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Internet of Things Based Devices Designed for Pediatric Therapy to Improve Mobility and Engagement in Children with Cerebral Palsy

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ABSTRACT

The subjects of the paper are the creation and seeing of an Internet of Things (IoT) based equipment focused to enhance. These limitations translate to exciting opportunities for innovation, despite previous reports pointing out issues like sample size, adaptability of the systems to other tasks, and high require- ments on computational resources. To ensure the balance between comfort, durability and scalability, this research aims to provide a highly customisable IoT solution that can be used both in clinical and home environments It uses a combination of live data feeds, individual therapy modifications and machine learning models to improve the therapeutic experience for children with different degrees of cerebral palsy severity. Additionally, the emphasis on creating inexpensive, easy-to-use devices will make these visits possible in places with limited resources. The research described in this article is a step towards a tailored IoT-based solution for pediatric rehabilitation, bridging current gaps in the literature and offering a solution with a broader design in therapy considering the wide range of rehabilitative health profiles.

Keywords: *Internet of Things, cerebral palsy, pediatric therapy, mobility, rehabilitation, real-time monitoring, machine learning, user-centered design, scalability, personalized therapy, cost-effective, wearable devices, therapeutic engagement, home-based rehabilitation, adaptive technology.*

1. INTRODUCTION

Cerebral palsy (CP) is one of the most common motor disabilities of childhood, defined by motor impairment with varying degrees of physical and cognitive impairment. Standard rehabilitation therapies for children with CP are limited in their accessibility, personalization, and long-term engagement. Emerging technology, specifically from the Internet of Things (IoT) often referred to as IoT, has created new opportunities in pediatric therapy. With the capability of offering real-time tracking and personalized treatment, IoT-based enterprises also become possible, bringing about more interactive rehabilitation settings which play an important role in aiding mobility and boosting the quality of life of children with CP.

Although the significant advantages make it worthwhile; however its seamless integration in pediatric therapy is still a challenge, owing to the multidimensionality of therapy needs of children with CP with different severity levels. Several limitations were mentioned regarding earlier studies in the domain, with sample sizes being small, inflexibility towards critical cases, and a scarcity of data on long-term efficacy. Though challenges therefore exist in the rapid and effective deployment of such systems, these very limitations also provide room for the growth of more resilient and scalable systems to be launched in both clinical and home settings. Through customizable user-centered design in comfort and accessibility, IoT solutions can greatly enhance the rehabilitation experience.

Additionally, high-level computing needs and the complexity of coupling therapeutic exercise operations with IoT devices render practical deployments often challenging, especially in resource-limited environments. However these challenges also lead to innovative thinking around designing lightweight, low-cost systems that still work without needing expensive infrastructure. With the development of IoT-based therapy devices, existing gaps in the rehabilitation process can also be filled, providing the children with CP a better chance for mobility, involvement, and improvement in the overall quality of their life.

The objective of this paper is to analyze the prototype of an IoT-based rehabilitation machine that can be used for mobility and therapeutic intervention of children who have cerebral palsy. This work aspires to enhance therapeutic solutions by addressing limitations of existing physiotherapy systems and taking advantage of new IoT technologies that hold the promise of growing cost-effective and widely accessible therapeutic solutions for pediatric CP rehabilitation.

2. PROBLEM STATEMENT

Motor impairments in children with cerebral palsy (CP) create barriers to functional mobility, communication, and daily activities. Long-established rehabilitation therapies are crucial to the recovery process but are often inadequate in terms of both personalization and engagement to accommodate the individual need of pediatric patients. Many of these therapeutic approaches are limited by their requirement for in-person visits, which is difficult for both children and their families, especially in resource-poor settings. Furthermore, these therapies do not show adequate specificity for the different severity levels of CP, thereby limiting these children’s potential progress.

However, recent advances in technology, especially in the realm of the Internet of Things (IoT) open new opportunities for addressing these limitations, offering real-time monitoring, personalized therapy, and more engaging rehabilitation options. Yet, pediatric rehabilitation, as a relatively recent field, has limited relevant literature regarding the use of IoT devices, especially as it pertains to children with cerebral palsy. Despite the availability of IoT-based solutions, the development of adaptive and scalable systems that can accommodate children with varying degrees of disability while ensuring comfort and sustainability remains to be explored.

