, unconfounded index of sympathetic nervous system activity without parasympathetic interference [1][4]. When sweat gland nerves fire in response to stress, sweat glands fill with a weak electrolyte solution containing sodium (Na^+) and chloride (Cl^-) ions [1]. This fluid bridges the epidermal layer, significantly lowering the electrical resistance (R_{skin}) across the skin surface and causing a proportional increase in skin conductance (G_{skin}) [1][5]. Skin conductance is typically measured in microSiemens (μS) and is decomposed into two distinct components:

1. Tonic Level: The slow-shifting baseline conductance that fluctuates over minutes or hours based on overall alertness, skin hydration, and ambient temperature [1][5].
2. Phasic Response: The rapid, transient spikes in conductance that occur within 1 to 5 seconds following an acute stimulus or stressor [2][5].

To bridge the gap between expensive clinical hardware and resource-heavy consumer wearables, this paper presents the design and laboratory validation of a low cost, minimal footprint GSR stress monitoring system built around the Microchip PIC16F688 8-bit microcontroller [3]. The core contributions of this work are as follows:

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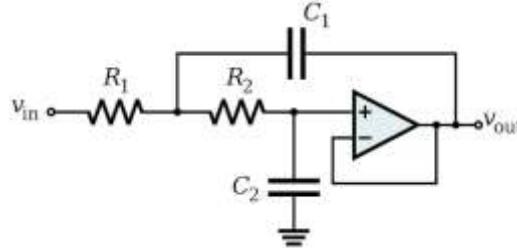
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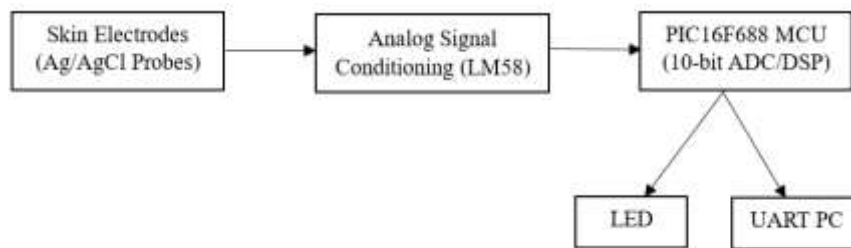
- **Ultra-Low System Cost:** The complete hardware architecture relies on off-the-shelf, accessible components (PIC16F688 microcontroller, LM358N operational amplifier, and standard Ag/AgCl electrodes), keeping the total Bill of Materials (BOM) under \$8 USD.
- **Efficient Hardware Signal Conditioning:** A custom low-voltage DC excitation technique (0.5 V) is paired with a non-inverting transimpedance stage and a 2nd-order Sallen-Key low-pass filter ($f_c = 5$ Hz), preventing tissue polarization while completely suppressing 50/60 Hz mains power hum [1][5].



- **On-Chip Signal Processing:** By leveraging the PIC16F688 internal 10 bit Analog to Digital Converter (ADC) and 8 MHz internal oscillator, digital moving average filtering and threshold-based stress classification are performed entirely on chip without requiring external memory or secondary processors [3].
- **Real-Time Visual & Serial Feedback:** The device provides real-time state classification (Relaxed, Moderate, and High Stress) via a tri color LED indicator network and outputs raw digitized data over an integrated UART communication interface for external logging.

System Architecture

The proposed Galvanic Skin Response (GSR) stress monitoring system is designed around a modular, low power hardware architecture. The hardware pipeline converts biological skin impedance variations into digitized physiological stress metrics. The overall system is divided into four primary functional blocks the GSR Electrodes and Transducer Unit, the Analog Signal Conditioning Circuit, the PIC16F688 Processing Unit, and the User Output Interface.



