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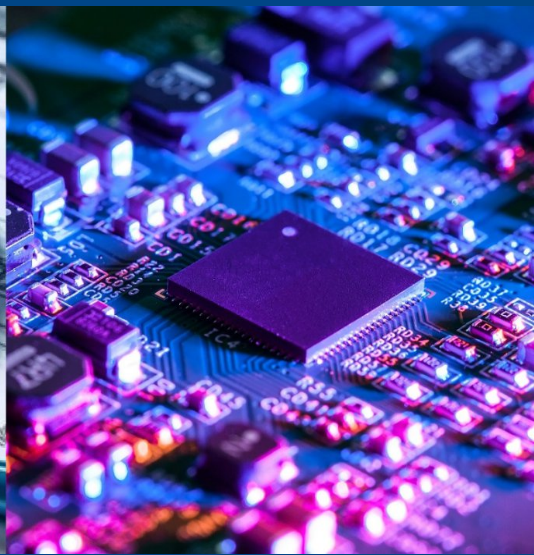

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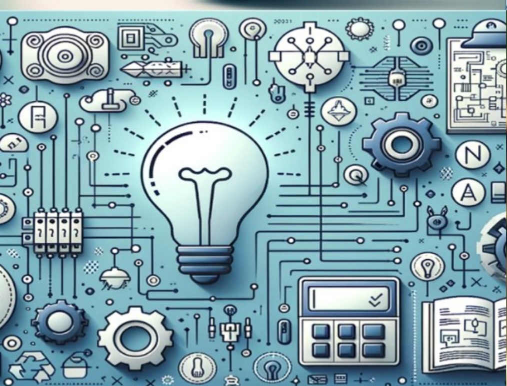

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System for Wearable Posture Monitoring and Correction (With a Focus on Spine)

Dr.S.A.Yuvaraj, Mohanapriya P, Sadhana D, Supriya M, Sweatha G

Professor, Department of BME, GRT-IET, Tiruttani, Tamil Nadu, India

BME IV-Year Student, Department of BME, GRT-IET, Tiruttani, Tamil Nadu, India

BME IV-Year Student, Department of BME, GRT-IET, Tiruttani, Tamil Nadu, India

BME IV-Year Student, Department of BME, GRT-IET, Tiruttani, Tamil Nadu, India

BME IV-Year Student, Department of BME, GRT-IET, Tiruttani, Tamil Nadu, India

ABSTRACT: Low back pain (LBP) has become one of the most common health issues worldwide, significantly affecting quality of life and productivity, and is often caused by prolonged poor posture and improper spinal alignment. Maintaining correct posture is essential for spinal stability and muscle balance, particularly in supporting the overall structure of the back. This project presents the design and development of an advanced IoT-based wearable posture monitoring and correction system that continuously tracks spinal alignment in real time. The system utilizes a combination of Inertial Measurement Unit (IMU) sensors and flex sensors integrated with an ESP32 microcontroller to accurately measure both orientation and curvature of the spine. By employing sensor fusion techniques, the device enhances the precision of posture detection compared to traditional single-sensor systems. When a deviation from the correct posture is identified, the system immediately provides biofeedback through vibration and buzzer alerts, prompting the user to correct their posture instantly. The integration of IoT technology enables wireless communication, allowing real-time data transmission, monitoring, and storage for long-term analysis through mobile or web-based platforms. This facilitates continuous tracking of user posture habits and opens possibilities for remote monitoring and assessment. The wearable design ensures that the system is compact, non-invasive, and comfortable for everyday use, making it suitable for students, office workers, and individuals prone to posture-related issues. By combining real-time monitoring, intelligent processing, and immediate corrective feedback, the proposed system offers an effective and affordable solution to reduce posture -related health problems and promote better spinal health.

KEYWORDS*:* IoT, ESP32, IMU Sensor, Flex Sensor, Wearable Technology, Posture Monitoring, Spinal Alignment**.**

I. INTRODUCTION

Posture is a fundamental aspect of human biomechanics that refers to the alignment of body segments in relation to each other and the surrounding environment, and it plays a vital role in maintaining overall physical health and functional efficiency. Proper posture ensures that the body's weight is evenly distributed across muscles, ligaments, and joints, thereby minimizing unnecessary strain and reducing the risk of fatigue and injury. The spine, being the central structural axis of the human body, is responsible for supporting body weight, enabling movement, and protecting the spinal cord, making its alignment crucial for maintaining a healthy posture. When the spine maintains its natural curvature, the body operates efficiently with optimal muscle coordination and minimal energy expenditure.