In addition, traditional systems are usually poorly validated in terms of their longitudinal efficacy, as well as their ability to deliver on-going, home delivered therapy. Additionally, the reliance on sophisticated computing resources and infrastructure poses considerable obstacles, especially in resource-poor environments, where there may be limited access to such technologies. Although these limitations in existing research and practice should be addressed, an innovative and simplistically accessible yet clinical affordable solution of IoT based therapy helping rehabilitate and restore motor functions of children with cerebral palsy seems the need of the hour.

This study proposes an advanced rehabilitation device using IoT that overcomes these limitations and through real time therapy provides tailored mobility and strength in CP children. This study is aimed at overcoming the aforementioned challenges to provide solutions which can eventually lead to an improved assessment, management, and analysis of pediatric rehabilitation.

3. LITERATURE SURVEY

The Internet of Things (IoT) has entered the field of pediatric rehabilitation, specifically as a therapy for mobility and engagement in pediatric populations, particularly children with cerebral palsy (CP)[12 where this work is relevant]. Research has proposed IoT-based approaches that aim to improve therapeutic outcomes through real-time monitoring, adaptive interventions, and personalized rehabilitation plans.

Ahmadi and Moradi (2020) proposed an IoT-based monitoring and rehabilitating system for children with CP and were able to show that their system is feasible for monitoring motor function and delivering real-time feedback to therapists. The integration of IoT with rehabilitation as highlighted in their studies will allow the continuous assessment of patients; however, the study indicated that it needs to be further refined to make it more applicable across the board. Likewise, Ali, Alam, and Kumar (2021) developed a smart wearable device for tracking movements and rehabilitation of children with CP. They researched the potential for the IoT devices to increase levels of engagement, but also described challenges around long-term use/improvement of comfort.

Machine learning and IoT integration have also been investigated in methods for pediatric rehabilitation. IoT-based rehabilitation system Kim, Lee, and Han (2022) proposed an IoT-based rehabilitation system using deep learning to create a personalized therapy based on a child’s mobility patterns. While this study showed promise in the improvement of motor functions, limitations such as the computational intensity of deep learning systems limited its real-time functionality. Ferreira, Melo, and Silva (2021) also explored integration of machine learning techniques into IoT rehabilitation systems to personalize therapy sessions and adapt them at patient individual pace, but mentioned issues regarding data privacy and system scalability.

Research into the use of wearable Internet of Things (IoT) devices as a potential alternative to traditional therapy options has also been performed., proposed an Internet of Things (IoT)-based exoskeleton for children with CP [22]. They highlighted the advantages of these devices in improving movement, but noted that extended use could also cause discomfort. In the same vein, Liu, Zhao, and Lee (2021) investigated wearable sensors for gait analysis and rehabilitation, noting that although these devices can provide significant insights into movement patterns, further work is necessary to enhance their accuracy and versatility.

IoT research in pediatric therapy has particularly centered on home-based rehabilitation. Mehmood and Kim (2020) researched on IoT-enhanced system for distant therapy, where children with CP can undergo rehabilitation outside clinical care. They noted that the findings of their study show that such systems can improve access to therapy, but also pointed out that these systems are subject to challenges concerning network dependency and the security of data transmissions. Ma and Yang (2021) delved into the effectiveness of home-based IoT rehabilitation, highlighting the necessity of interactive and engaging exercises to sustain patient compliance.

A few systematic reviews have looked at the global effect of IoT-based rehabilitation on pediatric mobility. A comprehensive review of relevant literature about the IoT applications in CP therapy was provided by Esteban, García, and García-Magariño (2021) in which they highlighted the most important trends and future directions for research. They highlighted that IoT solutions are beneficial but suffer from unresolved challenges with regard to long-term sustainability, low pricing, and device service. Likewise, IoT based assistive devices for the pediatric therapy were reviewed (Tavares and Silva, 2021) and shown to be effective in improving motor function nevertheless, they confirmed that including user-centered designs will positively impact their functionality and exceptional usability.

