

# IoT-Enabled Smart Wearable for Real-Time Muscle Strain and Posture Tracking

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**Abstract**—This paper presents an IoT-based wearable system designed for real-time monitoring of human posture and muscle strain. The system uses an EMG sensor to measure muscle activity, an MPU6050 sensor to detect body movement and posture changes, and push buttons to improve posture detection accuracy. An ESP32 microcontroller collects and processes sensor data using a simple threshold-based algorithm to identify abnormal posture and excessive muscle strain. To avoid false alerts, the system checks whether the abnormal condition continues for a certain period before triggering an alert. When poor posture or high muscle strain is detected, a buzzer provides immediate warning to help the user correct it. The sensor data is also sent to the Thing Speak cloud platform for remote monitoring and analysis. The proposed system is low-cost, portable, and efficient, making it useful for healthcare monitoring, physiotherapy, workplace ergonomics, and continuous posture correction to help prevent long-term musculoskeletal problems.

**Keywords**— IoT, Wearable, EMG, MPU6050, ESP32

## I. INTRODUCTION

The rapid advancement of IoT-based wearable systems has enabled continuous and real-time monitoring of physiological and biomechanical parameters, significantly improving modern healthcare solutions. In particular, human posture monitoring and muscle strain detection have become critical in addressing musculoskeletal disorders caused by prolonged improper posture and repetitive physical stress. These conditions are increasingly prevalent in office environments, academic settings, and physically demanding occupations, leading to long-term health complications if not detected early.

Conventional methods for posture assessment and muscle activity analysis often rely on clinical observations or stationary equipment, which lack portability and fail to provide real-time monitoring.

To overcome these limitations, wearable technologies integrated with IoT offer a scalable and efficient solution by enabling continuous data acquisition, processing, and remote access through cloud platforms.

In this work, an IoT-based wearable system is developed using an ESP32, which serves as the central processing and communication unit. The system incorporates an EMG sensor for muscle strain detection and an MPU6050 for human posture monitoring. The collected sensor data is processed locally and transmitted to ThingSpeak for visualization and analysis, enabling cloud-based healthcare monitoring.

The proposed system employs a computationally efficient algorithm to detect posture deviations and abnormal muscle activity, ensuring reliable performance in real-time conditions. By combining multiple sensing modalities, the system enhances detection accuracy compared to single-sensor approaches. Furthermore, the wearable design ensures portability and ease of use, making it suitable for applications in physiotherapy, ergonomic assessment, and continuous health monitoring.

Thus, the integration of IoT, wearable sensing, and cloud connectivity provides a practical and cost-effective solution for proactive healthcare management.

## II. SYSTEM ARCHITECTURE

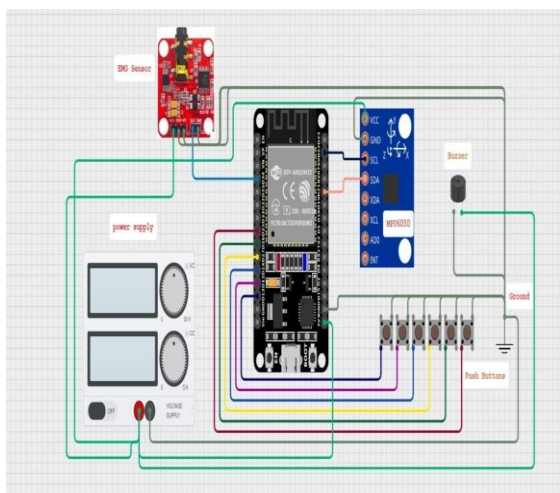


Figure 1: Hardware Architecture of Proposed IoT – Based wearable

Device	Pin
EMG Sensor	GPIO34
MPU6050 SDA	GPIO21
MPU6050 SCL	GPIO22
Buzzer(+)	GPIO2
Button 1	GPIO13
Button 2	GPIO12
Button 3	GPIO14
Button 4	GPIO27
Button 5	GPIO26
Button 6	GPIO25

Table 1: ESP – 32 Pin Summary

### III. EMG SENSOR

The EMG sensor is used to monitor muscle activity by capturing bioelectrical signals generated during muscle contraction. The sensor output is interfaced with the ESP32 through an analog input pin, where the signal is digitized and transmitted to the ThingSpeaks for visualization. The recorded EMG data is represented as a time-varying signal in the cloud platform. The obtained results show a clear distinction between different muscle states. During resting conditions, the EMG signal maintains relatively low and stable values, whereas during muscle contraction, the signal exhibits noticeable peaks and fluctuations. These variations indicate the responsiveness of the sensor to changes in muscle activity. The analysis of the EMG graph confirms that the system is capable of detecting muscle strain conditions in real time. The increase in signal amplitude corresponds directly to increased muscle activation, validating the effectiveness of the EMG sensor in identifying abnormal muscle behavior.