In recent years, rapid technological advancements and lifestyle changes have significantly influenced human posture habits. The increasing reliance on computers, smartphones, and other digital devices has led individuals to spend prolonged hours in static and often improper positions. Common postural deviations such as forward head posture, rounded shoulders, and slouched sitting have become widespread, especially among students and working professionals. These unnatural positions disrupt the normal curvature of the spine and place excessive stress on specific muscle groups and joints. Over time, such habits can lead to a variety of health complications, including chronic lower back pain, cervical spine disorders, muscle imbalances, fatigue, reduced respiratory efficiency due to restricted chest expansion, and an increased risk of long-term spinal degeneration. These issues not only affect physical well-being but also reduce productivity and quality of life.

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Conventional methods for posture correction, including physiotherapy, ergonomic adjustments, and orthopaedic supports such as braces, provide some level of improvement but are limited in their effectiveness. These approaches generally lack continuous monitoring and fail to offer real-time feedback, making it difficult for individuals to maintain correct posture consistently throughout the day. Additionally, most traditional solutions are reactive in nature, addressing posture-related problems only after symptoms have already developed rather than preventing them at an early stage. This highlights the need for a more proactive and technology-driven approach that can assist users in maintaining proper posture continuously.

With the emergence of wearable technology, embedded systems, and the Internet of Things (IoT), it has become feasible to develop intelligent solutions capable of real-time posture monitoring and correction. Wearable devices equipped with advanced sensors can continuously track body movements and spinal alignment, enabling accurate detection of posture deviations as they occur. By integrating microcontrollers with wireless communication capabilities, these systems can process sensor data efficiently and provide instant feedback to the user through alerts such as vibrations or sound signals.

The proposed system builds upon these technological advancements by introducing a smart, wearable, and IoT-enabled posture monitoring and correction device specifically designed to track spinal alignment with high accuracy. By utilizing a combination of inertial measurement units and flex sensors, the system captures both orientation and curvature of the spine, ensuring comprehensive posture analysis. The integration of an ESP32 microcontroller enables efficient data processing and seamless wireless communication for real-time monitoring and long-term data storage. This approach not only enhances the accuracy and responsiveness of posture detection but also provides users with valuable insights into their posture patterns. Overall, the system aims to bridge the gap between traditional posture correction methods and modern intelligent solutions by offering a continuous, non-invasive, and user-friendly approach to preventing and managing posture-related health issues.

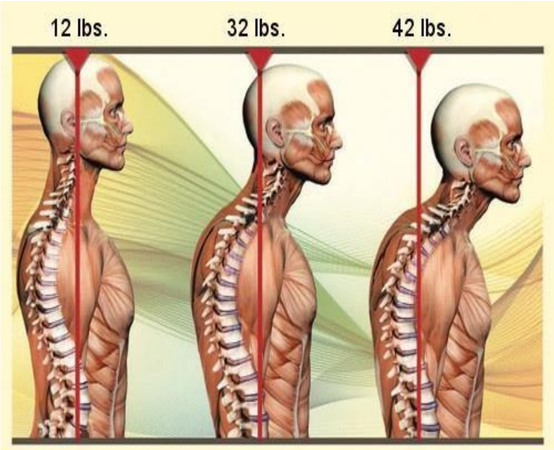

Fig.1: Bad posture representation

II. EXISTING SYSTEM

The existing system for managing posture-related problems and lower back pain primarily relies on clinical treatments and conventional therapeutic methods, which are often reactive rather than preventive in nature. Individuals experiencing persistent back pain are typically advised to undergo medical interventions such as surgery or to use specialized orthopedic devices like dynamic joint braces. While these approaches can provide relief in certain cases, they are generally invasive, costly, and require professional supervision, making them less accessible for continuous, everyday use. Surgical procedures, particularly those involving the spine, are usually performed using minimally invasive techniques that aim to reduce recovery time and physical trauma. However, despite advancements in medical technology, these procedures still involve significant risks, including infection, nerve damage, complications related to anesthesia, and in some cases, incomplete or temporary pain relief. Moreover, recovery from spinal surgery can take several months, often ranging from six months to a year, during which patients must limit their physical activities and

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undergo rehabilitation, making it a time-consuming and physically demanding process. Due to these risks and limitations, surgery is generally considered a last resort, recommended only when other conservative treatments have failed to produce satisfactory results.