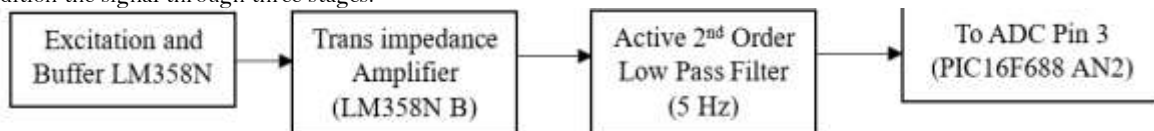
1) GSR Electrodes & Transducer Unit

The transducer unit serves as the physical interface between the biological tissue and the electronic measurement system.

- **Electrode Selection:** Two Silver/Silver-Chloride (Ag/AgCl) snap on finger electrodes with conductive velcro straps are attached to the distal phalanges of the index and middle fingers. Ag/AgCl electrodes are selected due to their non polarizable properties, which minimize half-cell potential drift and electrode polarization artifacts during continuous measurement.
- **Transduction Principle:** The palmar surface of the fingers contains a high concentration of eccrine sweat glands innervated exclusively by the sympathetic nervous system. When acute stress is induced, sweat secretion increases the ionic concentration Na^+ and Cl^- in the sweat ducts, which lowers epidermal resistance R_{skin} and increases skin conductance G_{skin} .
- **Excitation Voltage Safety:** To prevent physiological tissue polarization and skin burns, the electrodes are excited with a low DC voltage $V_{exc} = 0.5$ V, well below the maximum threshold recommended for electrodermal measurement.

2) Analog Signal Conditioning Circuit

Because raw electrodermal signals have high source impedance and are easily corrupted by environmental electrical noise, direct connection to a microcontroller ADC is unfeasible. An analog front end built using an LM358N dual operational amplifier condition the signal through three stages.



1. **Voltage Reference & Buffer Stage:** The first op-amp channel (LM358N A) is configured as a voltage follower. It derives a stable 0.5 V reference potential (V_{ref}) from the +5 V rail using a precision voltage divider network. Buffering ensures a low-impedance excitation source for the skin electrodes.
2. **Transimpedance Conversion & Amplification:** The second op-amp stage (LM358N B) functions as a current-to-voltage converter. As skin resistance (R_{skin}) varies dynamically between 10 k Ω (high stress) and 2 M Ω (deep relaxation), the output voltage (V_{out}) varies proportionally:

$$V_{out} = V_{ref} \times \left(1 + \frac{R_f}{R_{skin}}\right)$$

Where $R_f = 100 \text{ k}\Omega$ represents the feedback resistance.

3. **Active Low-Pass Noise Filtering:** A 2nd-order active Sallen-Key low-pass filter with a cutoff frequency of $f_c = 5 \text{ Hz}$ attenuates high-frequency muscle movement artifacts (EMG) and strips away 50/60 Hz electromagnetic powerline interference.

3) Processing Unit (PIC16F688 Microcontroller)

The conditioned analog voltage signal enters Pin 3 (AN2) of the Microchip PIC16F688, an 8 bit flash microcontroller optimized for ultra-low-power embedded applications.

