Posture Guard: An IoT-Based Posture Monitoring and Feedback System Using IMU Sensors

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Abstract

In this research, Posture Guard, an IoT-based assistive device to monitor the posture and detect prolonged immobility in elderly and differently-abled individuals, has been proposed. An MPU6050 IMU is used to measure the motion and orientation of the user. The ESP8266 is utilized as the controller for this purpose. The algorithm used in this system is CPE (Continuous Posture Evaluation) algorithm. This algorithm uses posture angles measured using the IMU to determine any deviation in posture with respect to pre-defined values. Further, it can detect the time duration during which there are no changes in the orientation or posture. In case there is an improper posture or high-risk scenario detected, the system sends out an alert to the user via voice and vibration feedbacks. However, in cases requiring urgent attention, GSM notification service is used to notify the caregiver regarding the situation. Besides, posture information is sent to the cloud server for real-time tracking of posture. As demonstrated in experimental results, the proposed system shows posture detection accuracy around 90%.

Keywords: Posture Monitoring, Internet of Things (IoT), MPU6050, ESP8266, Assistive Healthcare, Immobility Detection, Wearable Sensors, Remote Monitoring.

1. Introduction

Due to the rising numbers of musculoskeletal conditions and mobility problems experienced by senior and differently abled people, there is a need for the development of constant posture detection systems. Poor posture and extended periods without movement may

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cause severe medical issues, including back pain, pressure ulcers, poor blood flow, and spine damage. The traditional method of monitoring involves caregiver supervision and cannot be considered efficient and suitable for constant monitoring due to the impractical nature of the procedure. Recent breakthroughs in the fields of wearables and IoT have made possible the creation of smart health monitoring systems.

Nevertheless, a lot of the currently available solutions have limitations since they are either focused on postural correction or movement monitoring, but not the two together. Moreover, little consideration has been given to creating solutions for inclusive feedback provision and caregiver interaction in real time. In order to solve the problem, this paper suggests Posture Guard – an IoT-based assistive device for continuous posture monitoring and early diagnosis of risky conditions. It will use an MPU6050 IMU for recording of orientation parameters, which will be analyzed using the Continuous Posture Evaluation (CPE) algorithm. On the basis of this analysis, the system will issue multimodal feedback (voice/vibration notifications) and will send GSM messages to caregivers in case of risks. Additionally, the system will have cloud connectivity feature to enable continuous monitoring and analysis of patient's posture by healthcare professionals.

Objective of The Project

- To design an IoT system that will help monitor posture and detect any immobility through IMU sensors and the CPE algorithm.
- To offer instant feedback via voice prompts and vibrations and alert users and caregivers through GSM technology.
- To allow remote monitoring of patients and cloud data storage and visualization for medical analysis.

2. Literature Review

Indeed, there have been significant advancements in wearable sensor technology that contribute greatly to healthcare monitoring systems including those used for rehabilitation and posture analysis. The continuous monitoring of physiological and kinematic parameters has improved significantly thanks to healthcare monitoring systems which lead to better outcomes for the patient [1], [2]. In addition to providing valuable data through real time measurement of movements and posture of the human body, accelerometer and gyroscope can be used for health monitoring as well [3].

The adoption of the Internet of Things (IoT) has improved the healthcare monitoring system immensely because of their interoperability and ease of communication. IoT-enabled healthcare monitoring applications allow for remote monitoring and real-time transmission of patient information, thus increasing the availability of the service for caregivers. Devices that are equipped with both wearable and IoT technologies can be used to monitor non-invasively patients, something which makes them indispensable for preventive healthcare monitoring applications [4]. Recent research on healthcare monitoring systems focuses on posture monitoring systems that utilize sensor- based and IoT technologies. Posture asymmetry and orientation have been successfully detected through real-time sensor monitoring [5], [6].

Motion tracking devices have also been considered in order to monitor the individual's day-to-day motions as well as healthcare motions, but they tend to focus on activity recognition rather than posture and immobility recognition [7]. Specialized solutions have been implemented in order to solve posture-based health problems. For example, posture monitoring systems based on IoT-based smart furniture systems have been proposed to detect and warn about any posture issues that may arise from a sedentary lifestyle [8]. Posture monitoring devices designed to prevent back injuries have also been proposed through sensor technologies and live warning devices [9]. Despite the success of these devices in detecting postures, they are limited to certain scopes of monitoring.