III. PROPOSED SYSTEM

The proposed system presented in this project is an advanced wearable posture monitoring and correction solution designed to continuously track spinal alignment and provide real-time feedback to the user, thereby helping in the prevention of posture-related health issues such as lower back pain and muscle strain. Unlike traditional systems that rely on single-sensor inputs or periodic observation, this system integrates multiple sensing elements, specifically Inertial Measurement Units (IMU) and flex sensors, to achieve a more accurate and reliable assessment of posture. The IMU sensor can measure acceleration and angular velocity across multiple axes, which enables the system to determine the orientation and tilt of different segments of the spine, while the flex sensor detects bending by varying its resistance according to the curvature of the user's back.

At the core of the system is the ESP32 microcontroller, which is selected due to its high processing capability, low power consumption, and built-in Wi-Fi and Bluetooth communication features. Once calibration is complete, the device continuously collects real-time data from both IMU and flex sensors. This raw data is then processed using filtering techniques such as moving average or low-pass filtering to eliminate noise and ensure stable readings. After filtering, the system calculates important parameters such as angular deviation and bending levels, which are then compared with predefined threshold values to determine whether the current posture is correct or deviated. Based on this comparison, the posture is classified into different levels such as normal posture, mild deviation, and severe deviation.

Using the ESP32's Wi-Fi and Bluetooth capabilities, posture data can be transmitted to a mobile application or cloud platform, where it can be stored, analysed, and visualized. This allows users to track their posture history, monitor improvements, and gain insights into their daily habits. It also opens up possibilities for remote health monitoring, where healthcare professionals can access the data for further analysis and provide personalized recommendations. The wearable design of the system ensures that it is lightweight, compact, and comfortable for prolonged use, making it suitable for various environments such as offices, classrooms, and homes.

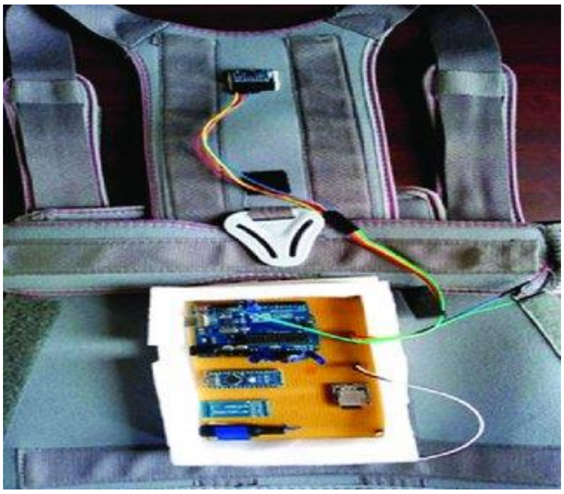

Fig.2: Wearable system using sensor

IV. DEVELOPMENT OF POSTURE CORRECTOR SCHEME

The development of the posture corrector scheme in this project focuses on designing a compact, wearable, and intelligent system that can continuously monitor spinal alignment and provide real-time corrective feedback to the user. The overall development process begins with identifying the key parameters required for accurate posture detection, primarily the orientation and curvature of the spine. To capture these parameters effectively, the system integrates

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Inertial Measurement Unit (IMU) sensors and a flex sensor, which are strategically positioned along the upper and lower regions of the back. This placement ensures that both angular movement and bending of the spine are measured simultaneously, enabling a comprehensive understanding of the user's posture. The hardware components are interconnected through a carefully designed circuit, with the ESP32 microcontroller serving as the central processing unit due to its high efficiency, low power consumption, and built-in wireless communication capabilities.