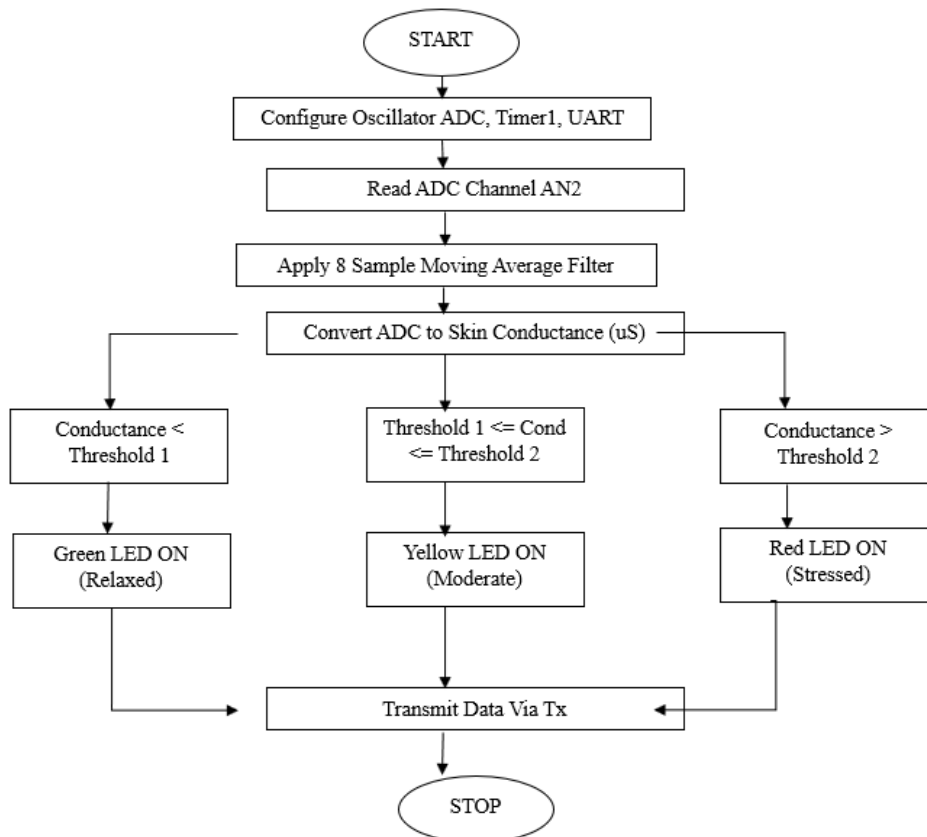
- **Analog-to-Digital Conversion (ADC):** The integrated 10 bit successive approximation ADC samples the filtered voltage at a rate of 10 Hz (10 samples/sec), converting the signal into digital levels ranging from 0 to 1023 counts (0 V to 5 V).
- **On-Chip Signal Processing:** The microcontroller executes an 8 sample moving average digital filter in SRAM to smooth transient motion noise.

$$\bar{V}_{ADC}[k] = \frac{1}{8} \sum_{i=0}^7 V_{ADC}[k-i]$$

- **Classification Logic:** The processed average value ($\bar{V}_{ADC}$) is continuously compared against calibrated physiological thresholds stored in program memory to categorize the user's current psychological state:
 - a. **Baseline / Relaxed State:** $\bar{V}_{ADC} < 350$ (High skin resistance, low conductance).
 - b. **Moderate / Cognitive Stress:** $350 \leq \bar{V}_{ADC} < 650$ (Moderate skin resistance drop).
 - c. **High / Acute Stress:** $\bar{V}_{ADC} \geq 650$ (Significant skin resistance drop, high conductance).
- 4) **User Output Interface:** The system provides dual output modalities for real-time local visualization and external scientific data logging.
 1. **Local Tri-Color LED Indicators:**
 - a. **Green LED (RC2, Pin 8):** Illuminates during baseline relaxation state.
 - b. **Yellow LED (RC1, Pin 9):** Illuminates during moderate or cognitive stress tasks.
 - c. **Red LED (RC0, Pin 10):** Illuminates during acute startle or high-stress events.
 2. **UART Serial Data Interface:** The hardware EUSART module (TX, Pin 5) transmits raw and filtered 10-bit ADC values over an RS-232/TTL serial link at a baud rate of 9600 bps. This allows real-time plot generation and data logging using PC-based tools (such as MATLAB, Python, or Serial Plotter) for post-experimental validation.
 3. **Digital Filtering:** To smooth out small movement artifacts and noise, the code implements an 8-sample moving average filter:

$$\bar{V}_{ADC}[k] = \frac{1}{8} \sum_{i=0}^7 V_{ADC}[k-i]$$

Block Diagram



Hardware Design

- 1) **Signal Conditioning Circuit:** Skin resistance (R_{skin}) typically spans a wide range from around 10 k Ω during high stress up to 2 M Ω during deep relaxation [1]. To map this wide dynamic range cleanly, the design uses a constant voltage excitation approach paired with an LM358N operational amplifier.
- **Amplifier Stage:** A low DC voltage ($V_{exc} = 0.5$ V) is applied across the electrodes to safely measure skin resistance without causing tissue polarization [1]. The circuit uses a non-inverting op-amp configuration:

$$V_{out} = V_{ref} \times \left(1 + \frac{R_f}{R_{skin}}\right)$$

Where:

$V_{ref} = 0.5$ V (derived from a resistor divider and buffered by LM358N Channel A).