Despite all the above developments, there are some constraints that exist. To begin with, most of the systems available in the market are only aimed at correcting postures or activities but fail to incorporate both in their solutions. There are also constraints such as lack of multimodal feedback, inclusiveness to differently-abled people, and caregiver communication services. Finally, very few companies make use of the internet in order to enable long-term analysis of posture and provide effective health care services from afar. All these issues point to the need for developing a new comprehensive system that incorporates all the elements described above.

3. System Design and Implementation

Posture Guard is an IoT assisted monitoring system to assist people with immobility and problems related to posture. This is specially designed for the elderly and differently abled people. The main aim of the project is continuous monitoring and sensing the immobile postures and positions that could lead to musculoskeletal disorders. In addition, this project gives real-time alert and notification mechanism for assisting the caregivers at correct time.

A. System Architecture

Figure 1 shows the architecture of the proposed system which includes sensing - Processing - communication and - alerting. The MPU6050 senses the user's position and posture and sends the data to ESP8266 for processing. It calculates posture deviations and immobility duration based on predefined thresholds. When abnormal posture is detected then it gives alert to the caregivers. Through Wi-Fi it sends data to the cloud platform where it shows the graph that is useful for the healthcare professionals.

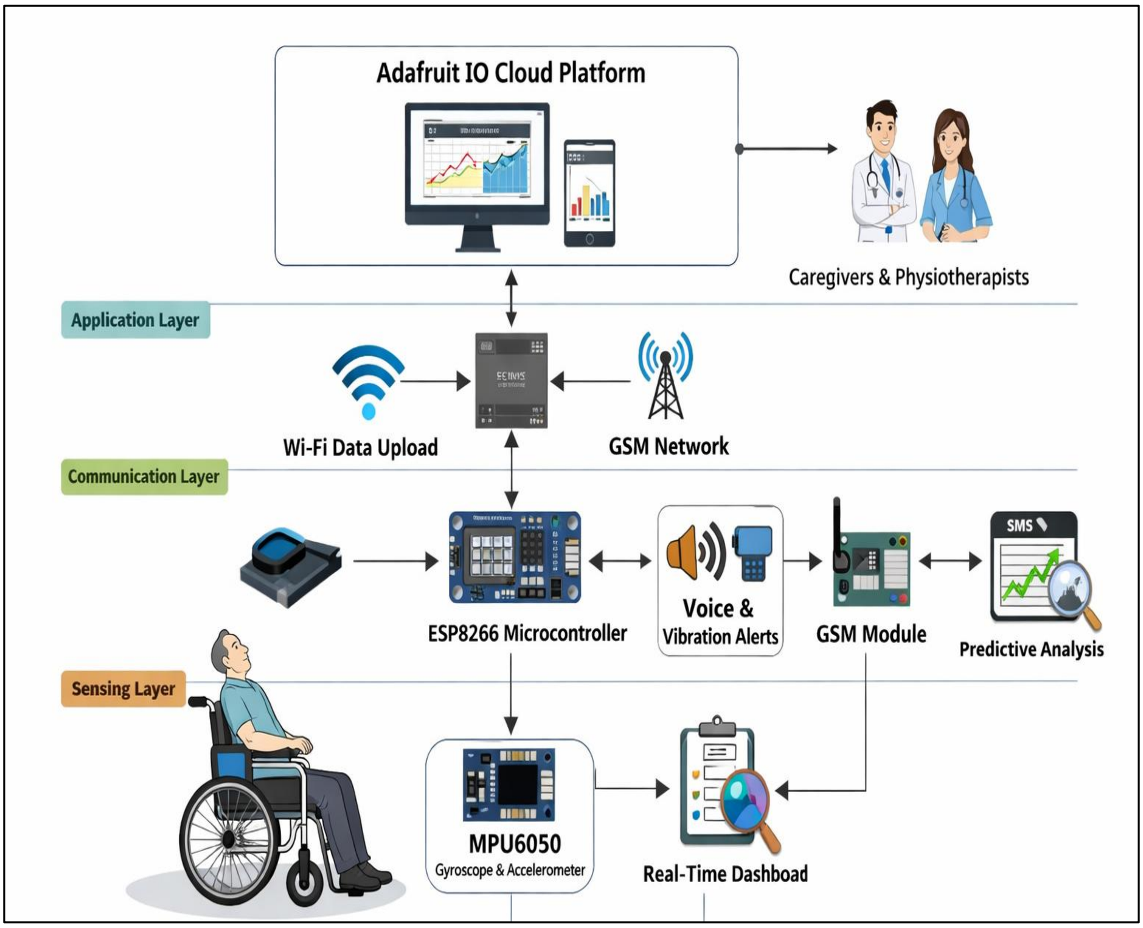

Figure 1. System Architecture of Posture Guard