During the development phase, significant emphasis is placed on calibration and data accuracy. Initially, the system is calibrated by allowing the user to maintain a correct posture, which is then recorded as a reference baseline. This baseline plays a crucial role in determining deviations during real-time operation. The sensors continuously collect raw data, which is then processed by the microcontroller using filtering techniques to eliminate noise and ensure stable readings. The processed data is further analysed to calculate angular deviations and bending levels, which are compared against predefined threshold values to classify the posture condition. This classification enables the system to distinguish between normal posture, mild deviation, and severe deviation, thereby improving the reliability of detection.

The system is designed to respond immediately when improper posture is detected by activating output components such as a vibration motor and buzzer. The intensity of the feedback varies depending on the severity of the posture deviation, ensuring that the user receives appropriate alerts without causing discomfort. Additionally, an OLED display is incorporated into the system to provide visual feedback, including posture status and sensor readings, which enhances user interaction and awareness.

The integration of IoT technology is a key feature in the development of this scheme, allowing the system to transmit posture data wirelessly using the ESP32's Wi-Fi or Bluetooth capabilities. This enables real-time monitoring through a mobile or web-based application, where users can track their posture patterns over time.
The collected data can also be stored for long-term analysis, helping users identify habits and make necessary improvements. The wearable design is carefully developed to ensure comfort and usability, using lightweight materials and adjustable straps so that the device can be worn for extended periods without inconvenience.

Overall, the development of the posture corrector scheme combines hardware integration, embedded programming, sensor calibration, and wireless communication to create a reliable and efficient system.

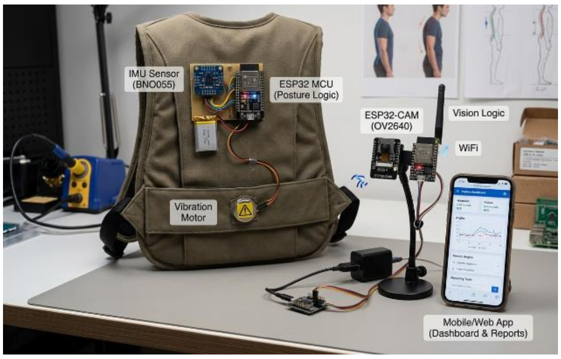

Figure. 3: Proposed Posture Corrector (**a**) framework and (**b**) component positioning.

V. BIOLOGICAL RESEARCH

The biological research carried out in this project focuses on understanding the impact of different types of poor posture on the human body and identifying the most effective location for sensor placement to ensure accurate posture monitoring. Despite their differences, a common characteristic observed in all three postures is the forward displacement of the head's centre of gravity relative to the base of the neck. This forward shift forces the neck to bend and causes the shoulders to round or hunch forward, leading to improper alignment of the upper body. Over prolonged periods, this imbalance can lead to chronic neck pain, stiffness, and reduced flexibility.

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In addition to affecting the neck, poor posture also has a significant impact on the upper and mid-back regions. The continuous hunching of the shoulders weakens the upper and middle back extensor muscles, which are responsible for maintaining an upright posture. Simultaneously, the muscles in the chest region tend to tighten due to prolonged contraction, further pulling the shoulders forward and reinforcing the poor posture habit. This combination of weakened back muscles and tightened chest muscles creates a cycle of postural deterioration, making it increasingly difficult for individuals to maintain proper alignment without external assistance or corrective measures.

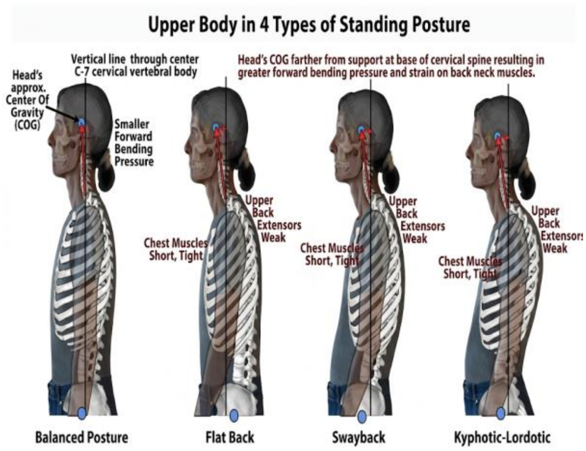

Fig 5: Three poor postures related to upper back

The research further highlights the critical role of the lower back in maintaining overall body posture. Proper lower back posture is essential for supporting the upper body, as it determines the alignment of the spine above the hips. The degree of this curvature is influenced by the tilt of the pelvis, which in turn is controlled by a group of muscles including the abdominal muscles, hip flexors, hip extensors, and lower back extensors.