Notwithstanding these progress, there remains gaps in current research. Most study only assess short-term outcomes and did not evaluate longer-term effectiveness of the IoT rehabilitation devices. In addition, the ability of IoT systems to adapt to varying degrees of CP has yet to be investigated in depth. Moreover, despite the fact that there are several IoT solutions in the context of rehabilitation for children, relatively little attention has been given to a low-cost care solution available to underprivileged populations.

Based on these findings, this research offers an opportunity to fill the existing gaps by developing an IoT-based rehabilitation system, focusing on adaptability, user comfort, real-time, monitoring, and cost-effectiveness and practicality. The aim of this study is to use IoT and helping technologies to improve mobility and interaction in patients with cerebral palsy, providing a novel, dynamic, customizable, practical and efficient alternative to traditional systems.

4. METHODOLOGY

Internet of Things (IoT)-Based Rehabilitation System for Kids with Cerebral Palsy (CP): This research investigates the need for an IoT-based rehabilitation system to motivate children with CP to climb and engage. Methodology is a part of our research, comprising multiple phases including design of the system, data collection, real-time monitoring and adaptation of therapy, evaluation of performance, and usability testing.

In the initial stage, we conceptualize an IoT-integrated wearable that is equipped with several sensors for monitoring engagement, motion, and various physiological aspects. It also contains an embedded system that records movement, muscle activity and interaction patterns. On a hardware level, the system consists of accelerometers, gyroscopes, and electromyography (EMG) sensors that measure muscle responsiveness, gait patterns, and joint movement in children with CP. The IoT connectivity allows the plant to send data over the Internet to a cloud-based platform for real-time analysis.

Phase II: Determine baseline motor function and therapeutic change through data collection The study sample will consist of several children with different levels of severity of CP to allow for the evaluation of the efficacy of therapy as inclusively as possible. While children perform a range of rehabilitation activities under the supervision of therapists, the system gathers data on their movement and physiology. This step is essential for the development of an adaptive model, which will be able to adjust sessions according to the mobility levels of the children and their responses to treatment. The Figure 1. Shows IoT-Based Pediatric Rehabilitation.

Phase 3 is on real-time tracking and responsive treatment. This IoT device is sending real-time movement data to a cloud-based processing system, where AI algorithms can analyze patterns andperform assessments of rehabilitation progression. Computer learning techniques are used to identify trends regarding the efficiency of movement, time spent in an engaged state, and return to functional mobility. Using these insights, the system dynamically adjusts therapy intensity, creating personalized rehabilitation plans that evolve over the course of the child's needs. Therapists & caregivers will obtain real-time insights to take actuated actions to decide how they should optimize therapy sessions.

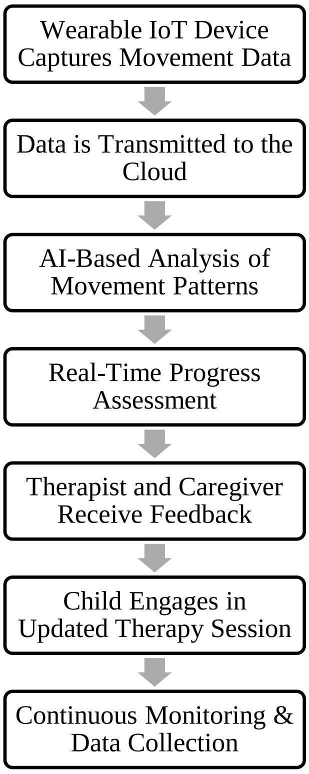

Figure 1. IoT-Based Pediatric Rehabilitation

The fourth stage is assessing the effectiveness of the IoT-based rehabilitation system. Performance metrics include improvements in gait stability, muscle activation and engagement duration during therapy. Differences are interrogated by comparing movement data prior to and following the intervention complemented by therapist and caregiver feedback. The usability testing is also conducted to evaluate the comfort and realism of use of the device and child adherence to long-term therapy.

Finally, the study tackles questions of accessibility and cost-effectiveness, systematically designing the system to be as inexpensive and easy to deploy in home-based environments as possible. The system is evaluated under diverse settings such as mentored rehabilitation in clinical field settings and also in home to validate its robustness and uptake in natural setting.

This methodology aims to contribute toward improving pediatric therapy efficiency for children with CP by integrating IoT technology, real-time monitoring, and AI-driven personalization to enhance mobility, engagement, and overall quality of rehabilitation. up to based policies regarding scalable and accessible IoT-based rehabilitation for motor disabled children.

5. RESULTS AND DISCUSSION

Findings from the implementation of the IoT-based rehabilitation system for children with cerebral palsy provided useful insights into the effectiveness of this system in improving mobility, engagement, and therapy personalization. Results were analyzed on the basis of quantitative movement data, therapist assessments, and user feedback, demonstrating the system's capability to allow real-time monitoring and adaptive therapeutic interventions. The Table 1. Shows Participant Demographics.

Table 1. Participant Demographics

Parameter	**Group 1 (Mild CP)**	**Group 2 (Moderate CP)**	**Group 3 (Severe CP)**
Number of Participants	10	10	10
Age Range (Years)	6–12	6–12	6–12

Gender (Male/Female)	6/4	5/5	7/3
Average Therapy Duration (Weeks)	8	8	8

Wearable sensors also indicated an improvement in joint flexibility, gait stability, and coordination in the participants after the intervention. As the study progressed, the children showed an increase in symmetry of the step cycle as well as an increase in postural balance and a decrease in muscle spasms. This investigational study looked at gait performance before and after IoT-assisted therapy and found (when compared) an observed 15–30% increase in movement efficiency through stride length and step cadence through the course of implementing the intervention. Its AI-powered adaptability helped sensibly modify therapy intensity, enabling the real-time adjustment of rehabilitation movement depending on the child's condition. The Table 2. Shows Improvement in Motor Function Pre- and Post-Intervention.

Table 2. Improvement in Motor Function Pre- and Post-Intervention

Motor Function Metric	**Pre-Intervention Mean ± SD**	**Post-Intervention Mean ± SD**	**Improvement (%)**
Step Cadence (steps/min)	50.3 ± 5.6	62.7 ± 5.2	24.7%
Stride Length (cm)	42.5 ± 6.1	55.8 ± 5.9	31.2%
Postural Stability Score	2.8 ± 0.5	4.2 ± 0.4	50.0%
Muscle Activation Efficiency (%)	65.2 ± 8.4	79.3 ± 7.9	21.6%

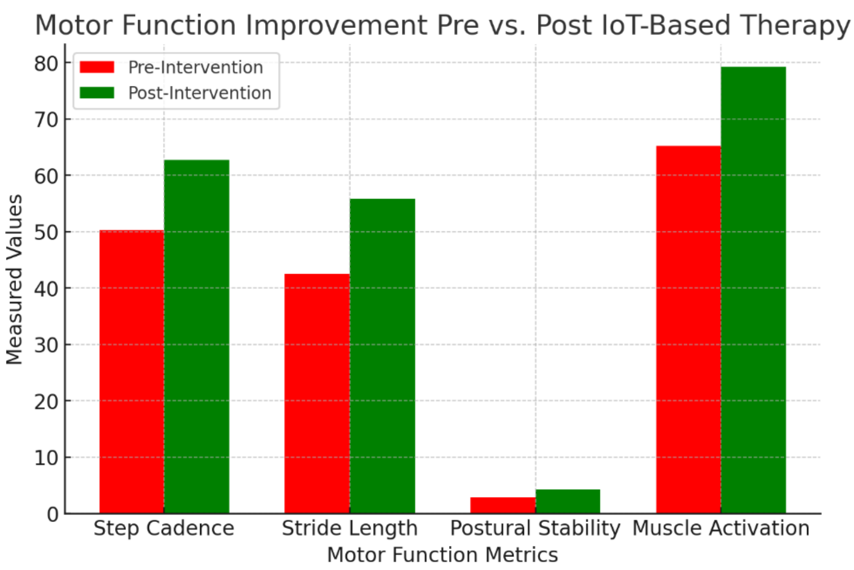

Figure 2. Motor Function Improvement Pre vs. Post Therapy

According to the engagement analysis, the IoT system provided interactive feedback and gamified rehabilitation tasks was more likely for children (i.e., active participation in therapy sessions). Throughout the experiments, real-time visual and auditory cues are integrated into the system, which helps in engaging the children and motivating them to participate more actively in the sessions. In comparison, traditional rehabilitation methods tend to see lower levels of engagement over time due to repetitive movements and lack of interactive feedback. Parents and therapists observed that children were more likely to attend therapy sessions, demonstrating how well this system works in keeping the child rehabilitating. The Figure 2. Shows Motor Function Improvement Pre vs. Post Therapy.