Posture Guard computes the body orientation angles using the data collected from the MPU6050. Immobility is detected by monitoring the minimal changes in the orientation. If the user stays in the same unsafe static posture, then it gives as high-risk condition. When angle deviation or prolonged immobility is detected, the system provides multimodal alerts. Voice alerts for users directly, vibration alerts for the people with hearing impairment and SMS notification for the caregivers. Posture angle data is sent to the cloud platform in real-time where the data is stored and processed to generate the graphs for visualization. This graph is useful for the healthcare professionals and physiotherapists. The operation of the system is dependent on a rechargeable battery source that allows for portability and monitoring all the time. The operational period of the system averages 6-8 hours in general. The power usage in the system can be controlled using the control of sampling frequencies of the sensors and reduced communications.

B. System Workflow

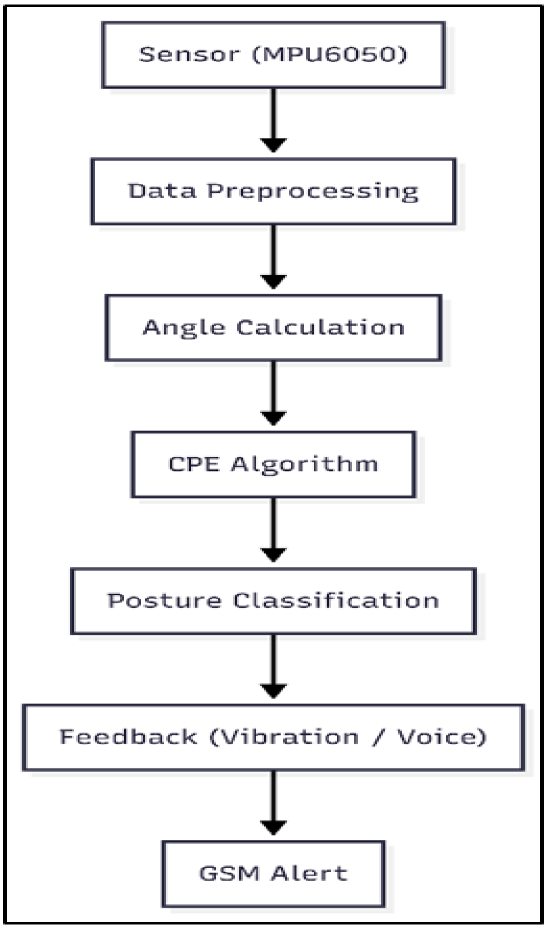

Figure 2. System Workflow of Posture Guard

The entire workflow of the proposed Posture Guard system is illustrated in below Figure 2. The Posture Guard process involves an ordered series of events that start with the acquisition of sensor data using the MPU6050 sensor that acquires real-time accelerometer and gyroscope data concerning the posture of the user and his/her body posture. Preprocessing involves the smoothing of the signal acquired by means of a moving average filter. Based on the smoothed data, calculation of angle postures like the pitch and roll angles is carried out by the application of trigonometric calculations. The angles obtained above are checked against predetermined threshold values in terms of posture status using the CPE algorithm.