It was observed that smaller flex sensors, such as the 2.2-inch variant, had limited capability in capturing the full range of spinal movement, making them less suitable for accurate posture monitoring. In contrast, larger flex sensors, particularly the 4.5-inch type, demonstrated better performance by covering a wider area and providing more reliable readings of spinal curvature.

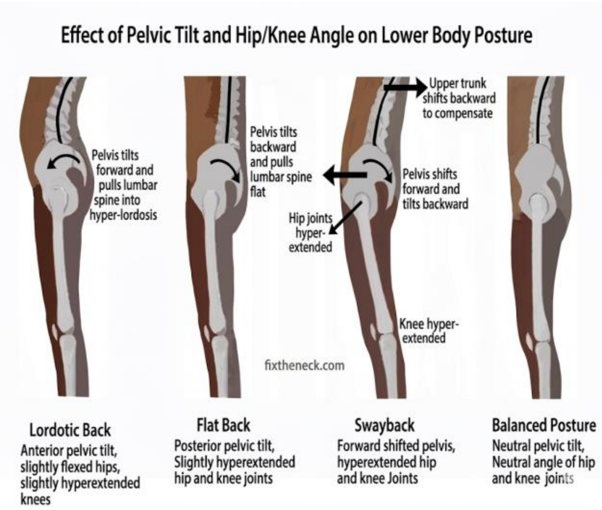

Fig.6: Three poor postures related to lower brace

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VI. WORKING

The working of the proposed posture monitoring and correction system is designed as a continuous and intelligent process that integrates sensing, analysis, feedback, visualization, and data storage to ensure effective posture management. Initially, the system acquires posture-related data using an Inertial Measurement Unit (IMU) sensor that is mounted along the spine. This sensor continuously captures motion and orientation parameters such as acceleration and angular rotation in multiple axes, which are essential for determining the alignment of the user's back. The placement of the IMU along the spine ensures that even slight deviations in posture can be detected accurately. Along with this, additional sensing such as flex measurement may be incorporated to capture the curvature of the spine, providing a more comprehensive understanding of posture.

Once the data is collected, it is transmitted to the microcontroller unit, where advanced processing takes place. The system utilizes AI-based algorithms implemented within the MCU to analyse the incoming sensor data in real time. These algorithms are designed to identify patterns in the user's posture by comparing current sensor readings with baseline values obtained during the calibration phase, as well as with predefined posture thresholds. The AI component enhances the system's capability by enabling more intelligent classification of posture into categories such as correct posture and poor posture, rather than relying solely on simple threshold comparisons. This allows the system to adapt better to variations in user behaviour and improve accuracy in posture detection.

After classification, the system provides immediate visual feedback to the user through an LCD or OLED display.
This display shows important information such as the current posture condition and the angle of deviation, helping the user to understand their posture status in real time. This visual representation increases user awareness and encourages conscious efforts to maintain proper posture. In addition to visual feedback, the system incorporates a vibration motor that acts as a biofeedback mechanism. Whenever improper posture is detected, the vibration motor is activated instantly to alert the user. This immediate feedback prompts the user to correct their posture, thereby creating a habit of maintaining proper alignment over time.

Furthermore, the system integrates a web camera to perform visual analysis of the user's posture. This adds an additional layer of monitoring by capturing images or video data, which can be analysed to validate sensor readings and improve overall accuracy. The combination of sensor-based and vision-based analysis ensures a more robust and reliable posture detection system. The visual data can also be used for advanced analysis or future improvements in AI models.

In addition to real-time monitoring and feedback, the system is designed to support long-term posture tracking through cloud integration. The processed posture data is transmitted to a cloud server using the wireless communication capabilities of the microcontroller. This allows the data to be stored securely and analysed over extended periods. Users can access this data through a mobile or web-based interface to review their posture history, identify patterns, and monitor improvements. This long-term analysis is particularly useful for understanding habitual posture issues and making informed adjustments to daily activities.

Overall, the working of the system forms a continuous loop in which posture data is acquired, analysed using intelligent algorithms, displayed for user awareness, and used to generate immediate corrective feedback, while also being stored for long-term monitoring. This integrated approach ensures that the system not only detects posture issues but also actively helps users correct them and maintain better spinal health over time.

VII. BIOFEEDBACK MECHANISM

The biofeedback mechanism in the proposed posture monitoring and correction system plays a crucial role in enabling real-time posture improvement by directly interacting with the user. Biofeedback, in this context, refers to the process of sensing the user's posture, analysing it, and immediately providing a response that encourages corrective action. In this system, the biofeedback loop begins with continuous acquisition of posture data from sensors such as the IMU and flex sensor, which monitor the orientation and curvature of the spine. These sensors detect even minor deviations from the ideal posture and send the data to the ESP32 microcontroller for processing.

Once the data is processed and compared with calibrated baseline values and predefined thresholds, the system determines whether the user is maintaining a correct posture or deviating from it. When the posture is identified as improper, the biofeedback mechanism is activated instantly without any noticeable delay. The primary form of feedback used in the system is a vibration motor, which provides a gentle and non-intrusive alert to the user. This tactile feedback is chosen because it is effective, private, and does not disturb others in the surrounding environment. The vibration serves as an immediate reminder for the user to adjust their posture, thereby creating a direct connection between the detected error and the corrective action.

In cases where the deviation is more significant or prolonged, the system can enhance the feedback by activating an additional alert mechanism such as a buzzer. This ensures that the user becomes more aware of severe posture issues and responds quickly. Alongside these alerts, the system may also display posture status and deviation angles on an OLED or LCD screen, providing visual reinforcement of the feedback. This combination of tactile and visual cues strengthens the effectiveness of the biofeedback process by engaging multiple senses.

An important aspect of the biofeedback mechanism is its continuous and adaptive nature. The system does not simply alert the user once; instead, it continuously monitors posture and provides feedback whenever improper alignment is detected. As the user responds to these alerts and corrects their posture, the system recognizes the improvement and stops the feedback, thereby reinforcing correct behaviour. Over time, this repeated cycle helps the user develop awareness and build a habit of maintaining proper posture even without external prompts.

Furthermore, the integration of AI-based analysis enhances the biofeedback mechanism by allowing more intelligent decision-making. Instead of relying solely on fixed thresholds, the system can adapt to individual posture patterns and provide more personalized feedback. Additionally, with IoT connectivity, feedback data can be logged and analysed over time, enabling users to track how often corrections are needed and how their posture improves. Overall, the biofeedback mechanism serves as the core functional element of the system, transforming posture monitoring into an interactive and behaviour-changing process that promotes long-term spinal health and reduces the risk of posture-related disorders.

VIII. SIMULATION OUTPUTS

The simulation of the proposed wearable posture monitoring and correction system was carried out to validate the functionality, accuracy, and responsiveness of the overall design before hardware implementation. The simulation environment was configured to replicate real-time posture conditions by providing varying sensor inputs corresponding to different spinal alignments. The results obtained demonstrate the effectiveness of the system in detecting posture deviations, classifying posture conditions, and generating appropriate feedback.

1. Simulation Setup

The simulation was designed using embedded system tools and virtual sensor inputs to mimic the behaviour of IMU and flex sensors. The ESP32 microcontroller logic was implemented using Arduino-based programming, where sensor values were either simulated through serial input or predefined datasets representing different posture conditions. Threshold values for posture classification were defined based on the calibrated baseline posture. The simulation also included virtual representations of output components such as OLED display, vibration motor, and buzzer to observe system responses.

2. Sensor Data Simulation

In the simulation, different posture conditions were represented by varying the sensor values. For correct posture, the IMU provided stable angle readings close to the baseline, and the flex sensor showed minimal bending. For incorrect posture, the sensor values deviated significantly, indicating spinal misalignment.

The simulation demonstrated that the system could successfully capture variations in angular orientation and curvature, which are essential for posture detection

3. Posture Classification Output

The simulated system classified posture into three categories based on the deviation from the baseline values. When the sensor readings were within a small acceptable range, the posture was classified as normal. Moderate deviations resulted in classification as mild poor posture, while larger deviations were identified as severe poor posture.

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4. Display Output Simulation

The OLED/LCD display output was simulated to visualize the posture condition and angle values. The display showed real-time updates of parameters such as spinal angle, posture status, and alert messages. For correct posture, the display indicated a normal status, while for incorrect posture, it displayed warning messages along with deviation values.

5. Feedback Mechanism Output

The biofeedback system was successfully simulated using virtual indicators for vibration motor and buzzer. When mild posture deviation was detected, the vibration motor was activated, providing a gentle alert. For severe deviations, both the vibration motor and buzzer were triggered, indicating a higher level of urgency.

6. AI-Based Analysis Output

The AI-based posture analysis was tested using simulated datasets representing different posture patterns. The algorithm was able to learn and differentiate between correct and incorrect posture conditions with improved accuracy compared to simple threshold-based methods.

7. Camera-Based Monitoring Output

The integration of webcam-based posture analysis was simulated to provide visual validation of sensor data. The system was able to capture posture images and analyse body alignment using basic image processing techniques.

8. Cloud Data Storage Output

The IoT functionality was simulated by transmitting posture data to a cloud server. The data was successfully stored and could be accessed for long-term analysis. Graphical representations such as posture trends and deviation frequency were generated, allowing users to monitor their improvement over time.

9. Performance Evaluation

The overall simulation results indicate that the system performs efficiently in real-time conditions. The posture detection accuracy was high due to the use of multiple sensors and AI-based analysis. The response time for feedback was quick, ensuring immediate user notification.

10. Summary of Simulation Results

The integration of AI, IoT, and biofeedback mechanisms enhances the overall functionality and effectiveness of the system. The results validate the design approach and confirm that the system can be implemented as a practical solution for posture monitoring and correction.

IX. RESULTS

The developed wearable posture monitoring and correction system was successfully implemented and tested based on the proposed design, and the results demonstrate that the system is capable of accurately detecting spinal posture and providing real-time corrective feedback. The integration of IMU sensors and flex sensors enabled effective monitoring of both orientation and curvature of the spine, allowing the system to identify posture deviations with high reliability. During testing, the system was able to clearly distinguish between correct posture and different levels of improper posture by comparing real-time sensor data with calibrated baseline values and predefined thresholds. The classification of posture into normal, mild deviation, and severe deviation was found to be consistent and responsive under various user conditions.

The ESP32 microcontroller efficiently processed continuous sensor data with minimal delay, ensuring real-time operation of the system. The implementation of filtering techniques helped in reducing noise and improving the stability of sensor readings, which contributed to more accurate posture detection. The AI-based analysis further enhanced the system's capability by improving classification accuracy and adapting to variations in individual posture patterns. This made the system more intelligent compared to conventional threshold-based approaches.

The vibration motor provided immediate and non-intrusive alerts for minor posture deviations, while the buzzer was activated for more severe conditions, ensuring that the user responded promptly. The OLED/LCD display successfully presented real-time posture status and angle values, increasing user awareness and enabling better understanding of posture conditions

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The system successfully stored and displayed posture data for long-term analysis, enabling users to track their posture habits and improvements over time. This feature adds significant value by transforming the system from a simple monitoring device into a comprehensive health tracking solution. Additionally, the optional webcam-based analysis provided supplementary validation of posture, further improving system reliability.

Overall, the results confirm that the proposed system is effective, reliable, and suitable for real-time posture monitoring and correction. It overcomes the limitations of existing methods by offering a non-invasive, cost-effective, and continuous solution for maintaining proper spinal alignment. The system not only detects posture deviations but also actively assists users in correcting them, thereby reducing the risk of long-term musculoskeletal problems and promoting better health and well-being.

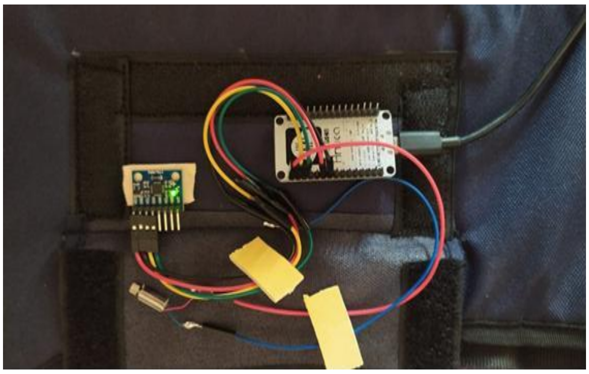

Fig.7: Hardware Unit

Posture Type	**IMU Angle Range (Spine)**	**Vision Detection (Neck/Head)**	**System Status**
Normal	0 degree to 15 degree	Neutral Alignment	Healthy
Slumped	>20 degree	Forward Head Tilt	Poor Posture
Lateral Lean	>20 degree	Asymmetric Shoulders	Poor Posture

Table 1. Expected result

Fig 8. Result of Poor posture

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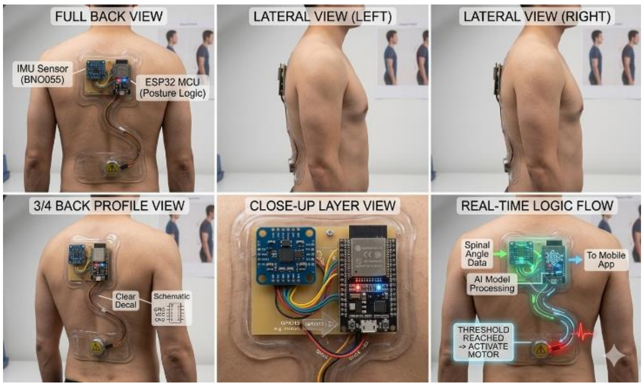

Fig 9. Different views of wearable posture monitoring and correction device

X.CONCLUSION

The developed wearable posture monitoring and correction system successfully addresses the growing problem of posture-related health issues by providing a smart, real-time, and user-friendly solution for maintaining proper spinal alignment. Based on the design and implementation presented in this project, the system effectively integrates IMU sensors and flex sensors with an ESP32 microcontroller to continuously monitor the orientation and curvature of the spine. The use of sensor fusion techniques enhances the accuracy and reliability of posture detection, overcoming the limitations of traditional single-sensor systems.

The system operates efficiently by acquiring real-time data, processing it using embedded algorithms and AI-based analysis, and classifying posture into different levels based on deviation from a calibrated baseline. The immediate biofeedback mechanism, implemented through vibration and buzzer alerts, plays a significant role in helping users recognize and correct improper posture instantly. This continuous feedback loop not only assists in real-time correction but also contributes to long-term habit formation, promoting better posture awareness among users.

In addition, the integration of IoT technology enables wireless communication, allowing posture data to be stored, monitored, and analysed over time through mobile or web-based platforms. This feature enhances the system's functionality by providing insights into user behaviour and enabling long-term health monitoring. The inclusion of display modules further improves user interaction by providing clear visual feedback regarding posture status and deviation levels.

Overall, the project demonstrates that the proposed system is a reliable, non-invasive, and cost-effective solution for posture monitoring and correction. It successfully shifts the approach from reactive treatment to proactive prevention, reducing the risk of chronic back pain and other musculoskeletal disorders. By combining real-time monitoring, intelligent analysis, and immediate feedback, the system contributes to improving spinal health and overall well-being, making it suitable for everyday use in various environments such as educational institutions, workplaces, and homes.

XI. FUTURE ADVANCEMENTS

Although the proposed system performs effectively, there are several opportunities for enhancement and expansion to make it more intelligent, adaptive, and scalable.

1. Machine Learning Based Personalization

In future versions, the system can incorporate Machine Learning (ML) algorithms either on-device or via cloud platforms. Instead of using fixed thresholds for posture detection, the system can learn the user's individual posture patterns over time.

2. Adaptive Feedback and Haptic Profiling

The current feedback system provides a uniform vibration alert for posture correction. In future developments, this can be enhanced by implementing adaptive haptic feedback.

A mild slouch can trigger a gentle vibration. A severe slouch can trigger a stronger and continuous alert

3. Predictive Health Analytics and Medical Integration

The cloud-based system can be further enhanced by incorporating predictive analytics. Postural Health Score.Peak fatigue periods (e.g., afternoon slouching) Risk analysis for spinal issues.

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| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

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