FINAL YEAR DESIGN PROJECT PROPOSAL

Wearable Robotic Trainer with AI-based Adaptive Motivation for Pediatric Gait Rehabilitation

Submitted By

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1. Introduction

The inspiration for this project originated from a first-hand observation of the challenges faced by physiotherapists while training children with motor and gait delays. These therapeutic sessions, though vital, often place a significant physical and mental burden on the therapists and can struggle to maintain a child's engagement and active participation. This firsthand insight led to the central idea of designing a "robotic trainer" that could serve as an effective assistive tool, thereby alleviating the load on therapists and enhancing treatment effectiveness for children.

This project, titled "Wearable Robotic Trainer with AI-based Adaptive Motivation for Pediatric Gait Rehabilitation," aims to address these critical limitations by seamlessly integrating modern technology into a single device. The proposed solution leverages a sophisticated electronic control system to provide precise support from a wearable lower-limb exoskeleton. A key innovation is the inclusion of a two-phase control strategy. In the second phase, the system uses EMG sensors to detect the child's movement intent, providing assistive support only when needed. This approach promotes the child's active participation and builds muscle memory. Furthermore, an adaptive motivational system that utilizes advanced artificial intelligence generates personalized, encouraging feedback and visual cues in real-time, transforming a potentially tedious therapy session into an engaging and enjoyable experience for the child.

Ultimately, this project represents a shift from traditional rehabilitation methods to a smart, automated solution, designed to actively foster a child's participation and improve long-term treatment outcomes.

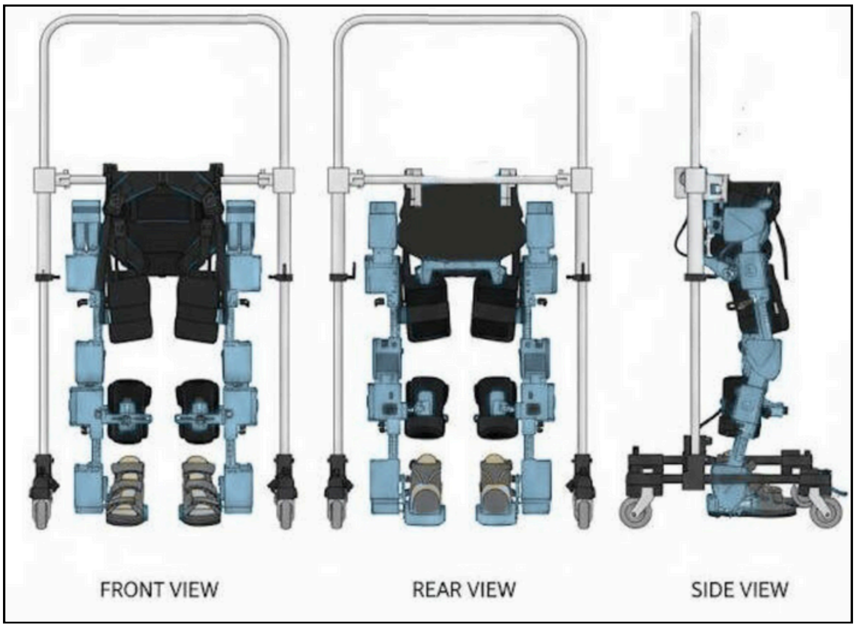

Figure 1: Proposed Design of the Device

2. Literature Review

The field of pediatric gait rehabilitation devices has witnessed significant progress. However, despite these advancements, several challenges still limit their long-term effectiveness and widespread adoption. These challenges include the high global prevalence of motor impairments in children, the critical need for early intervention, and a growing shortage of qualified pediatric physical therapists. The following studies highlight the state of the art and the persisting gaps.

2.1 Global Prevalence of Motor Impairments

- **W**orld Health Organization (WHO) and UNICEF. (2023). Global report on children with disabilities.

This report shows that motor impairments in children are a widespread global issue, affecting millions of children worldwide. These statistics confirm the urgent need for innovative and effective solutions that can be made accessible to children with these conditions, which justifies the importance of our project in providing an accessible solution.

2.2 The Critical Importance of Early Intervention

- Centers for Disease Control and Prevention (CDC). (2025). The Importance of Early Intervention for Motor Skills Development.
- C. V. S. C. S. K. A. V. R. A. S. S. N. O. M. G. A. A. G. O. M. I. K. M. A. F. A. D. C. A. C. B. F. A. H. (2025). The Effects of Early Robot-Assisted Therapy on Gross Motor Function in Children With Cerebral Palsy: A Randomized Controlled Trial. Developmental Medicine & Child Neurology.