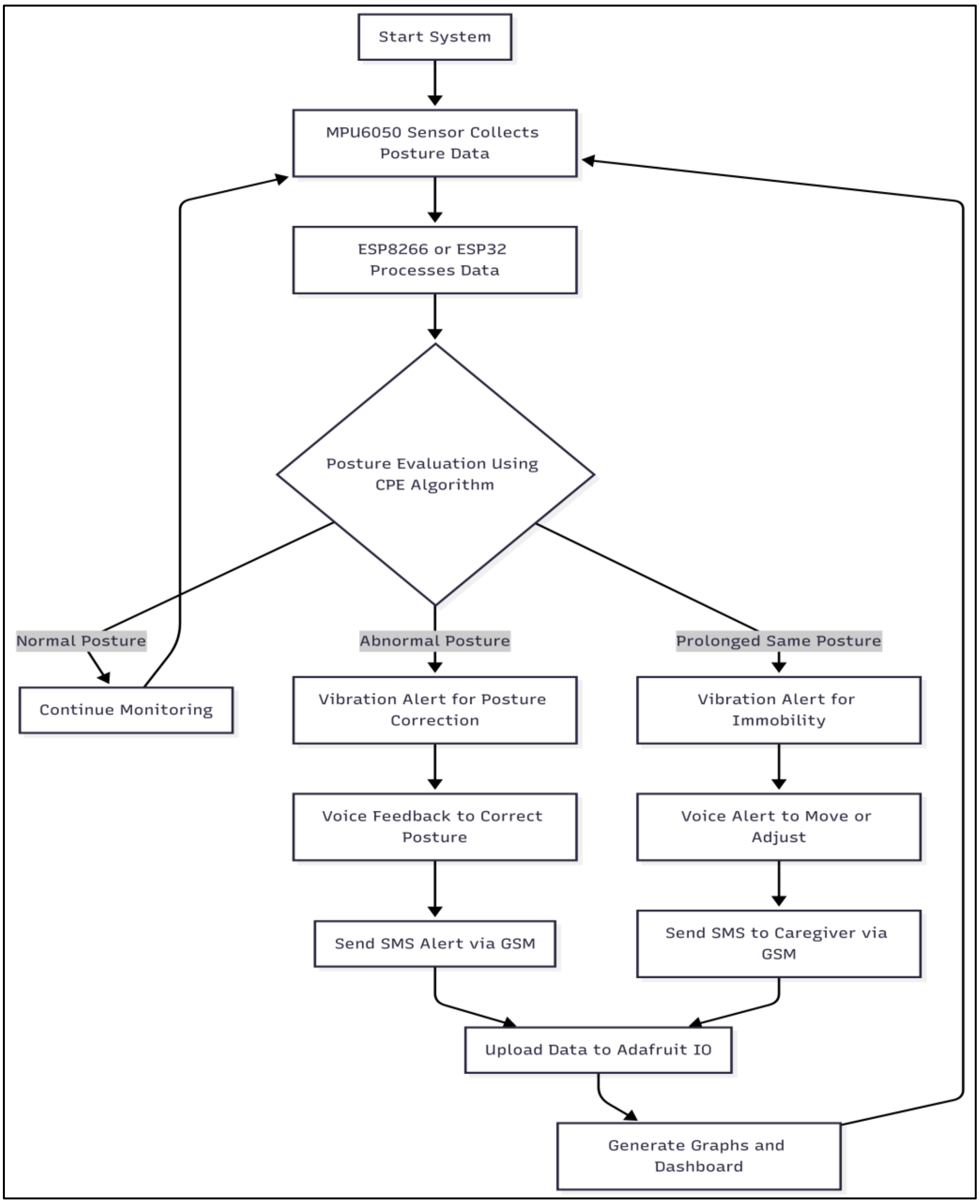

Figure 3. Detailed System Working Diagram

Depending on the results obtained, a posture can be classified as normal, improper, or immobile. In the case of an improper posture, multimodal alerts are issued by means of vibrations and voice messages to the individual concerned. In case there is persistence of a particular posture or immobility of the user for a period of time exceeding the specified one, SMS alert is sent to the caregiver using the GSM technology. At the same time, posture data is uploaded to the cloud server through the use of Wi-Fi communication channel.