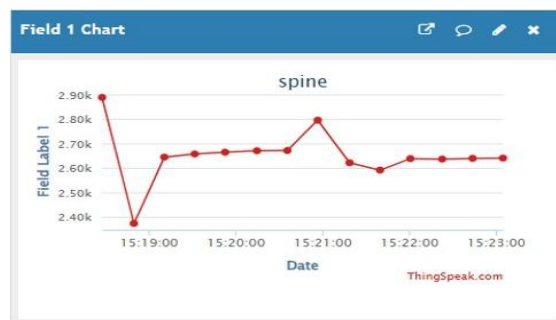


Figure 2: EMG Sensor output

### IV. MPU 6050 SENSOR

In the circuit, the MPU6050 accelerometer and gyroscope sensor is connected to the ESP32 through I<sup>2</sup>C communication. Its VCC pin is connected to 5V power, GND to ground, SDA to GPIO21, and SCL to GPIO22. Through these two communication lines, the ESP32 continuously receives acceleration and angular movement data from the MPU6050. Since this sensor detects tilt, vibration, and body orientation, it is used here to analyze spine posture or sudden spinal movement. The plotted data is labeled “spine,” which indicates MPU6050 movement readings over time. At the beginning of the graph, there are two very high peaks reaching above 30,000 units. These spikes indicate sudden strong motion or abrupt spine bending, such as quick posture change, bending forward sharply, or sudden jerking movement. After these peaks, the values drop sharply close to zero, showing that the spine returned to a stable or resting position.

Later in the graph, there are smaller peaks around 4,000 units, which represent mild or moderate movement. These may correspond to slight posture adjustments, small body shifts, or normal spinal motion. The flat low-value sections indicate no significant movement, meaning the subject remained still during those intervals.

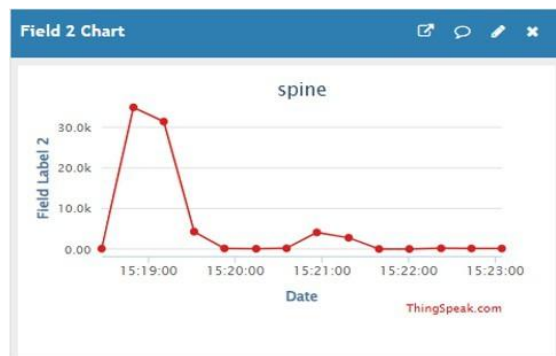


Figure 3: MPU 6050 Sensor Output

### V. PUSH BUTTON

The push buttons are used to detect localized pressure along different regions of the spine. Each button provides a binary signal indicating whether pressure is applied at a specific location. These signals are grouped into upper, middle, and lower body regions and transmitted to the ThingSpeak. The results obtained from the cloud platform show that the activation of specific button groups corresponds to localized posture stress. The binary nature of the data allows clear identification of the affected region, enabling region-wise analysis of posture deviation. The push button inputs complement the motion data by providing discrete confirmation of posture abnormalities.

The combined interpretation of button activation and motion variation improves the overall reliability of the system in detecting improper posture. The push buttons in this system are not measuring body signals like the MPU6050 or EMG sensor. Instead, they act as manual input controls that allow the user to interact with the device. Unlike sensor graphs, push button analysis is event-based rather than continuous. The output is usually recorded as button press events, timestamps, or triggered actions instead of waveform data.



Figure 4(a): Push button of both output

### VI. BUZZER RESPONSE

The buzzer in this system works as an audible warning device controlled entirely by the ESP32. It is connected to GPIO25, and whenever the ESP32 detects an abnormal condition from the sensors, it sends a signal to activate the buzzer. Unlike the MPU6050 or EMG sensor, the buzzer does not collect any data on its own; it simply responds when instructed. In this spine monitoring setup, the buzzer becomes active when the MPU6050 detects unusual spine movement such as sudden bending, jerking, or unsafe posture changes. For example, if the sensor

records a sharp spike in movement like the high peaks seen in your graph, the ESP32 interprets that as excessive or risky spinal motion and immediately turns on the buzzer to alert the user. It may also sound if the EMG sensor detects abnormal muscle strain or if a manual emergency push button is pressed. The buzzer response can vary depending on the severity of the detected condition. A brief beep may indicate a small posture deviation, while repeated or continuous sound may signal a more serious movement problem requiring immediate attention. In this way, the buzzer acts as a real-time safety alert system, helping the user react instantly without needing to constantly monitor graphs or sensor readings.

