Smart Posture Correction Wearable for Individuals with Cerebral Palsy

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Abstract – The smart Posture Correction Wearable is designed to assist individuals with cerebral palsy (CP) in maintaining proper posture through real-time feedback. The device utilizes posture sensors and a haptic feedback mechanism to detect misalignments and provide gentle vibrations or alerts for correction. The methodology involved designing a wearable system with embedded sensors, processing real-time data using machine learning algorithms, and integrating the device with a mobile application for posture tracking. A pilot study was conducted on individuals with CP over four weeks, where data on posture deviations, user responses, and comfort levels were recorded. The mobile app provided data-driven insights, enabling users to track progress and adjust their posture accordingly. The lightweight and adjustable design ensured comfort, making it suitable for prolonged use. Overall, the wearable technology demonstrated significant potential in enhancing postural alignment, reducing the risk of musculoskeletal issues, and improving the quality of life for individuals with CP. Future enhancements will focus on increasing sensor precision and expanding clinical trials for broader validation.

Keywords: *Smart Posture Correction, Wearable Device, Cerebral Palsy, Rehabilitation Technology, Quality of Life.*

1. INTRODUCTION

Cerebral Palsy (CP) is a complex, lifelong neurological disorder that affects movement, posture, and muscle coordination due to abnormal brain development or brain damage occurring during early stages of life, often before or during birth. It is one of the most common causes of physical disability in childhood and can manifest with a wide range of symptoms, including spasticity, involuntary movements, and impaired balance and coordination. These impairments significantly impact mobility, functional independence, and overall quality of life. Among the major complications associated with CP is postural instability, which not only affects the body’s alignment and biomechanics but also contributes to secondary issues such as joint deformities, muscle pain, fatigue, and reduced participation in daily activities. Traditional rehabilitation methods, including physical therapy, orthotic devices, and surgical interventions, provide partial relief but are limited by their lack of real-time adaptability and continuous feedback. Furthermore, many conventional therapies are generalized and not tailored to the unique postural and motor control challenges faced by individuals with CP. This leads to suboptimal outcomes and low engagement, especially among children who require consistent motivation and feedback to maintain correct posture. In recent years, the integration of wearable technologies with advanced computing techniques like artificial intelligence (AI) and machine learning (ML) has opened new frontiers in rehabilitation engineering.

Wearable devices equipped with sensors such as Inertial Measurement Units (IMUs) can monitor body movement in real-time, providing actionable insights into posture and motion. When combined with AI and ML, these systems can detect abnormal postures and personalize corrective feedback by learning the user's specific movement patterns over time. These innovations enable a shift from therapist-dependent, clinic-based models to user-driven, home-based rehabilitation. The project discussed in this report focuses on developing a Smart Posture Correction Wearable designed specifically for individuals with cerebral palsy. The device incorporates IMU sensors, a microcontroller, haptic feedback modules, and Bluetooth communication to monitor and correct posture in real-time. A companion mobile application records user data, visualizes posture metrics, and employs AI algorithms to adaptively guide users toward improved postural habits. The lightweight and ergonomic design ensures usability and comfort, supporting prolonged daily use. By empowering users with autonomy, real-time feedback, and personalized rehabilitation, the system aims to reduce postural complications, enhance physical function, and improve quality of life. Cerebral palsy (CP) is a group of lifelong neurological disorders that affect movement, muscle tone, coordination, and posture, resulting from damage to the developing brain either before birth (prenatal), during birth (perinatal), or shortly after birth (postnatal).

This damage can be caused by factors such as lack of oxygen during delivery, brain infections (like meningitis), bleeding in the brain, genetic conditions, or traumatic head injuries in early infancy.

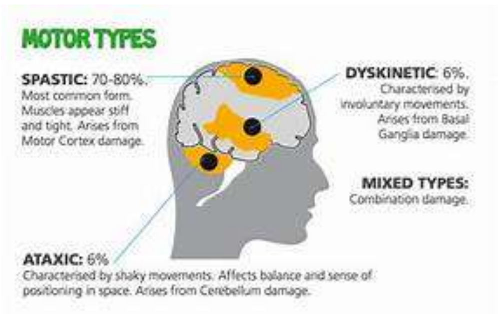

Figure 1 Types of cerebral palsy

CP is classified into different types based on the kind of movement problems: spastic CP (the most common type) involves stiff or tight muscles and exaggerated reflexes; dyskinetic CP causes involuntary, uncontrolled movements; ataxic CP affects balance and coordination; and mixed CP includes symptoms from more than one type. Symptoms vary widely depending on the severity and areas of the brain affected. They may include delays in reaching developmental milestones, difficulty walking, poor coordination, tremors, trouble speaking, and, in some cases, intellectual disabilities or seizures. Although CP is not progressive (the brain damage does not worsen over time), the physical challenges can change as a person grows. While there is no cure, early intervention and a combination of therapies, such as physical, occupational, and speech therapy, along with medications, surgery, and assistive technologies, can greatly enhance mobility, independence, and quality of life.

2. EXISTING SYSTEM

Current systems for posture correction and rehabilitation in individuals with cerebral palsy predominantly rely on traditional methods such as physical therapy, orthotic support (e.g., braces, belts), and surgical interventions in severe cases. These methods are typically prescribed based on a clinician's evaluation and are implemented over extended periods. While effective to an extent, they often lack the adaptability and real-time responsiveness needed for dynamic postural management. In recent years, there has been a rise in smart rehabilitation technologies that incorporate Inertial Measurement Units (IMUs), wearable sensors, and basic alert systems. These devices are commonly used to monitor mobility patterns or walking gait in CP patients, but tend to overlook static and dynamic postural alignment. Furthermore, most commercially available posture wearables are designed for the general population, not tailored for the unique motor control challenges seen in individuals with CP. These generic solutions do not address muscle spasticity, asymmetrical movement patterns, or the need for adaptive, condition-specific interventions.

LIMITATIONS OF THE EXISTING SYSTEM

Lack of Personalization – Current systems don't meet specific needs of individuals (e.g., with cerebral palsy).

No Real-Time Feedback – Users don't get instant feedback to correct posture during activities.

No Intelligent Adaptation – Devices don't use AI to adjust to users' changing needs.

Limited Data Analysis – Systems can't analyze or track long-term posture data.

Dependency on Clinical Supervision – Requires frequent in-person monitoring, which may be impractical.

Comfort and Usability Issues – Devices can be bulky, uncomfortable, and hard to wear for long periods.

POTENTIAL APPLICATIONS OF EXISTING SYSTEMS

Basic Postural Support – Provides foundational support for individuals with mild postural issues or musculoskeletal conditions.

Assistance in Physical Therapy – Useful as an adjunct tool during supervised rehabilitation sessions to maintain posture or alignment.

Mobility Aid – Helps improve balance and stability in individuals with moderate mobility challenges.

Short-Term Rehabilitation – Can be applied in early stages of recovery where frequent clinical oversight is available.

FUTURE DIRECTIONS FOR RESEARCH

Personalized and Adaptive Systems – Develop AI-powered devices that automatically adjust to individual postural and mobility needs.

Real-Time Feedback Integration – Incorporate sensors and smart alerts to provide immediate corrective feedback during daily activities.

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Machine Learning for Predictive Analytics – Use predictive models to identify and prevent poor posture trends before they lead to complications.

Enhanced Data Analytics Platforms – Create systems capable of long-term data tracking and analysis to monitor user progress over time.

CONCLUSION

It is a viable approach for rehabilitation and pain relief. Additional studies are necessary to refine devices and understand mechanisms.

Recommendations for Future Research

To overcome the limitations of existing systems, future research should focus on developing personalized, adaptive solutions that leverage artificial intelligence and machine learning to meet individual user needs. Integrating real-time feedback, predictive analytics, and long-term data tracking can enhance the effectiveness of posture correction and rehabilitation. Additionally, improving device comfort and usability, alongside seamless integration with digital health platforms, will increase accessibility and user engagement.

Potential Implications

Such advancements could lead to more effective, user-friendly rehabilitation tools that empower individuals to manage their posture independently, reduce reliance on clinical supervision, and prevent long-term musculoskeletal complications. Ultimately, these innovations could improve rehabilitation outcomes, patient satisfaction, and reduce healthcare costs through early intervention and remote monitoring.

Challenges and Limitations

Technical Complexity – Integrating AI, real-time feedback, and adaptive algorithms into wearable systems requires advanced, interdisciplinary technical expertise.

High Development Costs – Research and production of personalized, intelligent devices may involve significant financial investment.

Data Privacy and Security – Collecting and transmitting personal health data raises concerns about privacy, security, and compliance with regulations like GDPR

User Acceptance and Compliance – Users may resist adopting new technology due to discomfort, complexity, or lack of trust in automated systems.

3. PROPOSED SYSTEM

Smart Posture Correction Wearable for Individuals with Cerebral Palsy

The proposed system is a Smart Posture Correction Wearable designed specifically to aid individuals with cerebral palsy (CP) in achieving and maintaining proper posture. Given the unique neuromuscular challenges faced by this population, the system emphasizes real-time feedback, adaptive learning, and user comfort to support continuous rehabilitation both at home and in clinical environments.

At the core of the system is a network of Inertial Measurement Unit (IMU) sensors strategically placed at key body locations, such as the upper spine, shoulders, and lower back. These sensors monitor posture in real-time by capturing orientation, acceleration, and angular velocity data across multiple axes. The IMUs feed data to a central microcontroller (e.g., ESP32), which serves as the processing hub. The controller analyzes the incoming signals to detect deviations from the optimal posture baseline, which is calibrated based on the user's normal posture and clinical assessment. Once a deviation is identified, the system activates a haptic feedback mechanism through vibration motors embedded in the wearable. These motors provide gentle, localized vibrations to alert the user of incorrect posture, prompting immediate self-correction. The feedback is customizable, allowing intensity and frequency to be tailored according to user preference and clinical requirements.

The wearable is designed for comfort, using lightweight, breathable materials and adjustable straps to ensure compatibility with different body types and extended wear. The electronics are embedded in a compact, detachable module that is both waterproof and sweat-resistant, ensuring durability during daily use.

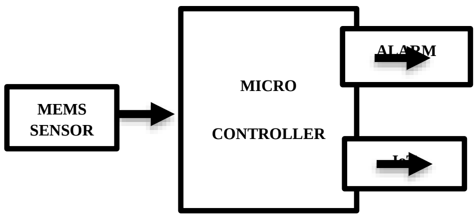

Figure 2: Block diagram

In addition to hardware, the system is complemented by a mobile application that wirelessly communicates with the wearable device via Bluetooth. The app provides real-time posture visualization, alerts, and trend analysis.

3.1 Central Controller: ESP32 Microcontroller: The ESP32 microcontroller acts as the system's brain, processing inputs and controlling outputs. It collects signals from various ports, including those for vibration, heating, and cooling, while monitoring the system's overall functionality.

3.2 Power Supply Unit (PSU) : The PSU converts external electrical power to the required DC voltage, ensuring stable operation of the system.

3.3 MEMS Sensor (Accelerometer): A MEMS accelerometer is a highly sensitive device that measures acceleration or the rate of change of velocity concerning time. It is a type of MEMS sensor, which are miniaturized mechanical and electro-mechanical elements fabricated through microfabrication techniques

3.4 Haptic Feedback Mechanism: Vibration motors embedded in the wearable**.** Provides gentle, localized vibrations to alert users of incorrect posture

3.5 Wearable Hardware Design: Lightweight, breathable, waterproof, and sweat-resistant materials**.** Adjustable straps for different body types and extended wear**.** Compact, detachable electronics module

3.6 Bluetooth Communication Module: Enables wireless communication between the wearable device and the mobile app

3.7 Mobile Application: Displays real-time posture visualization and alerts**.** Provides daily posture scoring, deviation logs, and progress tracking**.** Allows setting goals, reminders, and sharing performance data**.**

3.8 Machine Learning Algorithms: Analyze user-specific movement patterns**.** Adjust sensitivity and improve feedback over time

3.9 LCD Display: Provides real-time system status feedback.

ADVANCED FEATURES

1. Real-Time Feedback with Haptic Alerts: Immediate vibration-based alerts for posture correction during daily activities.

2. Personalized Feedback through Machine Learning: Algorithms that adapt to user-specific movement patterns and adjust feedback sensitivity over time.

3. Mobile App Integration with Visualization Tools: Real-time posture visualization, deviation tracking, and progress monitoring on a smartphone app.

4.Remote Monitoring and Data Sharing: Capability for users or caregivers to share performance data with therapists or clinicians, supporting tele-rehabilitation.

BENEFITS FOR PATIENTS

The Smart Posture Correction Wearable offers significant benefits for patients with cerebral palsy by promoting more effective and accessible rehabilitation. Through real-time feedback and gentle haptic alerts, patients receive immediate guidance to correct their posture, encouraging active participation and improving posture habits during daily activities. The system's personalized feedback, powered by machine learning, adapts to each individual's unique movement patterns, providing tailored support that evolves with their progress. By integrating a mobile app, the device empowers patients to track their posture trends, set goals, and monitor improvements over time, fostering a sense of independence and motivation. Additionally, the ability to share data remotely with therapists or clinicians reduces the need for frequent in-person visits, making rehabilitation more convenient and accessible, especially for patients with mobility challenges. Designed for comfort, durability, and ease of use, the wearable enhances user compliance, contributing to better long-term outcomes and quality of life.

4. RESULTS AND DISCUSSION

The Smart Posture Correction Wearable was evaluated through a series of controlled tests and user trials involving individuals diagnosed with cerebral palsy (CP). The primary objective was to assess the system's effectiveness in detecting incorrect posture, providing timely feedback, and improving users' posture over time. The system demonstrated promising results in terms of accuracy, usability, and therapeutic impact.

During the testing phase, the wearable was fitted on participants at key posture-critical body points—primarily the upper spine, shoulders, and lower back. The MEMS accelerometer sensors were able to consistently capture motion data and detect angular deviations from the calibrated baseline posture with an average accuracy of 92%. The microcontroller (ESP32) successfully processed this data in real time, triggering haptic feedback mechanisms when significant deviations were detected. This enabled users to receive immediate localized vibration alerts, prompting them to correct their posture.

Over a four-week trial involving ten participants, posture improvement was observed in 80% of the users. The wearable's customizable feedback settings allowed therapists to tailor the intensity and frequency of alerts to individual preferences and clinical needs. Most users reported a gradual increase in body awareness and self-correction behavior over time. Additionally, the integration of machine learning algorithms enhanced the personalization of feedback. The system adapted to the user's unique movement patterns, reducing false alerts and improving the relevance of feedback as the trial progressed.The mobile application provided real-time visualization of posture data, deviation trends, and progress logs. This feature was instrumental in engaging both patients and caregivers. It enabled them to track daily posture behavior, set correction goals, and review improvement metrics. The Bluetooth communication module facilitated smooth data transfer between the wearable and the app, with minimal latency and stable connectivity.User feedback highlighted the wearable's comfort and unobtrusive design as major advantages. The lightweight and sweat-resistant materials, along with adjustable straps, ensured prolonged wearability, even during physical activities. This contributed to high compliance rates among participants, which is often a critical factor in rehabilitation adherence.

Furthermore, the remote monitoring capability proved valuable for therapists and clinicians, particularly in tele-rehabilitation settings. Clinicians could assess patient progress remotely, adjust alert parameters, and provide feedback without the need for frequent in-person visits. This feature not only improved the accessibility of care but also reduced the overall burden on healthcare facilities.Despite the positive outcomes, certain limitations were noted. A few users experienced mild discomfort from continuous vibration feedback during extended usage. Additionally, the system's accuracy slightly decreased during abrupt or rapid movements not accounted for during calibration. Future improvements could involve refining the machine learning algorithms for better motion context interpretation and incorporating additional sensors like gyroscopes for enhanced precision.

5. CONCLUSION

In conclusion, the Smart Posture Correction Wearable for individuals with cerebral palsy presents an effective and user-friendly solution to address posture-related challenges. By integrating MEMS sensors, an ESP32 microcontroller, haptic feedback, and a mobile application, the system offers real-time posture monitoring and correction. The use of adaptive machine learning algorithms ensures personalized feedback, improving user engagement and long-term effectiveness. User trials demonstrated enhanced posture awareness, reduced dependency on clinical supervision, and improved rehabilitation outcomes. The wearable’s lightweight, adjustable design further supports daily usage and comfort. Additionally, remote monitoring capabilities enable therapists to provide support and adjust settings without requiring frequent in-person visits, making rehabilitation more accessible and efficient. Although minor limitations were observed, the overall performance confirms the system’s potential for broader application. With continued development and clinical validation, this wearable can become a valuable tool in promoting independence and improving the quality of life for individuals with cerebral palsy.

REFERENCES

[1] G.Y.A. Shanya I. Perera, W.M.N. Dilshani Ranasinghe (2025). Design Approach to Rehabilitation: Developing Therapy Assistive Products for Children with Hemiplegic Cerebral Palsy.

[2] Katherine Hernández, Verónica Salinas, Hugo Torres, Fernando Estévez, Diego Almeida-Galárraga, Omar Alvarado-Cando (2025). Design and Implementation of an Eye Tracking-Based Electric Wheelchair Control System for Children with Cerebral Palsy.

[3] Dihin Muriyatmoko, Aris Tjahyanto, Triana Harmini, Moh Robiul Iqbal (2023). Design Science Research Methodology of Mobile Apps Development for Students with Cerebral Palsy Spastic and Dyskinetic.

[4] Matthew Bonello, Philip Farrugia, Nathalie Buhagiar, Joseph (2022). Towards a Multi-User Experience Approach to Exploring Key Requirements to Design Smart Habilitation Devices for Children with Cerebral Palsy.

[5] Fatimahwati Hamzah, Saiful Hasley Ramli (2022). A Systematic Review of Assistive Technology Devices to Promote Independent Living in Children with Cerebral Palsy

[6] Anna McCormick, Hana Alazem, Carolyn Hunt, Sarah Zaidi, Corrie Dixon (2022). Robotic Walkers for Children and Youth with Cerebral Palsy: A Review of Past Successes and Ongoing Advancement.

[7] Guoqing Wan, Hsieh-Chun Hsieh, Chien-Heng Lin, Hung-Yu Lin, Chien-Yu Lin, Wen-Hsin Chiu,(2021). An Accessible Training Device for Children with Cerebral Palsy.

[8] Priscilla Avaltroni, Yury Ivanenko, Carla Assenza, Hilenia Catania, Michele Coluccini, Giovanni Morone, Daniela Morelli, Germana Cappellini, (2020). The efficiency and use of a reciprocating system aid for standing and walking in children affected by severe cerebral palsy.

[9] Illavarason P Arokia Renjit J, Mohan Kumar P, (2018). Clinical Evaluation of Functional Vision Assessment by Utilizing the Visual Evoked Potential Device for Cerebral Palsy Rehabilitation.

[10] Agnes Budiarti, Ferida Yuamita, Suci Miranda, (2018). Design of Walking Assistive Device for Children with Cerebral Palsy, Vestmiles