Flowchart (Figure 3) shows the complete operation process of Posture Guard system, which is comprised of four processes: the first process of system initialization, followed by posture data acquisition from MPU6050, acquisition of processed data through ESP8266 processor, and finally analysis of acquired data by using the posture classification and evaluation process. As evident from Figure 3, the CPE module decides the state of the user, whether that is normal posture, improper posture, or immobility. On identifying normal posture, the process continues uninterrupted, simultaneously monitoring and updating the feedback data for visualization purposes. For abnormal posture, vibration notification and audio feedback start automatically to sensitize the user for immediate posture adjustment. For the user continuing in the same posture for an extended duration, the immobility detection algorithm initiates vibration notifications and audio prompts for the user to move or adjust, as shown in Figure 3. For critical conditions, SMS notification is sent to caretakers through the GSM module. In the meantime, the user's posture as well as relevant information is uploaded into the cloud-based computing system for analysis. Data analysis allows providing feedback and generating graphs to monitor trends in the patient's posture and time spent without moving.

C. System Specification

Table 1 shows the system specifications of the proposed Posture Guard

Table 1. System Specifications

Components	Specifications	Usage
Microcontroller	ESP8266	Acts as the core processing unit that receives sensor data, executes the CPE algorithm, and manages Wi-Fi communication with the cloud platform.
Sensor	MPU6050	A 6-DoF IMU sensor used to capture accelerometer and gyroscope data for calculating posture angles (pitch and roll) and detecting posture deviations.

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Communication	Wi-Fi, GSM	Wi-Fi enables real-time data transmission to the cloud, while GSM is used to send SMS alerts to caregivers during prolonged immobility or incorrect posture.
Power Supply	Rechargeable Battery	Provides portable and continuous power to the system, enabling wearable and long-duration monitoring applications.
Alert Mechanism	Vibration Motor, Voice Feedback, SMS Alert	Delivers multimodal feedback: vibration for silent alerts (hearing-impaired users), voice feedback for guidance, and SMS alerts for caregiver notification.
Cloud Platform	Firebase, IoT Dashboard	Stores posture data and provides real-time visualization and long-term analysis for healthcare monitoring and rehabilitation support.
Programming Language	Embedded C, Arduino IDE	Used for implementing sensor data processing, posture evaluation logic, and system control functions.
Sampling Rate	~10 – 15 Hz	Ensures continuous posture monitoring with a balance between responsiveness and power efficiency.
Operating Voltage	3.3V – 5V	Supports low-power operation, making the system suitable for wearable and portable healthcare devices.

D. Pseudocode

Algorithm: Continuous Posture Evaluation (CPE)

```
Input:
   Accelerometer data (ax, ay, az)
   Gyroscope data

Output:
   Posture Status (Normal / Incorrect / Stationary)

Begin

1. Initialize system
2. Read accelerometer and gyroscope data

3. Compute posture angles:
   pitch ← atan2(-ax, sqrt(ay² + az²))
   roll  ← atan2(ay, az)

4. If first reading then
      refPitch ← pitch
      refRoll  ← roll
```

```
    prevPitch ← pitch
    prevRoll  ← roll
    Start stationary timer
  End If

5. Compute deviation:
    pitchDiff ← pitch - prevPitch|
    rollDiff  ← roll - prevRoll|

6. If (pitchDiff > 30° OR rollDiff > 30°) then
    Posture ← Incorrect
    Trigger vibration alert
    Play voice feedback
    Send SMS alert to caregiver
    Reset stationary timer
  Else
    Posture ← Normal
  End If

7. Check immobility condition:
  If (|pitch - prevPitch| < 1° AND |roll - prevRoll| < 1°) then
    If (stationary time > 10 sec) then
      Posture ← Stationary
      Trigger alert
    End If

    If (stationary time > 30 sec) then
      Repeat alert
    End If
  Else
    Reset stationary timer
  End If

8. Update previous values:
    prevPitch ← pitch
    prevRoll  ← roll

9. Send posture data to cloud platform

      End.
```

4. Results and Discussions

Tests were conducted for the Posture Guard system in order to measure its efficiency in terms of posture monitoring, detecting inactivity, and timely notifications to the users.