These studies highlights that early intervention at a young age is crucial for improving treatment outcomes and the development of motor skills in children with disabilities. This aligns with our project's goal of providing a system that can be used effectively in very early stages, enhancing a child's mobility and independence.

2.3 Therapist Shortage and High Demand

- American Physical Therapy Association (APTA). (2025). PTJ: New Workforce Forecast Projects PT Shortages Through 2037.

This document confirms the projected and ongoing shortage of physical therapists, which poses a significant challenge to providing intensive, one-on-one therapy for children with disabilities. Our project offers a solution to this problem by providing a tool that can support existing therapists and expand the scope of treatment without requiring significant additional human resources.

2.4 The Effectiveness of Robotic Therapy

- **J**. Y. Choi et al., (2024). Overground Gait Training With a Wearable Robot in Children With Cerebral Palsy.
- A. A. A. S. A. G. G. P. M. F. (2024). Robotic devices for gait rehabilitation in children: a systematic review and meta-analysis of clinical effectiveness. European Journal of Physical and Rehabilitation Medicine.

These studies collectively provide strong evidence for the effectiveness of robotic gait training. The work by Choi et al. demonstrates a clear improvement in walking ability, while the systematic review by A.A.A.S.A. et al. confirms that robotic devices offer superior outcomes compared to traditional methods. This research reinforces our project's foundation and its potential for significant clinical benefits.

2.5 The Gap in Structured Training Protocols

- C. Bayón et al., (2018). A robot-based gait training therapy for pediatric population with cerebral palsy.
- S. K. K. P. H. S. (2025). Rehabilitation protocols for robotic gait training in children with movement disorders: a systematic review of clinical trials. Journal of Pediatric Rehabilitation.

These studies collectively highlight a critical gap between the technical effectiveness of existing robotic systems and their practical clinical application. The work by Bayón et al. emphasizes that robotic systems must be accompanied by structured and systematic training protocols. Building on this, the systematic review by S.K.K.P.H.S. demonstrates that a lack of standardized training protocols is a major barrier to the widespread adoption of robotic devices in clinical practice. This research validates our project's goal of developing a systematic training protocol that ensures consistent and effective therapy outcomes.

2.6 Challenges in Exoskeleton Design

- J. Pacheco-Chérrez et al., (2025). Recent Advances in Pediatric Wearable Lower-Limb Exoskeletons for Gait Rehabilitation: A Systematic Review.
- S. F. S. (2024). Human-Robot Interaction and the Design of Pediatric Rehabilitation Exoskeletons. Journal of NeuroEngineering and Rehabilitation.

These studies confirm that a critical gap exists in current exoskeleton design regarding interactive and motivational components. This research reinforces the importance of our project's focus on a psychologically engaging, AI-based system to enhance a child's engagement and adherence to therapy.

3. Research Gap & Motivation

Research Gap

Based on the literature review, the following gaps remain in current pediatric gait rehabilitation devices:

- There is a significant global prevalence of motor impairments in children (WHO & UNICEF), but the availability of qualified pediatric physical therapists to provide intensive, one-on-one therapy is limited (APTA).
- Many solutions do not offer a gradual progression of support, starting with full assistance for non-ambulatory children and transitioning to an "assist-as-needed" strategy as the child's capabilities improve. This limitation hinders the development of independent movement, despite the proven importance of early intervention (CDC).
- Most existing systems lack intelligent motivational components, which are crucial for maintaining children's engagement during therapy and ensuring positive long-term outcomes (Pacheco-Chérrez et al.).
- There is a critical absence of systematic training protocols to guide the practical use of robotic systems, leaving a gap between technical effectiveness and clinical application (Bayón et al.).

These limitations reduce the effectiveness and accessibility of gait rehabilitation for children. Therefore, developing a solution that is technologically advanced, clinically guided, and motivating is essential. This project aims to improve treatment outcomes and enhance the quality of life for children by addressing these unmet needs.

Motivation

The motivation for this project was born from an emotional connection developed after watching inspiring videos of physical therapists working with children on social media platforms. Witnessing the dedication of these professionals in helping children walk moved us to consider how engineering could provide a supportive solution. This led us to delve deeper into pediatric physical therapy, recognizing a pressing need for innovative engineering tools that could enhance therapeutic effectiveness and provide continuous support. This project is our attempt to blend technology with humanistic care, with the ultimate goal of making a tangible difference in the lives of these children.