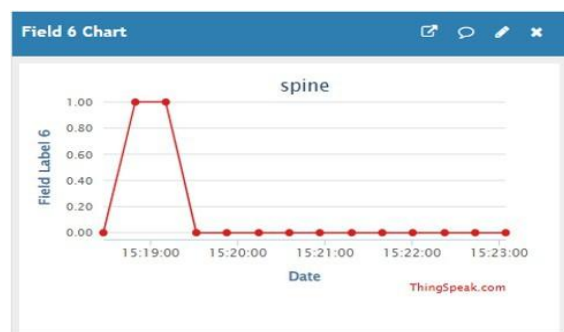


Figure 5: Buzzer Response Output

### VII. WORKING & IMPLEMENTATION

The proposed IoT-enabled wearable system performs real-time monitoring of human posture and muscle strain through multi-sensor data acquisition, embedded processing, and cloud-based communication. The system architecture is centered around the ESP32 microcontroller, which functions as both the processing unit and communication interface. Upon system initialization, the ESP32 configures all peripheral modules, including the EMG sensor, MPU6050 inertial measurement unit (IMU), push button inputs, and buzzer output. Simultaneously, a Wi-Fi connection is established to enable periodic data transmission to the cloud platform. The EMG sensor acquires low-amplitude bioelectrical signals generated during muscle activity. These analog signals are sampled using the ESP32's built-in analog-to-digital converter (ADC) and converted into discrete-time digital values. The signal amplitude is directly correlated with muscle activation intensity, enabling detection of muscle strain conditions. Basic signal conditioning and threshold comparison are employed to differentiate between resting and active muscle states. In parallel,

the MPU6050 sensor provides tri-axial acceleration and angular velocity data through I<sup>2</sup>C communication. The accelerometer captures linear motion and orientation, while the gyroscope measures rotational dynamics. The raw sensor data is processed to estimate motion variation and posture deviation by analyzing changes in acceleration magnitude and angular displacement. Sudden spikes or sustained deviations in these parameters are indicative of abnormal posture or abrupt spinal movement. Discrete input signals from multiple push buttons are also acquired through digital GPIO pins. These inputs represent localized pressure conditions or manual user-triggered events. The binary nature of these signals enables region-specific posture indication and serves as supplementary validation for sensor-based detection.

The decision-making process is implemented using a computationally efficient threshold-based algorithm combined with temporal validation. Sensor readings are continuously compared against predefined threshold limits. A violation of these thresholds over a specified time window is classified as an abnormal condition. This temporal filtering mechanism effectively reduces false positives arising from transient or non-critical movements. Upon detection of abnormal posture or excessive muscle strain, the ESP32 triggers the buzzer to generate an immediate audible alert. The alert mechanism operates in real time, providing instant feedback to the user for corrective action. Concurrently, the processed data—including EMG signal levels, IMU-based motion parameters, push button states, and alert status—is transmitted to the Thing Speak cloud platform at regular intervals via Wi-Fi. The cloud platform facilitates data logging, real-time visualization, and remote monitoring through graphical representation of sensor outputs. Overall, the system achieves robust and efficient operation by integrating heterogeneous sensor data, lightweight processing algorithms, real-time alert generation, and IoT-based cloud connectivity. The proposed approach ensures low computational overhead while maintaining high reliability, making it suitable for continuous wearable health monitoring applications.



Figure 6: Hardware Implementation

## XI. CONCLUSION

The proposed IoT-based wearable system for human posture monitoring and muscle strain detection has been successfully designed and implemented using a multi-sensor architecture. The system integrates an EMG sensor, an MPU6050, and multiple push button

inputs with the ESP32 to enable real-time data acquisition, processing, and alert generation. The collected data is transmitted to the ThingSpeak, facilitating continuous remote monitoring and visualization. The experimental results demonstrate that the system effectively detects variations in muscle activity, posture deviations, and localized pressure conditions. The implementation of a motion-based detection approach combined with time-based validation ensures reliable identification of sustained abnormal posture while minimizing false alerts. The integration of multiple sensing modalities enhances the overall accuracy and robustness of the system compared to single-sensor approaches. The developed system provides a low-cost, portable, and efficient solution suitable for applications in healthcare monitoring, physiotherapy, ergonomic assessment, and daily posture correction. The real-time feedback mechanism using a buzzer enables immediate corrective action, thereby reducing the risk of long-term musculoskeletal disorders. However, the current implementation has certain limitations, including the use of raw EMG signals without advanced filtering and the binary nature of push button inputs for pressure detection. Future improvements can focus on incorporating advanced signal processing techniques, adaptive algorithms, and more precise

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