Figure 4(a) and 4(b) show the internal and external structure of the Posture Guard system.

Figure 4(a). Internal View of Posture Guard

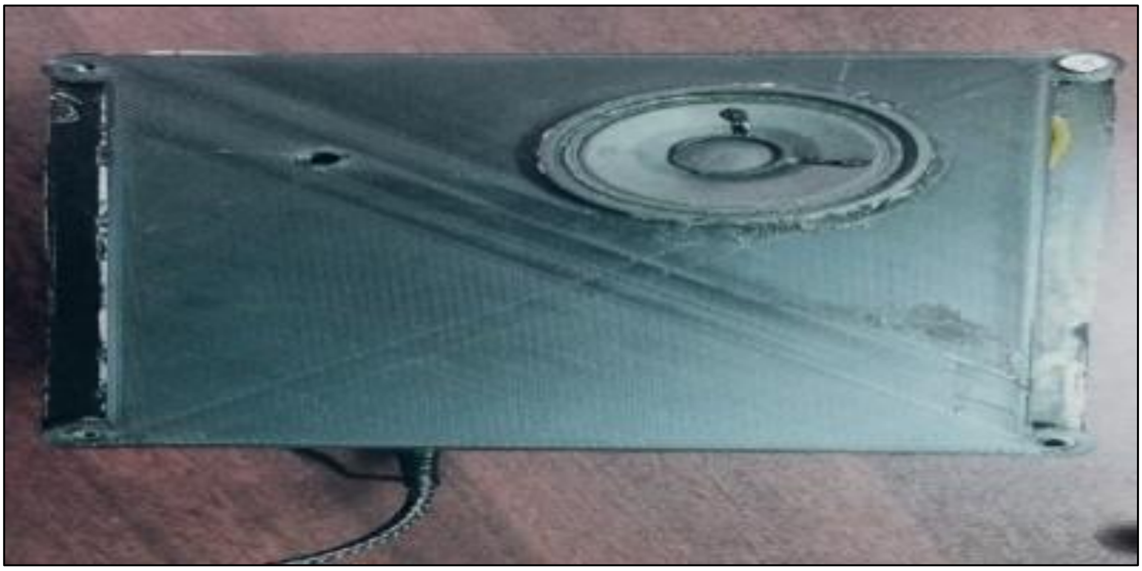

Figure 4(b). External View of Posture Guard

It was found that the system had an accuracy rate of 90%, according to experiments performed. Nevertheless, there have been certain issues, such as problems caused by sensor drifts, abrupt motions, and sensor positioning. False alarms have been generated by the system when the abrupt motion is detected as a posture deviation; false negatives were registered when the posture shift took place gradually.

This system was able to detect the postures of the user by comparing the angle of the posture with the threshold value set. Some of the types of postures that might be captured by the system include the forward bend posture, slouching and the lateral posture. The application of the continuous monitoring technique plays a critical role in detecting improper posture by the user well before they can experience any discomfort due to such postures. The system performed satisfactorily in terms of posture detection accuracy as shown in the following tables (2,3,4,5). In order to test the effectiveness of the proposed posture detection system, a number of experiments were carried out on the system with varying postures including correct posture, slouching and leaning forward. The experiment was carried out on a total of 150 samples, with 50 samples for each posture type.

Table 2. System Performance

Posture Type	**Total samples**	**Correctly detected**	**Accuracy (%)**
Correct Posture	50	46	92
Slouch Posture	50	45	90
Forward Lean	50	44	88
Overall	150	135	90

As shown in Table 2, the designed system has an overall posture recognition accuracy rate of 90%. The maximum accuracy rate occurs when the system detects correct posture, whereas there may be small differences in recognizing slouching and leaning postures because of noise from sensors and small movements by the user.

$$\text{Accuracy} = \frac{\text{Number of Correct Predictions}}{\text{Total Samples}} \times 100$$

This accuracy rate can be determined using the equation above, where the correct prediction rate is the number of times the system correctly recognized the posture. Despite its accuracy, some misclassifications are possible due to sensor drift, body movement, and changes in the posture of the individual. For instance, the transitional postures from correct posture to slouching posture may cause misclassification. Also, any noise in the acceleration measurements and incorrect placement of sensors may affect the angle calculations.

The interactions between the multi-modal warning system and the user included the use of voice feedback to give instructions on how to improve posture, and vibration alerts for the hearing-impaired users. The reliability of the GSM module was confirmed by the delivery rate of the message within 3-5 seconds on average. There were no instances of failure in the message transmission process during testing. Along with accuracy, Table 3 shows that response time and delay in detection are some other criteria used for assessment. Table 4 shows communication assessment for SMS alerts sent promptly to caregivers when the system detects a life-threatening situation.

Table 3. Performance Metrics

Parameter	Value
Sampling Rate	50 Hz
Detection Delay	1.2 seconds
Alert Response Time	2 seconds

In summary, the experimental results confirm the capability of the Posture Guard system to detect postural deviation with high accuracy and reliability.

Table 4. Communication Evaluation

Test	Message Sent	Delivered	Success Rate
Trial 1	20	19	95%
Trial 2	20	20	100%

The messages transmitted from the GSM to the caretakers are illustrated in Figure 5. From the experiments carried out, it is evident that the suggested Posture Guard system manages to integrate postural monitoring, immobility detection, and instant messaging functionality. This suggested system is unique compared to other systems due to the fact that, although the other systems specialize in one field only, the suggested system has managed to combine everything in a single package. The system operates effectively by monitoring postural deviations and notifying the user immediately whenever the deviation occurs. It even has an additional feature of cloud-based visualization.

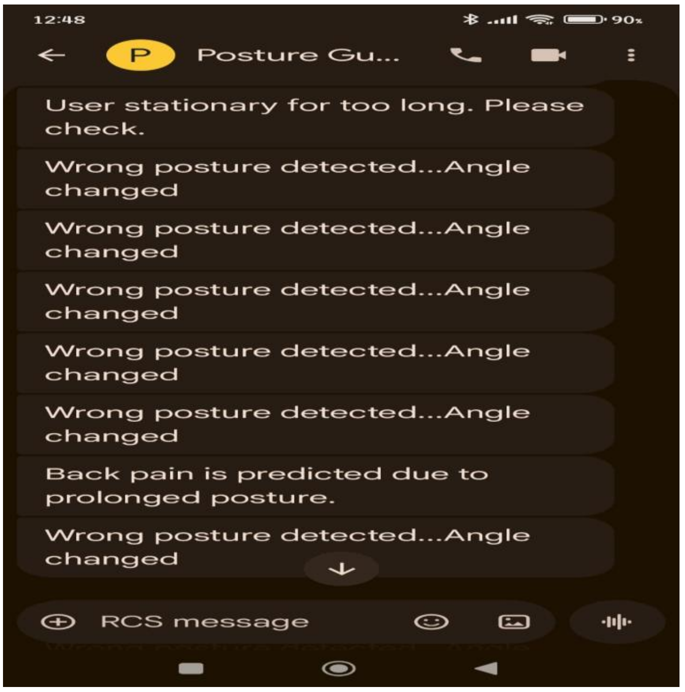

Figure 5. Message through GSM to Caregivers

5. Conclusion

In conclusion, this research introduced Posture Guard, an assistive device that combines IoT technology to sense the user's posture and monitor immobility through IMU sensors and CPE algorithms. It is evident that the proposed posture monitoring system can detect the posture with an accuracy of about 90% and immobility, besides triggering alerts. This device integrates voice feedback, vibration alerts, and GSM-based notifications to ensure accessibility and responsiveness among the majority of users despite their different capabilities. Besides, cloud integration facilitates long-term postural analysis and helps medical professionals develop rehabilitation plans for patients. In summary, Posture Guard is a cost-effective, portable, and scalable device for preventive healthcare. Further research on Posture Guard may consider incorporating other physiological sensors like heart rate, pressure, and SpO2, among others, in addition to integrating advanced machine learning algorithm.

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