Envisioned System Behavior

Introduction This document outlines the envisioned operation of the wearable robotic trainer designed for gait rehabilitation in children with motor delays. It describes how we imagine the system will function in real-life use, including its response to the child's movement, the interaction between sensors and actuators, and the overall flow of control. This draft represents our current understanding and goals regarding how each component should behave and interact to ensure smooth, safe, and effective operation.

**For clarity, all new updates and design modifications are presented in blue text.

AI-Based Interactive Motivation System

To make the rehabilitation process more engaging for children, we will integrate a small interactive display and a USB-powered speaker connected to the Raspberry Pi. The system will use ChatGPT to generate short, friendly, and encouraging phrases based on the child's progress, along with selecting a suitable facial animation from a preloaded set of animations stored on the Raspberry Pi.

The Raspberry Pi will then:

- Display the selected facial animation on the screen.
- Convert the generated text into speech using a text-to-speech engine and play it through the USB mini speaker.

This setup allows ChatGPT to act as a friendly "digital coach" that reacts to different training events for example, walking a certain number of steps or completing an exercise by choosing both an appropriate expression and an encouraging phrase. The Raspberry Pi handles all display and audio playback tasks, while the AI only controls these motivational features and does not interact with or control the robotic hardware.

User Interface and System Initialization At the beginning of each session, the system is controlled through a user interface (UI) accessed from a laptop. This interface is operated by the therapist or trainer supervising the child's rehabilitation process. The main screen displays a list of all registered children who have previously used the device. For each child, the system shows their last completed training session, the selected mode, and whether the session was completed successfully. Before starting a new session, the therapist is prompted to input the following:

1. Child's Name
2. Training Phase – Phase 1 (full assistance) or Phase 2 (responsive assistance)
3. Exercise Type – Static (balance training) or Walking
4. Training Duration – Number of steps (for walking) or number of minutes (for static)
5. Support Level – Percentage of the child's weight that the robot should support. In Phase 1, the robot is expected to carry nearly 100% of the child's weight.

Once the parameters are set, the therapist can start or stop the session using dedicated Start and Stop buttons on the interface.

During the session, the UI continuously displays real-time data, including:

- Selected Exercise Type, Phase, and Duration
- Sensor Readings such as:
  - Load Cell – shows how much weight the child is bearing
  - EMG Sensor (Phase 2 only) – detects whether the child is initiating any movement
  - Rotary Encoders – provide joint angle data from the servo motors

This feedback helps the therapist monitor the child's participation and response, and evaluate the effectiveness of the session in real time.

Phase 1: Walking Exercise – Full Robotic Assistance

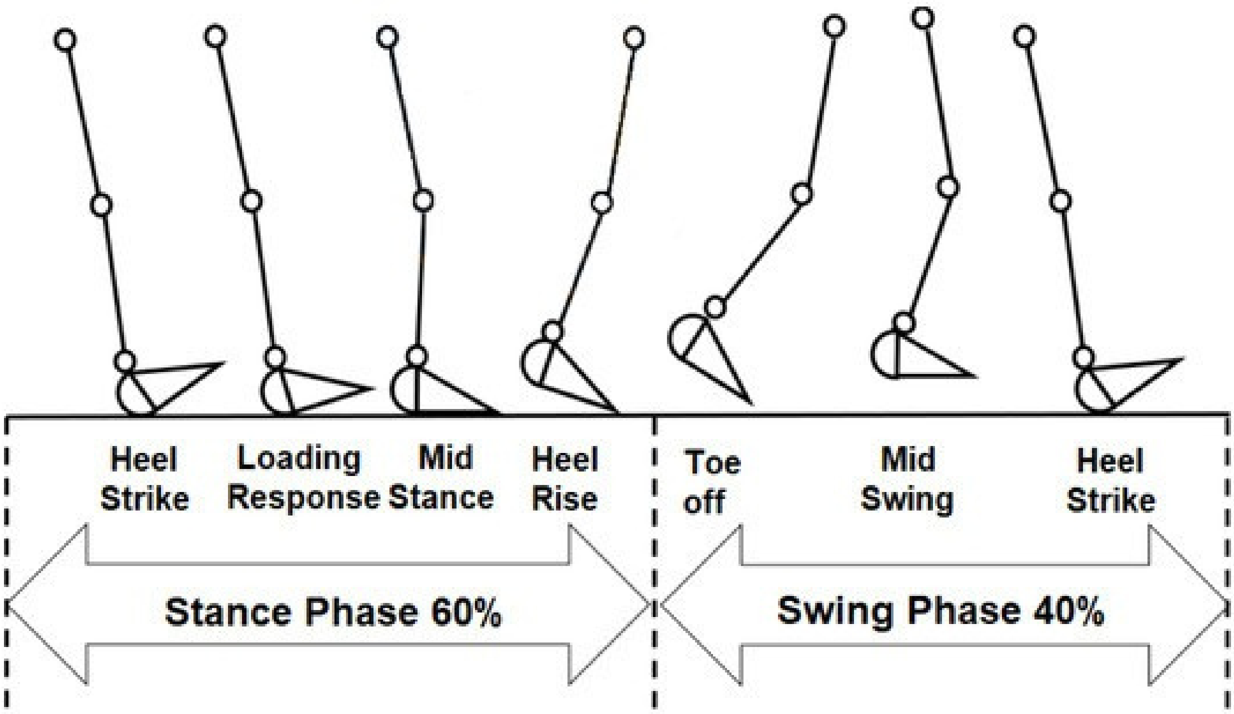
If the therapist selects Phase 1 with Walking as the exercise type, the robot will take full control of the child’s movement and body weight support.

