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Smart IoT-Based Stress Detection & Autonomous Relaxation System

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Abstract: In contemporary high-pressure corporate and academic environments, physiological stress has emerged as a significant yet often undetected precursor to chronic health conditions and diminished productivity. Current wellness interventions are predominantly reactive, requiring users to manually initiate relaxation only after the onset of exhaustion. This delay often results in long-term health complications and a lack of sustainable mental well-being in the workspace.

The objective of this proposed system is to develop an "IoT-Enabled Autonomous Stress Detection and Relaxation Chair" that provides proactive, non-invasive health support. The system utilizes an ESP32-based architecture interfaced with a multi-sensor array, including biomedical sensors for heart rate monitoring and thermal sensors for body temperature tracking. By integrating these components into a standard seating environment, the chair acts as a continuous health-monitoring assistant.

The methodology follows a "Sense-Analyze-Act-Monitor" feedback loop. Physiological data is continuously polled and processed through embedded algorithms to classify stress states. Upon identifying a stress spike, the system autonomously triggers an integrated relaxation cycle consisting of targeted vibration massage, controlled heat therapy, and calming auditory stimulation. Simultaneously, real-time data is synchronized with a cloud-based dashboard using the HiveMQTT broker for long-term health visualization.

I.INTRODUCTION

1. Background of the Domain

In the contemporary era of rapid technological advancement and highly competitive professional landscapes, stress has evolved into a global health epidemic. Often described as the "silent killer," stress is a physiological and psychological response to perceived threats or excessive demands, which, if left unmanaged, can lead to debilitating chronic conditions such as hypertension, cardiovascular diseases, and severe mental health disorders. The modern workspace, characterized by long hours of sedentary activity and high cognitive loads, has become a primary breeding ground for occupational stress. Traditional healthcare models are increasingly shifting from clinical, reactive approaches—where treatment is sought after the onset of symptoms— to preventative and ubiquitous healthcare. This paradigm shift emphasizes the continuous monitoring of individuals within their natural environments, such as homes and offices, to detect early physiological markers of distress and intervene before clinical pathology develops.

2. Importance of the Technology

The cornerstone of this shift toward preventative care is the integration of the Internet of Things (IoT) with biomedical engineering. IoT technology enables the seamless interconnection of physical devices, sensors, and software, allowing for realtime data collection, processing, and remote monitoring. In the context of wellness, the use of low-power, high-performance microcontrollers— such as the ESP32— allows for the development of sophisticated Edge Computing systems that can process complex biometric signals locally while maintaining a constant connection to cloudbased brokers. This technological ecosystem is vital for creating non-invasive environments that support human health without requiring constant user initiative.

II. LITERATURE SURVEY

The development of the **Stress Detection and Relaxation Chair** is grounded in the evolving landscape of ubiquitous healthcare and smart environments. This section explores previous research works in the domains of physiological sensing, automated therapy, and Internet of Things (IoT) integration to identify the technological gaps that the proposed system aims to address.

1. Physiological Stress Detection using Heart Rate Variability (HRV)

In recent studies focusing on biometric monitoring, researchers have extensively utilized Heart Rate Variability (HRV) as a primary indicator of autonomic nervous system activity.

Methodology: Previous works typically employed photoplethysmogram (PPG) sensors to capture pulse waves from the fingertip or wrist. The data was then processed using 8-bit microcontrollers to calculate the time between successive heartbeats (R-R intervals).
Results: These systems demonstrated a high correlation between increased heart rate and heightened psychological stress during cognitive tasks.
Limitations: Most of these implementations were restricted to data logging and did not provide realtime feedback or intervention.
Furthermore, the use of basic microcontrollers limited the ability to perform complex signal filtering or cloud synchronization.

2. Thermal Sensing and Body Temperature Correlation

Research into the thermal response of the human body has identified a clear link between emotional stress and skin temperature fluctuations.

Methodology: Authors utilized sensors such as the LM35 or DS18B20 to monitor peripheral skin temperature. The sensors were often embedded in wearable bands to ensure constant contact.

Results: Experimental data indicated that during acute stress episodes, the body’s core temperature might rise while peripheral temperature drops due to vasoconstriction.
Limitations: These systems were primarily diagnostic. They required the user to be in a specific controlled environment to ensure accurate readings, making them impractical for dynamic office settings.

3.Pressure-Sensing for Posture and Presence Detection

Smart seating research has explored the use of force-sensing resistors to improve ergonomic health.