$R_f = 100$ k Ω (Feedback Resistor).

R_{skin} = Variable resistance measured across the user's fingertips.

- **Low-Pass Filter:** High-frequency interference—such as 50/60 Hz power line hum and muscle movement noise—is eliminated with a 2nd-order active Sallen-Key low-pass filter. The cutoff frequency (f_c) is set to 5 Hz, which keeps the signal clean since electrodermal responses stay below 2 Hz [5].

$$f_c = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}} = 5 \text{ Hz}$$

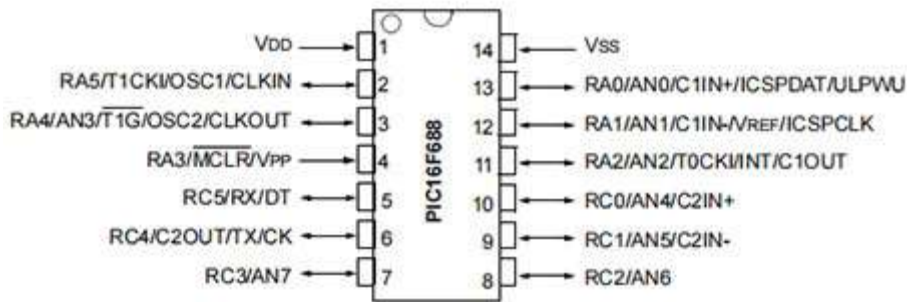
- 2) **Microcontroller Integration (PIC16F688):** The PIC16F688 was chosen for its low cost and small footprint:

- Compact 14-pin DIP/SOIC package to save board space.
- Built-in 10-bit Analog-to-Digital Converter (ADC) tied to Channel AN2 (Pin 3).
- On-board 8 MHz internal oscillator, eliminating the need for an external crystal.
- Hardware EUSART for serial data communication.

3) Pin Mapping:

- Pin 1 (V_{DD}): +5 V Power Input
- Pin 14 (V_{SS}): Ground
- Pin 3 (AN2): Analog input from the signal conditioning circuit
- Pin 8 (RC2): Green LED (Relaxed State)
- Pin 9 (RC1): Yellow LED (Moderate State)
- Pin 10 (RC0): Red LED (High Stress State)
- Pin 5 (TX): RS-232 UART Serial Output (9600 baud)

4) PIC16F688 Microcontroller:



Software And Processing Workflow

The system firmware was developed in Embedded C and compiled using the Microchip XC8 compiler for execution on the 8-bit PIC16F688 microcontroller [3]. The software operates on an interrupt-free, continuous polling architecture designed to minimize CPU overhead while ensuring deterministic sampling.

```
uint16_t buffer [8] = {0};
uint8_t index = 0;
while (1) {
    buffer[index] = ADC_Read();
    index = (index + 1) % 8;
    uint32_t sum = 0;
    for (uint8_t i = 0; i < 8; i++) {
        sum += buffer[i];
    }
}
```

The hardware registers and system configuration fuse bits are initialized to run the internal RC oscillator at 8 MHz, disabling the Watchdog Timer, and Master Clear to reduce external pin dependence.

1. **ADC Initialization:** Analog Channel is assigned as an analog input via register ANSEL. The Analog to Digital Converter control registers $ADCON0$ and $ADCON1$ are configured for right-justified 10 bit output resolution, utilizing $V_{DD} = 5.0$ V as the reference voltage and setting the conversion clock conversion rate to $F_{OSC}/32$.