In this phase, the robot lifts the child completely by the hips using a dedicated support harness attached to the robotic frame, similar to a child swing. This ensures the child is fully suspended, eliminating any load on the legs. To confirm that the child is no longer bearing any weight, feedback from the load cell sensors is continuously monitored.

Once the system verifies that the child is fully supported, the walking exercise begins. The robot initiates a series of gait cycles, corresponding to the number of steps previously entered by the therapist through the user interface.

A gait cycle represents one complete walking motion (from heel strike to the next heel strike of the same foot). The robot executes these cycles by driving the servo motors at the hips, knees, and ankles through predefined joint angle sequences that simulate natural walking. Each joint angle is carefully coordinated to ensure smooth and realistic movement.

These motion sequences are based on well-established scientific models of human gait, which have been studied and reviewed. The robot's firmware uses these models to control joint positions at every stage of the gait cycle, ensuring safe and biomechanically accurate walking patterns for the child.



Phase 1: Static Exercise (Ex: High Knees Training)

If the therapist selects Phase 1 with Static Exercise as the training type, the robot will assist the child in performing isolated leg movements while keeping the rest of the body stable. One example of this is the High Knees exercise, which focuses on lifting the knees alternately to a target height. Once the parameters are entered and the therapist presses the Start button, the robot ensures the child is fully supported in the harness, lifting the body weight through the hip attachment. This guarantees that the child does not bear any load during the exercise, as verified by the load cell sensors.

The robot then begins raising and lowering each knee alternately in a repeated motion, simulating the high knees movement. This helps strengthen the child's hip and thigh muscles, and improves balance and body awareness while being fully supported.

Throughout the session, the robot:

- Executes controlled and rhythmic lifting using the hip and knee joint actuators
- Monitors the system for safety and stability
- Tracks the number of completed repetitions
- Records whether the child completed the session or not
- Saves performance data such as movement accuracy, session duration, and load sensor readings for future review

This data allows the therapist to monitor progress over time and make adjustments to the training intensity or support level as needed.

Phase 2: Responsive Assistance Based on Child's Movement In Phase 2, the robot remains inactive until it detects an intentional movement initiated by the child. If walking is selected as the exercise type, the robot will not begin any motion on its own. Instead, it continuously monitors the child's joints using (EMG) sensors attached to the relevant muscle groups controlling the hips, knees, and ankles.When the system receives a valid signal from the EMG sensors—indicating a bending motion—the controller interprets it as the child attempting to initiate a step. The robot then provides a brief assistive push to support the motion and encourage walking. This assistance is time-limited and lasts only a few seconds to promote the child's active participation. To avoid closed-loop feedback errors, EMG sensor readings are temporarily disabled during the robot's assistive motion. This prevents the system from misinterpreting the robot's own movement as a new attempt by the child. Once the assistive action is completed, the EMG sensors are reactivated, and the system returns to its standby mode, waiting for the next voluntary movement. This interactive control strategy ensures that the child remains engaged and actively involved in the training process, while the robot adapts its support based on real-time feedback.

Replacing Flex Sensors with EMG Sensors

In our initial design, flex sensors were used to detect joint movement as an indication of the child's intent to move. We have now decided to replace them with (EMG) sensors. The reasons include:

- EMG sensors can directly measure muscle activation, providing a more accurate signal of movement intent.
- They are easy to integrate and program with the Raspberry Pi when paired with an Analog-to-Digital Converter (ADC), since the Raspberry Pi does not natively read analog inputs.
- This change improves the responsiveness and accuracy of our Phase 2 control strategy.