4. Problem Statement

The high global prevalence of motor impairments in children, coupled with a limited number of qualified therapists, has created a critical need for effective and scalable rehabilitation solutions. Existing technologies often fail to provide the continuous, adaptive support and motivational components necessary for a child's active participation and long-term therapeutic engagement. This project addresses this unmet need by developing a wearable robotic trainer that combines precise "assist-as-needed" support with an AI-based motivational system, aiming to improve the accessibility and effectiveness of pediatric gait rehabilitation.

5. Objectives of FYDP

- Customize and integrate the actuation system (servo motors, sensors) into a wearable exoskeleton structure designed for a child around three years of age. This objective focuses on developing a system tailored for early intervention, crucial for maximizing long-term functional gains.
- Develop and integrate a comprehensive control system using a Raspberry Pi 4 to precisely manage two distinct training modes: a full-support mode and an "assist-as-needed" mode, to facilitate intensive physical therapy sessions. This approach aligns with the principle of intensive rehabilitation, which is considered the most effective method for this population.
- Integrate a unified sensing system using EMG sensors and load cells to accurately detect a child's movement intent and weight-bearing, enabling precise control for the "assist-as-needed" strategy.
- Create an AI-based interactive motivation system that uses a display and speaker to provide personalized, real-time encouragement to the child during therapy sessions.
- Design and develop a user interface (UI) for the therapist, allowing them to configure training parameters and monitor the child's performance and progress accurately.

6. Societal and Industrial Impact

Our project is more than just a technical solution; it aims to create a tangible and positive impact on society and industry. By addressing key challenges in pediatric rehabilitation, our project contributes to the following United Nations Sustainable Development Goals (SDGs):

Sustainable Development Goal		Impact on Society and Industry
SDG 3	Good Health and Well-Being	Our project contributes to this goal by providing an effective and innovative rehabilitation tool for children with motor impairments. It enhances their mobility and improves their quality of life through a therapy program that is specifically designed to meet their needs.
SDG 9	Industry, Innovation, and Infrastructure	This project represents a model of technological innovation in the healthcare sector. By integrating exoskeleton, artificial intelligence, and an interactive control system into a single device, we contribute to building new and innovative infrastructure in the field of pediatric rehabilitation.
SDG 8	Decent Work and Economic Growth	Our project offers a practical solution to support physical therapists, which increases their efficiency and helps them provide treatment to a larger number of patients. This contributes to the growth of the healthcare sector and creates opportunities for more effective and sustainable work.

7. Project Development Methodology

The development of our project will follow a systematic and phased approach to ensure all components are thoroughly designed, developed, and tested before final integration. This methodology is divided into three main phases, which will be executed concurrently where possible, as detailed in our accompanying Gantt chart.

7.1 Phase 1: Design and Hardware Procurement

This initial phase focuses on the foundational work. We will finalize the mechanical design of the exoskeleton, ensuring it is age-appropriate and safely accommodates a child. Concurrently, we will procure all necessary hardware components, including the Raspberry Pi 4, servo motors, EMG sensors, and load cells.

- Finalize the mechanical design of the exoskeleton frame.
- Source and purchase all electronic and mechanical components.
- Perform initial assembly and calibration of the hardware.

7.2 Phase 2: Component Development and Programming

Once the hardware is procured, this phase will begin with a modular approach. We will develop the core software and hardware components independently to streamline the process and allow for parallel work within the team.

- Core Control System: Program the Raspberry Pi 4 to manage motor control and acquire real-time data from all sensors. This initial stage will focus on developing the foundational code for the full-support mode.
- User Interface (UI) Development: A custom graphical user interface will be designed and coded to provide the therapist with a dashboard. We plan to use Python and the Flask framework to build this interface, allowing them to configure training parameters, monitor real-time data from the sensors, and track the child's progress over time.
- AI & Motivational System Development: The logic for the AI-based system will be developed to create a dynamic and engaging user experience. For audio feedback, we will use an AI text-to-speech tool to generate motivational text in real-time based on the child's performance and convert it to speech. For visual feedback, we will create a library of pre-designed animation files (e.g., happy, excited, surprised). The AI will then select and display the most appropriate animation on the screen based on the child's current progress.

7.3 Phase 3: System Integration and Final Testing

This final and critical phase will combine all developed components into a cohesive, functional unit. We will then conduct rigorous testing to ensure the system performs as expected in a simulated therapeutic environment.

- Integrate all hardware and software components into the final prototype.
- Implement the "assist-as-needed" control strategy, fine-tuning the algorithms to process real-time sensor data from the EMG and load cells.
- Conduct comprehensive system testing to validate functionality, safety, and performance, ensuring the system meets all our core objectives.

This methodical approach ensures a robust final product that is not only functional but also aligned with our core objectives and the principles of effective pediatric rehabilitation.