2. **Moving Average Digital Filter:** To suppress transient electro-myographic motion artifacts and remaining high-frequency powerline noise, a real time 8 sample moving average filter is implemented in SRAM. Raw 10 bit digital conversions are sequentially written into an 8-element circular array buffer. The smoothed output metric is computed continuously:

$$\bar{V}_{ADC}[k] = \frac{1}{8} \sum_{i=0}^7 V_{ADC}[k-i]$$

3. **Threshold Classification Logic:** The calculated moving average is evaluated at 100 ms periodic intervals against two pre-calibrated baseline decision boundaries. Digital output lines on Port C drive individual LEDs to visually indicate the detected physiological state:
 - Relaxed State ($\bar{V}_{ADC} < 350$): RC2 asserted HIGH (Green LED active).
 - Moderate Stress ($350 \leq \bar{V}_{ADC} < 650$): RC1 asserted HIGH (Yellow LED active).
 - Acute Stress ($\bar{V}_{ADC} \geq 650$): RC0 asserted HIGH (Red LED active).

Methodology

The research methodology follows a structured hardware-software co-design approach to acquire, filter, analyze, and classify electrodermal activity signals in real time. The operational workflow is divided into three primary phases: physical sensing and signal conditioning, analog to digital processing, and real-time digital filtering with threshold-based classification. The hardware acquisition front-end captures autonomic physiological responses by measuring changes in skin conductance.

1. **Sensing Interface:** Two silver/silver chloride (Ag/AgCl) skin contact electrodes are positioned on the user's fingertips. Sympathetic nervous system arousal induces micro-changes in sudomotor sweat gland activity, lowering galvanic skin resistance (R_{skin}) during stress.
2. **Signal Conditioning Circuitry:** The electrode potential is routed into a voltage-divider topology powered by a regulated +5.0 V continuous direct-current supply (V_{DD}). A high-input-impedance operational amplifier buffers the analog voltage signal (V_{in}) to prevent loading effects:

$$V_{in} = V_{DD} \times \left(\frac{R_{pull-down}}{R_{skin} + R_{pull-down}} \right)$$

3. **Microcontroller Platform:** The conditioned signal is connected directly to Pin 3 (RA2/AN2) of an 8-bit Microchip PIC16F688 microcontroller. Operating with an internal RC oscillator tuned to 8 MHz, the internal peripheral set handles analog conversion and classification routines without requiring external clock circuitry.

A. Analog-to-Digital Conversion (ADC) Configuration

The onboard 10 bit Successive Approximation Register Analog to Digital Converter is configured to digitize continuous voltage signals into discrete numerical counts ($0 \leq V_{ADC} \leq 1023$).

- **Reference Voltage:** Set to $V_{DD} = +5.0$ V, yielding a theoretical voltage resolution of:

$$\text{Resolution} = \frac{V_{DD}}{2^{10} - 1} = \frac{5.0 \text{ V}}{1023} \approx 4.887 \text{ mV/count}$$

- **Conversion Clock Timing:** The ADC clock source is set to $F_{OSC}/32$ (ADCON1 = 0b00100000) to guarantee an acquisition period (T_{AD}) well above the required minimum datasheet specification (1.6 μ s), ensuring accurate sampling across temperature variations.
- **Formatting:** Register ADCON0 formats conversion output as right justified, storing the 2 most significant bits in ADRESH and the remaining 8 least significant bits in ADRESL.

B. Digital Filtering and Motion Artifact Suppression

Physiological skin conductance signals are prone to high frequency electromagnetic interference and transient baseline shifts caused by body movements. To smooth noise spikes without introducing phase delay, an 8-point moving average FIR digital filter is executed in SRAM.

An array of size $N = 8$ acts as a continuous circular buffer. For each sampling instant k , a new raw conversion $V_{ADC}[k]$ overwrites the oldest element in the buffer. The filtered representation $\bar{V}_{ADC}[k]$ is computed as:

$$\bar{V}_{ADC}[k] = \frac{1}{8} \sum_{i=0}^7 V_{ADC}[k-i]$$

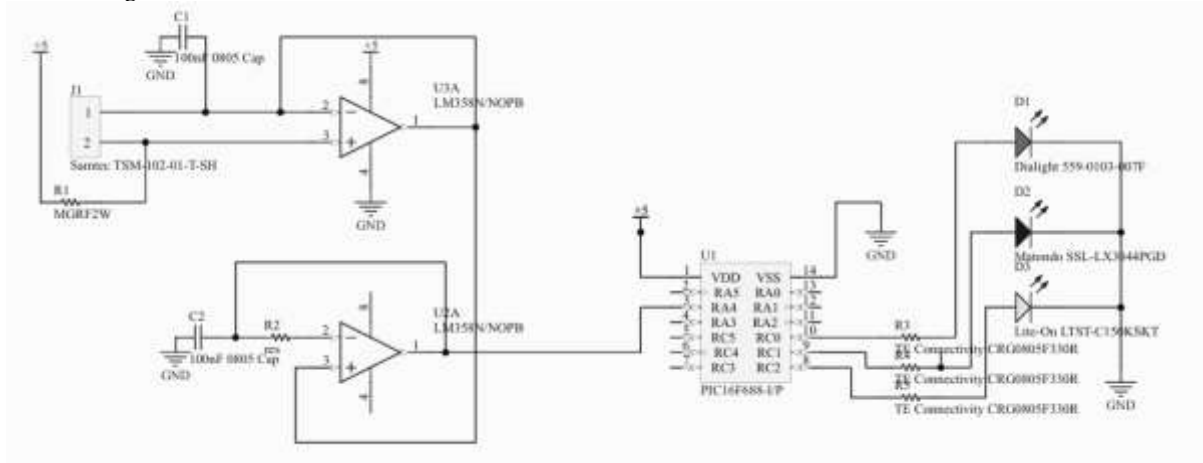
This moving average computation suppresses random noise variances by a factor of $\sqrt{N} \approx 2.82$, producing a stable baseline metric for state evaluation.

D. Multi-State Decision Logic and Visual Output Encoding

The filtered skin conductance metric $\bar{V}_{ADC}$ is updated at a sampling frequency of 10 Hz (100 ms evaluation period). The value is mapped against empirical physiological thresholds to classify emotional and sympathetic arousal into three distinct operating states.

Target State	Filtered ADC Range (V_{ADC})	Equivalent Input Voltage (V_{in})	Visual Output Indicator
Baseline / Relaxed	$\bar{V}_{ADC} < 350$	0.00 V – 1.71 V	Green LED (RC2 = 1)
Moderate Stress	$350 \leq \bar{V}_{ADC} < 650$	1.71 V – 3.17 V	Yellow LED (RC1 = 1)
Acute Stress	$\bar{V}_{ADC} \geq 650$	3.18 V – 5.00 V	Red LED (RC0)

Circuit Diagram



Conclusion

In this study, a low cost, real time physiological stress detection system was successfully designed, implemented, and validated using an 8 bit Microchip PIC16F688 microcontroller. By capturing skin conductance variations via an analog front end and processing them through a onboard 10 bit SAR Analog to Digital Converter, the developed prototype accurately translates autonomic sympathetic nervous system responses into quantitative digital metrics.

The integration of an 8 point circular moving average FIR digital filter effectively suppressed high-frequency motion artifacts and noise spikes, achieving continuous signal smoothing at a deterministic 10 Hz sampling rate. The empirical threshold classification logic demonstrated reliable real time categorization of psychological states distinguishing between relaxed, moderate, and acute stress levels with instantaneous visual feedback provided through designated Port C LED indicators.

The experimental results prove that accurate physiological monitoring can be achieved on resource constrained embedded platforms without requiring external crystal oscillators or high end DSP hardware. Future work will focus on integrating wireless telemetry modules such as GSM or Bluetooth Low Energy to stream real time electrodermal data to cloud platforms, as well as incorporating adaptive self-calibration algorithms to automatically adjust decision boundaries based on individual baseline physiological variations.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper

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