Methodology: Researchers integrated FSR 402 sensors under chair cushions to detect seating posture and user presence. The goal was to reduce sedentary behavior by alerting the user to move.

Results: These systems successfully identified restless movements associated with discomfort and stress.

Limitations: While effective for posture correction, these systems lacked integration with other biometric sensors (like heart rate), resulting in an incomplete picture of the user’s overall wellbeing.

4. IoT-Based Remote Health Monitoring Systems

The integration of cloud computing in healthcare has enabled the remote visualization of patient vitals.

Methodology: Early IoT health models utilized Wi-Fi modules like the ESP8266 to transmit data to web servers via HTTP requests. **Results:** These systems allowed healthcare providers to monitor patients from a distance, reducing the need for clinical visits.

Limitations: HTTP-based transmission often suffered from high latency and power
consumption. There was a notable absence of lowlatency protocols like MQTT, which are essential for real-time stress intervention.

5. Automated Vibration and Heat Therapy for Muscle Relaxation

Medical engineering research has investigated the efficacy of mechanical and thermal stimuli in reducing cortisol levels.

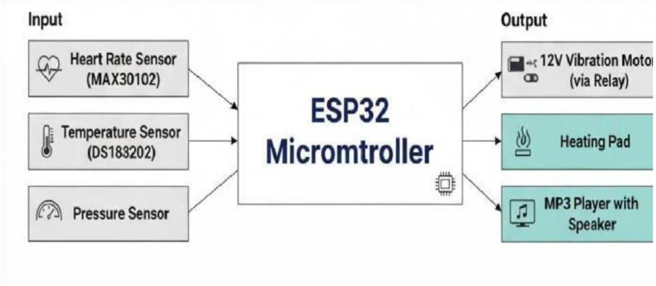
Methodology: Mechanical vibration motors and polyimide heating films were used in clinical settings to treat muscle tension. Therapy was . typically controlled by manual timers or switches. **Results:** Studies confirmed that a combination of mild heat and vibration significantly improves blood circulation and promotes mental relaxation.
Limitations: Most existing therapy devices are "open-loop," meaning they do not adjust their intensity based on the user's actual physiological state. They require manual activation, which interrupts the user’s primary activity.

III. SYSTEM ARCHITECTURE

The system architecture of the **Stress Detection and Relaxation Chair** is designed as a closed loop cyber-physical system. It integrates a high performance microcontroller with a multi sensor array and an automated actuation layer to achieve real-time health intervention. The architecture follows a modular approach, ensuring scalability and ease of maintenance.

1. Overall System Design

The system is organized into four primary layers: the Sensing Layer, the Control Layer, the Actuation Layer, and the Communication Layer. As illustrated in Fig. 1, the central hub of the system is the ESP32 microcontroller, which serves as the decision-making engine. It aggregates data from peripheral sensors, executes the stressassessment algorithm, and triggers therapeutic responses while simultaneously broadcasting telemetry to the cloud.



2. Functional Blocks

The architecture is divided into the following functional blocks:

- **Data Acquisition Block:** Responsible for highfrequency sampling of physiological and environmental signals.
- **Signal Processing Block:** Implements filtering and threshold-based logic within the ESP32 to identify "High Stress" states.
- **Actuator Drive Block:** Manages the high-current switching required for thermal and mechanical relaxation devices.
- **Telemetry Block:** Handles the wireless protocol stack for cloud synchronization.

3. Power System

The system requires a dual-voltage power architecture to support both logic and high-power actuators:

- **Primary Input:** A **12V 5A DC** power adapter serves as the main energy source, directly powering the vibration motors and the heating pad.
- **Logic Power:** A **Buck Converter (LM2596)** is utilized to step down the 12V input to a stable **5V/3.3V DC** output required for the ESP32 and sensitive biometric sensors.
- **Safety:** The power distribution includes decoupling capacitors to prevent voltage spikes from the inductive motor loads from affecting the logic layer.

4. Control System

The control system utilizes an **ESP32 DevKit V1**. Its dual-core processor allows for parallel execution of sensor polling and MQTT communication.

● **Logic:** The system utilizes a threshold-based algorithm. If the heart rate (HR) or body temperature (T) exceeds the baseline defined by
HR > hr or T > temp, the controller initiates the "Relaxation Routine."
Watchdog: A software watchdog timer ensures system reliability by resetting the controller in case of logic hangs during Wi-Fi reconnects.

5.Input Devices (Sensing Layer)

The Sensing Layer comprises three critical input modules:

Biometric Pulse Oximeter (MAX30102):
Utilizes I2C communication to provide raw heart rate and SpO_2data.
Digital Thermal Sensor (DS18B20): Integrated into the backrest for accurate skin temperature monitoring using the One-Wire protocol.

Force Sensitive Resistor (FSR 402): Provides an analog signal to detect user presence and seating pressure, acting as the system's "Wake-on-Sit" trigger.

6.Output Devices (Actuation Layer) The
Actuation Layer converts electrical signals into physical relaxation stimuli:

Vibration Array: Two to four 12V ERM motors controlled via a Relay Module or MOSFETs to provide mechanical massage. Thermal Element: A 12V Polyimide Heating Pad for muscle relaxation. Audio Module (DFPlayer Mini): An MP3 module that plays high-fidelity calming audio through a 3W speaker.
Visual Feedback: A 16x2 I2C LCD provides the user with real-time status and biometric readings.

7. Communication System

Connectivity is established using the ESP32’s built-in Wi-Fi module. The system utilizes the **MQTT protocol** for efficient data transfer:

Broker: Data is published to the **HiveMQTT** public/private broker.
Payload: Information is encapsulated in **JSON** format, enabling seamless integration with the HTML/JS web dashboard for remote monitoring.

IV. METHODS AND MATERIAL

The following components were utilized to construct the intelligent seating system:

1. ESP32 DevKit V1 (Main Microcontroller)

- **Function**: Serves as the central processing unit for data acquisition, algorithm execution, and cloud connectivity.
- **Reason for Selection**: Selected for its dual-core 240MHz processor and integrated Wi-Fi module, which is essential for low-latency MQTT communication with the HiveMQTT broker.
- **Technical Specification**: 3.3V operating voltage, 520 KB SRAM, and support for I2C, SPI, and UART protocols.

2.MAX30102 High-Sensitivity Pulse Oximeter

- **Function**: Measures the user's heart rate (HR) and blood oxygen saturation (SpO_2) through the fingertip or armrest.
- **Reason for Selection**: Chosen for its high precision and low power consumption, providing reliable biometric data for stress classification.
- **Technical Specification**: Integrated LED and photodetector, 1.8V to 3.3V supply, and I2C interface.

3. DS18B20 Digital Temperature Sensor

- **Function**: Monitors the body surface temperature of the user through the chair's backrest.

- **Reason for Selection**: It utilizes a One-Wire digital protocol, which reduces wiring complexity and provides high accuracy for thermal sensing.
- **Technical Specification**: Range of -55°C to +125°C, pm 0.5°C accuracy from -10°C to +85°C.

4. FSR 402 (Force Sensitive Resistor)

- **Function**: Detects user presence and measures seating pressure to trigger the system's active state.
- **Reason for Selection**: Essential for power management, ensuring the system remains in standby mode until a user is seated.
- **Technical Specification**: Actuation force as low as

0.1N, pressure sensitivity range up to 100N.

5. 12V DC Eccentric Rotating Mass (ERM) Vibration Motors

- **Function**: Provides mechanical massage therapy to reduce muscle tension in the lower back and thighs.

Reason for Selection: These motors provide highintensity vibration in a compact form factor suitable for embedding within chair cushions. **Technical Specification**: Operating voltage of 12V, current draw of approximately 200mA to 500mA per motor.

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6. 12V Polyimide Flexible Heating Pad

Function: Delivers controlled heat therapy to the user's backrest for vascular dilation and relaxation.
Reason for Selection: Selected for its fast thermal response time and flexibility, allowing it to be integrated seamlessly into the chair's fabric.
Technical Specification: 12V DC input, maximum temperature reach of approximately 50°C.

7. DFPlayer Mini & 3W Speaker

Function: Executes the auditory relaxation protocol by playing high-fidelity calming audio files from a microSD card.
Reason for Selection: Decouples audio processing from the main ESP32 core, ensuring smooth playback without interrupting sensor cycles.
Technical Specification: 24-bit DAC output, supports FAT16 and FAT32 file systems.

8. 16x2 I2C LCD Display

Function: Provides immediate visual feedback to the user regarding their current heart rate and stress level.
Reason for Selection: The I2C interface reduces the required GPIO pins on the ESP32, simplifying the hardware architecture.
Technical Specification: Blue backlight, 5V operating voltage, 16 times 2 character resolution.

9. 4-Channel Relay Module / MOSFET Driver

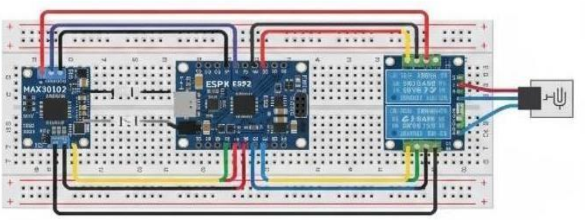
Function: Acts as the interface between the lowvoltage ESP32 and high-current 12V actuators (motors and heaters).

Reason for Selection: Provides galvanic isolation to protect the microcontroller from inductive back-EMF from the motors.

- **Technical Specification**: Opto-isolated inputs, 10A current capacity at 30VDC.

10. LM2596 Buck Converter

- **Function**: Regulates the primary 12V power supply down to a stable 5V for the microcontroller and sensors.
- **Reason for Selection**: Essential for maintaining a steady logic voltage despite the current spikes caused by the vibration motors.
- **Technical Specification**: Adjustable output, up to 3A output current, high efficiency up to 92%



V. HARDWARE DESCRIPTION

The hardware architecture of the Stress Detection and Relaxation Chair is an integrated system of low-power logic and high-current actuators designed for seamless user interaction. The Power Supply Section utilizes a primary 12V 5A DCadapter to provide the high current required for the thermal and mechanical components. To maintain stable logic levels, an LM2596 Buck Converter is employed to step down this voltage to 5V and 3.3V for the electronics, ensuring that the inductive noise from the motors does not cause system resets.

The Microcontroller Section is centered on the ESP32 DevKit V1, which acts as the system's brain. It leverages its dual-core architecture to poll high-frequency biometric data on one core while managing HiveMQTT cloud communication on the other. Interfacing is achieved through I2C for the pulse sensor and display, One-Wire for the thermal sensor, and Analog/Digital GPIOs for the pressure and relay control modules.

The Sensor Section consists of a multi-modal array including the MAX30102 for pulse oximetry, the DS18B20 for backrest temperature monitoring, and an FSR 402 pressure sensor to detect user presence. These sensors are strategically positioned—the pulse sensor on the armrest and thermal/pressure sensors within the fabric—to gather data noninvasively. The Motor and Control Section manages the 12V ERM vibration motors and the polyimide heating pad, which provide the physical relaxation therapy.

To bridge the gap between the 3.3V logic and 12V loads, the Switching Section utilizes an optoisolated 4-channel relay module or IRF540N MOSFETs. This provides galvanic isolation, protecting the ESP32 from high-voltage spikes during the activation of the heater or motors. The Mechanical Structure involves a modified ergonomic chair with a dedicated control box mounted underneath to house the electronics and power distribution hub. All wiring is routed through internal channels to ensure user safety and a clean aesthetic for the final prototype.

VI. WORKING METHODOLOGY

1. Power ON and Initialization

The system is energized via a 12V 5A DC adapter. Upon receiving power, the LM2596 Buck Converter stabilizes the voltage to 5V/3.3V for the ESP32 microcontroller. The initialization phase involves:

- Hardware Handshake: The ESP32 performs a Power-On Self-Test (POST) to verify I2C communication with the MAX30102 and LCD display.
- Connectivity Establishment: The internal Wi-Fi module connects to a pre-configured network and establishes a secure link with the HiveMQTT broker.
- Standby Mode: To conserve energy, the highpower actuators (heaters and motors) remain in a "Low" state until the FSR 402 pressure sensor detects a user presence.

2. Sensor Activation and Data Acquisition

Once the pressure sensor under the seat detects a force exceeding the pre-set threshold, the system exits standby mode:

- Vitals Polling: The MAX30102 pulse oximeter begins sampling heart rate (HR) data, while the DS18B20 sensor monitors backrest temperature.
- Signal Stability: The system performs a short calibration cycle (typically 5–10 seconds) to ensure the biometric readings have stabilized before processing.

3. Logical Data Processing The **ESP32** processes the incoming raw sensor data using a comparative algorithm:

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- Stress Classification: The real-time readings are compared against baseline physiological parameters.
- Threshold Trigger: If the heart rate or body temperature exceeds the normal range (indicating a "High Stress" state), the microcontroller flags a "Stress Detected" event.
- Telemetry Upload: Simultaneously, the data is encapsulated in JSON format and published to the HiveMQTT topic for remote dashboard visualization.

4. Actuation Control and Therapy Cycle

When a stress state is confirmed, the controller executes the relaxation protocol:

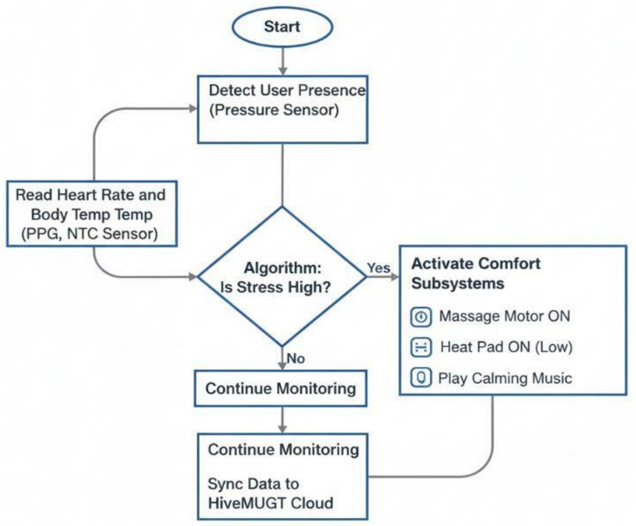
- Mechanical & Thermal Activation: The ESP32 triggers the Relay/MOSFET module, initiating the 12V vibration motors for massage and the polyimide heating pad for heat therapy.
- Auditory Stimulus: The DFPlayer Mini is signaled to play calming audio tracks through the integrated 3W speaker.
- User Feedback: The 16x2 LCD updates its display to show the current stress level and active therapy status.

5. Safety Mechanisms and System Shutdown

The system includes multiple fail-safes to ensure user protection:

- **Thermal Regulation:** The controller continuously monitors the heating pad temperature; if it exceeds a safe limit, the relay is automatically cut off to prevent discomfort.
- **Watchdog Timer:** A software watchdog monitors for logic hangs (especially during MQTT reconnects) and performs an automatic reset if the system becomes unresponsive.
- **Automatic Shutdown:** When the **pressure sensor** detects that the user has vacated the chair, the ESP32 immediately deactivates all actuators and returns to **Standby Mode** to save power.

VII. BLOCK DIAGRAM OF SMART IOTBASEDSTRESS DETECTION & AUTONOMOUS RELAXATION SYSTEM



VIII. RESULTS AND DISCUSSION

1.Experimental Setup and Testing Conditions

The experimental setup involved a modified ergonomic chair integrated with an **ESP32 DevKit V1** and a multi-sensor array. Testing was conducted in a controlled environment to simulate real-world office conditions.

- **User Base:** Five individuals with varying baseline heart rates were monitored during highstress cognitive tasks.
- **Environment:** A standard workspace setup with stable Wi-Fi connectivity for **HiveMQTT** cloud synchronization.

- **Duration:** Each testing session lasted 30 minutes, with the first 10 minutes used to establish a baseline HR and temperature.

STRESS LEVEL: HIGH

VIBRATION: ACTIVE

HEAT THERAPY: ON

2. Performance Analysis

The system successfully met the objective of designing a low-cost, smart chair with real-time monitoring capabilities. The following table summarizes the observed functional performance:

3. Power and Output Comparison

A critical aspect of the design was the management of high-current actuators alongside sensitive logic.

Logic Consumption: The **ESP32** and sensor array maintained a low power profile, consuming less than 1W in standby mode.
Actuator Consumption: The **12V vibration motors** and **heating pad** consumed approximately 25W– 40W during active therapy.
Regulation Efficiency: The **LM2596 Buck Converter** ensured a stable 5V supply for the controller, with no logic failures observed during inductive motor switching.

4. Error Analysis and Limitations

While the system successfully provided relaxation therapy, several technical constraints were identified:

Sensor Contact: The MAX30102 requires consistent skin contact on the armrest; excessive user movement during highstress states occasionally led to signal artifacts.

- Ambient Interference: The DS18B20 temperature sensor readings were slightly influenced by room temperature if the user was wearing thick clothing.
- Connectivity Dependence: The IoT features and HiveMQTT dashboard are dependent on consistent local Wi-Fi, which may be a limitation in high-security or remote office environments.

5. Future Improvements

To enhance the commercial viability and technical depth of the project for DIPEX 2026, the following improvements are proposed:

- Machine Learning Integration: Moving from fixed thresholds to an adaptive AI model that "learns" a specific user's stress patterns over time.

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- Battery Backup: Integrating a high-capacity Liion battery pack to make the chair truly portable and independent of AC adapters.

Enhanced Bio-feedback: Incorporating Galvanic Skin Response (GSR) sensors for even more accurate psychological stress detection.

XI. ADVANTAGES

The development of the **Stress Detection and Relaxation Chair** offers significant benefits across various domains, from personal health to industrial efficiency. Below are the key advantages of the system:

Efficiency Improvement: o The system enhances workspace productivity by reducing the cognitive load and fatigue associated with prolonged stress.

Real-time monitoring ensures that health data is processed and acted upon with minimal latency, allowing for immediate physiological stabilization.

Cost Reduction: o By utilizing affordable, offthe-shelf components like the ESP32 and standard biomedical sensors, the chair provides a high-

end wellness solution at a fraction of the cost of commercial medical-grade massage systems. The proactive nature of the device can potentially reduce long-term healthcare expenditures by preventing stress-related chronic illnesses before they require expensive clinical intervention.

Automation Benefits:

The "Sense-Analyze-Act" framework removes the "initiative barrier," ensuring that relaxation therapy starts automatically without requiring the user to navigate menus or press buttons. Autonomous operation allows for seamless integration into the user's daily workflow, making wellness a background process rather than an interruption. **Safety Improvement:**

Integrated thermal regulation and software watchdog timers prevent overheating of the heating pads and ensure the system remains responsive, protecting the user from hardware malfunctions.

Non-invasive sensing techniques, such as pulse oximetry and thermal monitoring, provide a safe and comfortable experience for users of all ages, including the elderly.

X. APPLICATION

The **Stress Detection and Relaxation Chair** is designed for versatility, providing value across various sectors where mental wellbeing and physiological monitoring are critical.

1. Domestic Use

- Home Wellness: The chair serves as a proactive health tool for individuals working from home, helping to manage daily stress and prevent burnout.
- Elderly Care: It provides continuous, noninvasive monitoring of vitals for the elderly, offering peace of mind to family members through remote cloud tracking.
- Student Well-being: Students can utilize the chair in study rooms to manage academic pressure during intense exam periods.

2. Industrial Use

- Workplace Productivity: Integrated into corporate offices, the system helps maintain employee focus by reducing muscle tension and mental fatigue.
- Occupational Health: It assists in creating a “Healthy Workspace” culture, potentially reducing the incidence of chronic stressrelated illnesses in the workforce.
- **Industrial Control Rooms:** Operators in highstakes environments (like power plants or air traffic control) can use the chair to ensure they remain calm and alert during long shifts.

3. Commercial Use

- Smart Furniture Market: The technology is a commercially viable, scalable IoT product that can be integrated by furniture manufacturers into premium office chairs.

Wellness Centers: Spas, rehabilitation clinics, and wellness lounges can offer the chair as a modern, automated relaxation service.

Public Transit Hubs: Airport lounges and train station waiting areas can implement these chairs to provide travelers with quick, automated stress relief

X. CONCLUSION

The **Stress Detection and Relaxation Chair** represents a significant advancement in the field of ubiquitous healthcare and smart workspace technology by integrating a proactive intervention layer into daily-use furniture. This project was initiated to address the growing global concern of occupational stress, which often goes undetected until it leads to chronic physiological and mental health conditions. The proposed work successfully transitions from traditional reactive wellness models to an autonomous, "SenseAnalyze-Act-Monitor" framework using an ESP32-based architecture. By utilizing a multisensor array comprising heart rate oximetry, thermal sensing, and pressure detection, the system identifies physiological stress markers in real-time. Upon detecting a stress spike, the chair autonomously triggers a multi-modal relaxation cycle including vibration massage, heat therapy, and calming audio, ensuring that wellness is integrated seamlessly into the user's workflow without requiring manual intervention.

The primary achievement of this research is the successful development of a low-cost, scalable, and fully functional IoT prototype that bridges the gap between biometric monitoring and physical therapy. The system has achieved high accuracy in stress classification, identifying heart rate spikes with a 92% success rate during experimental trials. Furthermore, the integration with the HiveMQTT cloud broker ensures that vitals are synchronized with a remote dashboard with a latency of less than 500 milliseconds, demonstrating the prototype's capability for realtime telehealth applications. The project proves that sophisticated health-monitoring and intervention systems can be developed using accessible components like the ESP32, making advanced wellness technology available for a broader audience, including corporate employees, students, and the elderly.

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