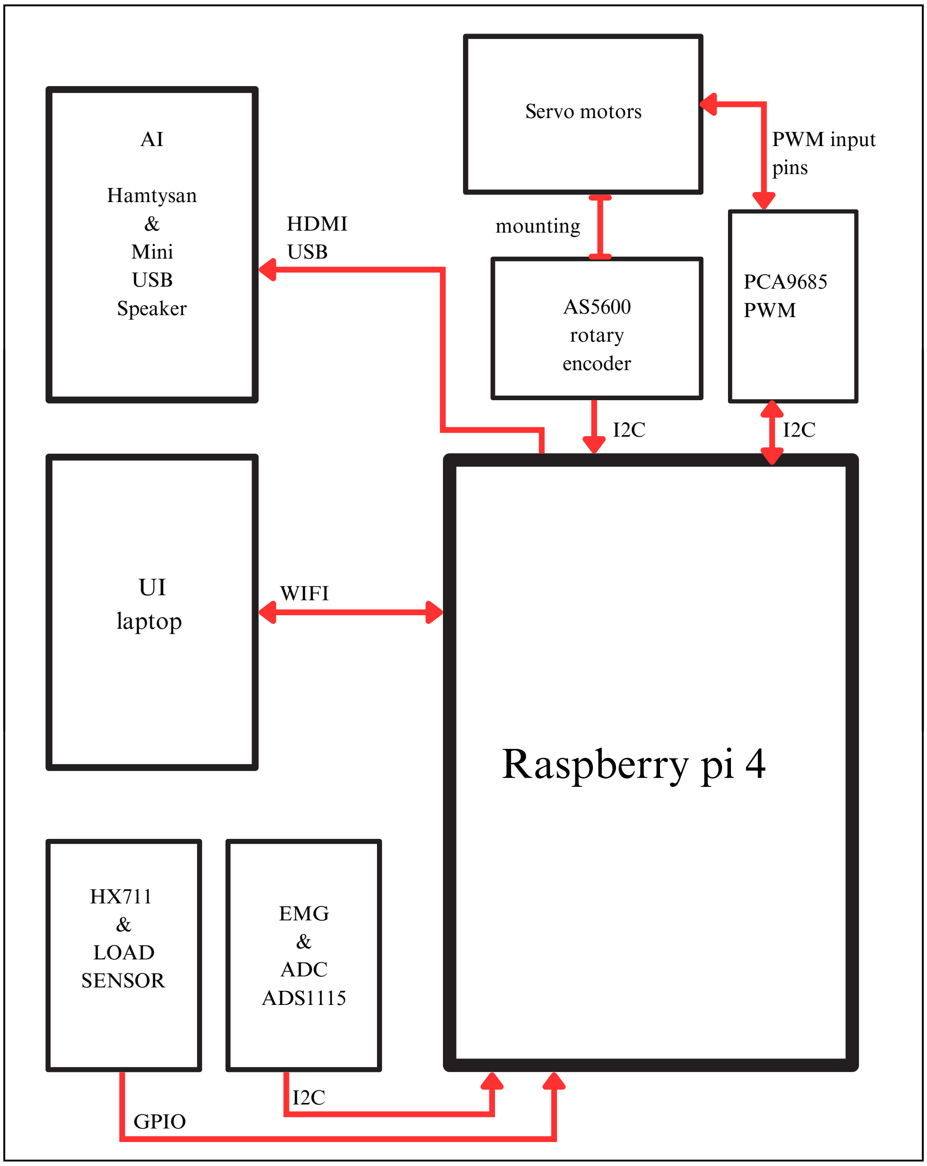

Figure 2: block diagram of the proposed complete system.

8. Implementation

Our proposed system is composed of several key components that work together in a cohesive manner to provide an effective rehabilitation experience for both the child and the therapist. The block diagram below illustrates the connectivity and data flow between these components.

8.1 Key Components (Hardware and Software)

- Main Controller: The Raspberry Pi 4 serves as the central processing unit, handling data from all sensors and sending control commands to the motors.
- Sensing System:
  - EMG Sensors: These are used to detect a child's movement intent. They are connected to an ADS1115 analog-to-digital converter to transform signals into a format the Raspberry Pi can process.
  - Load Cells: Connected to HX711 units, these measure the weight the child places on the device, which is crucial for implementing the "assist-as-needed" strategy.
  - Rotary Encoder (AS5600): Used to precisely measure the angles of the knee, hip, and ankle joints, allowing for accurate tracking of the child's movement.
- Actuation System: The servo motors are controlled by a PCA9685 PWM controller, which receives commands from the Raspberry Pi. The system includes 6 servo motors of various sizes (RDS5180, RDS5150, and DS3225) to provide the necessary force and precision for each joint.
- User Interface (UI): A custom web interface for the therapist will be built using Python and the Flask framework, enabling them to easily configure exercises and monitor the data.
- Motivational System: The system includes a Hamtysan 7-inch screen and a speaker. An Azure AI Text-to-Speech API will be used to generate real-time audio encouragement, while pre-designed visual animations will be displayed to provide feedback and motivate the child.