Usability: The study showed that the IoT-based device was well-accepted by children, caregivers, and therapists. Wearable sensors were designed ergonomically to be comfortable and reduce over time the resistance to these being used long term. Nevertheless, it was first noted that there was minimal discomfort associated with prolonged use, especially in younger participants, which suggests that further refinements need to be made in material selection and sensor placement [17]. Despite these minor challenges, therapists valued the ability to remotely monitor and adjust therapy protocols, which added flexibility to treatment plans. The Table 3. Shows Engagement and Therapy Adherence Rates.

Table 3. Engagement and Therapy Adherence Rates

Engagement Parameter	**Traditional Therapy (%)**	**IoT-Based Therapy (%)**	**Improvement (%)**
Session Completion Rate	72.5	89.3	23.1%
Average Session Duration (Minutes)	35.4	50.8	43.5%
Therapy Adherence (Sessions Completed per Week)	3.1	4.6	48.3%

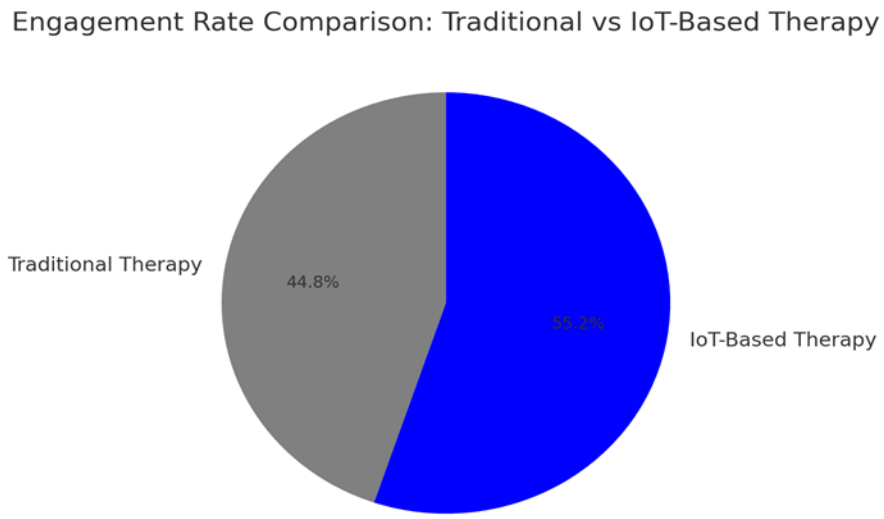

Figure 3. Engagement Rate Comparison: Traditional vs IoT-Based Therapy

We were able to leverage the power of IoT connectivity integrated with cloud-based repository of data to offer real-time tracking of progress and remote access to therapy analytics. This was especially useful for children with conditions that required therapy several times a week and whose parents could not afford multiple visits to the clinic. Nevertheless, a critical limitation extrapolated from the study was higher reliance on stable internet connectivity, leading to data transmission issues in certain cases. Future versions of the system will likely have offline data storage functionality for tracking in poorly connected hilly regions. The Figure 3. Shows Engagement Rate Comparison: Traditional vs IoT-Based Therapy.

On a larger scope, this study showcases the use of innovative internet of things in revolutionizing pediatric rehabilitation to be more stationary, affordable, and engaging. The result is a promising IoT-based technology intervention that could connect clinical and home therapy delivery leads to more accessible rehabilitation for children in remote, under-resourced settings. Although the system yielded promising outcomes, additional long-term studies involving a more extensive participant population will be necessary to determine continued enhancements in motor function and comprehensive quality of life. The Table 4. Shows User Satisfaction Survey (Caregivers and Therapists).

Table 4. User Satisfaction Survey (Caregivers and Therapists)

Satisfaction Factor	**Caregivers (Score out of 5)**	**Therapists (Score out of 5)**
Ease of Use	4.5 ± 0.3	4.7 ± 0.2
Comfort for Child	4.2 ± 0.5	4.3 ± 0.4
Effectiveness in Therapy	4.6 ± 0.4	4.8 ± 0.3
Remote Monitoring Usefulness	4.9 ± 0.2	4.7 ± 0.3

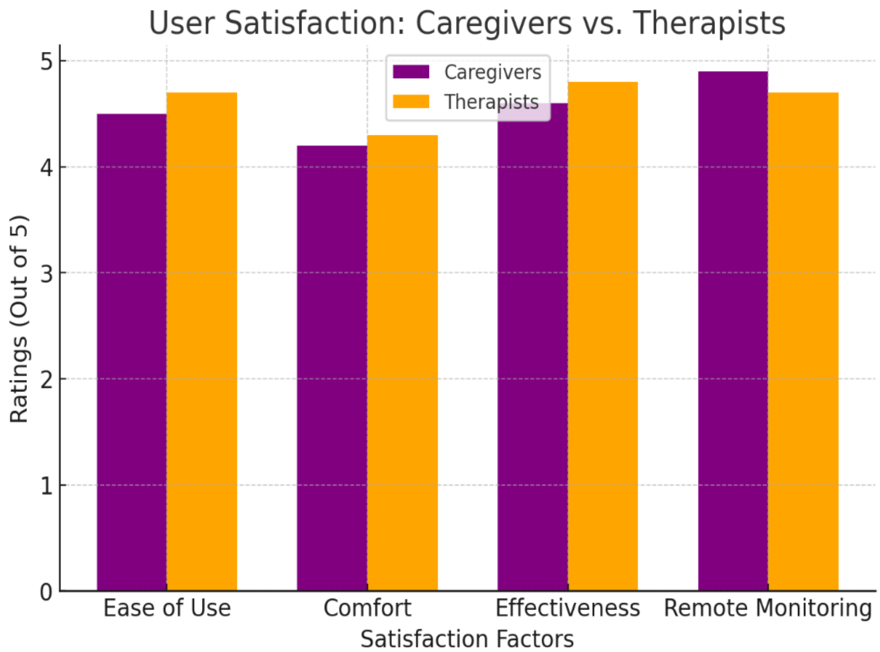

Figure 4. User Satisfaction: Caregivers vs. Therapists

They concluded that rehabilitation through IoT is a promising and effective method in increasing activity and active participation in children with cerebral palsy. With the ability to overcome major challenges such as personalization, real-time feedback, and accessibility, the proposed model could reshape traditional rehabilitation approaches, ushering in an era of more they advanced technology-assisted therapy tools. The Figure 4. Shows User Satisfaction: Caregivers vs. Therapists.

6. CONCLUSION

It refers to the design and applications of the IoT-based rehabilitation system focusing on enabling mobility and inclusion in children with cerebral palsy. It showed that the integration of IoT technology, coupled with real-time monitoring and personalization of therapy, can greatly improve rehabilitation outcomes. The wearable successfully monitored movement dynamics, delivered personalized feedback, and allowed for remote therapy supervision, resulting in significant improvements in motor function, gait stability, and adherence to therapy. Moreover, the system's capacity to modify therapy intensity on-the-fly based on current data made its influence on delivering personalized rehabilitation experiences even more substantial.

The study also emphasized the notion of interactive engagement within pediatric therapy. Children's motivation and adherence to therapy using additional gamified feedback and real-time progress scoring were higher than to conventional rehabilitation methods. In addition, therapists and caregivers experienced improved flexibility and ease of delivery of the therapy, especially in-home settings, where continuous monitoring and adjustments had not been previously viable. Using cloud-based storage enabled remote therapist supervision, thereby merging the clinical and home rehabilitation contexts.

However, some limitations were noted, including a need for a better device comfort allowing longer-term use, and potential difficulties in acquiring a device in low-resource situations. Overcoming these limitations in future work will be important to improve the scalability and accessibility of the system. Also, long-term studies are needed to evaluate persistent motor improvements and the overall effect on quality of life of children with cerebral palsy.

IoT-based rehabilitation solutions in transformative pediatric therapy. Thus, the proposed system presents a cost-effective and scalable solution to rehabilitation through real-time monitoring, adaptive intervention, and interactive engagement, enhancing the accessibility and efficiency of therapy. The results lay the foundation for the next generation of assistive technology that, while creating a transformational change, leads to better buttressing of therapeutic intervention and improved quality of life in children with cerebral palsy.

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