8.2 Mechanism of Action

The system provides two intensive therapeutic protocols, specifically designed for two different patient groups, based on the principles of CME (Cuevas Medek Exercises):

Group 1: Walking & Muscle Power (d450, b730)

- Phase 1: The exercise begins with 100% partial body weight support (PBWS), with a limited range of motion and a slow gait speed. Here, the robot provides full support to ensure a safe and controlled movement for the child.

- Phase 2: The partial body weight support (PBWS) is reduced, with an increased range of motion (ROM). The "assist-as-needed" strategy is activated here, where the robot provides support only when necessary, which fosters the child's independent movement.

Group 2: Joint Mobility, Endurance & Stability (b710, b740, b715)

- Phase 1: Full PBWS is provided during fixed and specific exercises, such as high-knee lifts. The range of motion is small, and the duration is short.
- Phase 2: The partial body weight support (PBWS) is reduced, with an increased range of motion and duration. Here, the child is encouraged to maintain their stability with less assistance from the robot.

The motivational system operates continuously in both protocols. The AI processes real-time sensor data to evaluate the child's performance. Based on this evaluation, two decisions are made:

- Auditory Motivation: An AI tool generates custom motivational text (e.g., "Good job!" or "You are strong!") , which is then converted into speech to be heard by the child.
- Visual Motivation: The AI selects from a pre-designed library of animations (e.g., a smiling face or a celebration icon) to display on the screen, providing positive visual reinforcement that corresponds with the child's performance.

9. Project Milestones, Timelines and Deliverables

	Milestone/ Deliverable	Timeline									
		Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Phase 1	Design,Procurement & Assembly										
Phase 2	Core Component Programming										
	UI & AI Development										
Phase 3	System Integration										
	Adaptive Control Implementation										
	Final System Testing										
	Final Report & Presentation										

10. Estimated Project Cost

Component	Quantity	Unit Price (Rs.)	Total (Rs.)
ADS1115	1	800	800
AS5600	6	200	1200
PCA9685	1	750	750
EMG Sensor	1	4000	4000
HX711 + Load Sensor	2	510	1200
Hamtysan Screen	1	15,651	15,651
RDS5180 Servo (60 kg)	2	4252.5	8,505
RDS5150 Servo (150 kg)	2	5,950	11,900
DS3225 Servo (25 kg)	2	1,425	2,850
Raspberry Pi 4	1	19,400	19,400
Total Estimated Cost			**95,330**

11. Annex A. Complex Engineering Activities (CEA attributes)

CEA Attribute		Project Relevance
EA3	Innovation	Our project demands a creative application of engineering principles and research-based knowledge to generate a new or improved solution. Our system's innovative approach combines a sophisticated electronic control system, and an AI-based adaptive motivational system into a single, cohesive device, which addresses significant gaps identified in the existing literature.
EA4	Consequences to Society & Environment	The outcomes of our project have significant positive consequences for society. By improving the accessibility and effectiveness of pediatric gait rehabilitation, our solution will directly enhance the quality of life for children with motor impairments and their families. It addresses a critical healthcare need and contributes to sustainable and ethical healthcare solutions.
EA1	Range of Resources	This project involves the management and use of diverse and significant resources, including financial resources (budget), technical resources (sensors, motors, and controllers), informational resources (research papers and scientific literature), and human resources (the project team).
EA2	Level of Interaction	The project requires addressing multiple, often conflicting, requirements. This includes balancing the cost of components against the required performance and interacting with various stakeholders, such as the supervisor and potential users, to resolve technical and functional trade-offs.
EA5	Familiarity	Our project extends beyond routine engineering practice. It requires the application of fundamental principles of programming, and artificial intelligence in an unfamiliar and specific context: the development of a wearable robotic device designed for pediatric rehabilitation.

12. References

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13. Comments of the Supervisor

I have carefully reviewed this proposal and find the objectives and scope appropriate. I hereby approve the document for submission as part of the Final Year Design Project

Name of Supervisor: Dr. Muhammad Bilal

Signaturesr: