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Smart Continuous Passive Motion for Hand Rehabilitation

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ABSTRACT

Continuous Passive Motion (CPM) devices are essential tools in post-operative and neurological rehabilitation. This paper presents the design and implementation of a cost-effective, smart CPM device for hand rehabilitation using embedded systems. The device automates passive hand movements through a linear actuator controlled by a Node MCU microcontroller and L298N motor driver. The system is equipped with safety features such as limit switches and a real-time OLED display interface for enhanced usability. Experimental evaluation demonstrates reliable and repeatable motion, making the device suitable for home-based therapy in low-resource settings.

INTRODUCTION

Rehabilitation following hand injuries or surgeries often demands intensive and prolonged therapy to restore functional mobility. Traditional therapist-led therapy is labor-intensive and costly, often limiting its availability in rural or economically constrained regions. Continuous Passive Motion (CPM) devices automate the rehabilitation process, providing repetitive, controlled motion to joints without requiring patient effort. However, commercially available CPM machines are prohibitively expensive and lack adaptability.

This study addresses these limitations by developing a Smart CPM device that is cost-effective, programmable, and portable. By employing an embedded control system, the device enhances therapeutic outcomes while ensuring safety and ease of use, even in non-clinical environments.

Problem Statement

Rehabilitation plays a crucial role in post-surgical recovery, but many patients lack access to affordable and efficient CPM devices due to high costs and outdated manual systems. The existing CPM devices available in the market suffer from the following limitations:

- High Cost – Commercial CPM machines range between ₹50,000 – ₹1,00,000, making them unaffordable for many hospitals and individuals.
- Limited Hand Rehabilitation Devices – Most CPM devices are designed for knee and shoulder therapy, while hand rehabilitation is often ignored.
- Manual Adjustments – Traditional CPM devices lack remote control and require physiotherapists to manually adjust the settings.
- Use of Servo Motors – Many existing devices rely on servo motors, which cause jerky movement, consume more power, and require frequent maintenance.
- Lack of IoT-Based Monitoring – No smart features like mobile app control, real-time therapy adjustments, or remote monitoring are available in traditional CPM machines.

Thus, there is a need for an innovative, cost-effective, and smart rehabilitation solution that ensures smooth motion, user customization, and remote therapy control.

Objectives

This project aims to design and develop a smart, low-cost CPM device specifically for hand rehabilitation, overcoming the challenges of existing systems. The primary objectives are:

- Develop a CPM device using linear actuators to ensure smooth and controlled movement, replacing servo motors.
- Integrate IoT-based control using NodeMCU and the Blynk App to allow remote therapy adjustments.
- Provide adjustable therapy settings (speed, range of motion) to accommodate different patient needs.
- Ensure low power consumption and minimal maintenance, making it suitable for long-term use.
- Make the device affordable and accessible for small clinics, hospitals, and home users.

By achieving these objectives, the Smart CPM Device for Hand Rehabilitation will bridge the gap between cost, accessibility, and technology-driven physiotherapy.

Scope of the Project

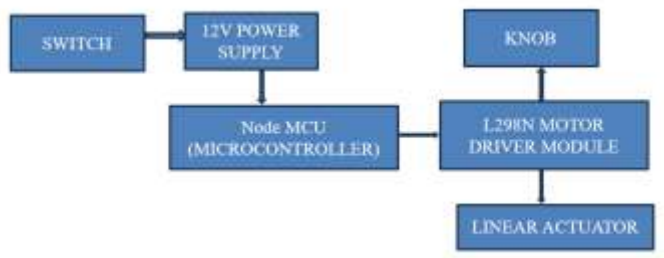
The project is designed to be cost-effective, efficient, and easy to use in both clinical and home settings. The scope of this work includes:

- Designing and fabricating a CPM prototype using linear actuators to provide precise movement.
- Implementing a microcontroller-based control system (NodeMCU ESP8266) for therapy automation.
- Developing a mobile application using Blynk for remote therapy customization.
- Conducting performance tests to evaluate motion smoothness, power efficiency, and therapy effectiveness.
- Comparing the developed device with existing commercial CPM systems to highlight cost-effectiveness and usability.

SYSTEM DESIGN

The proposed Smart CPM device is engineered to move the fingers and wrist in a linear path through controlled extension and retraction. It incorporates:

A NodeMCU ESP8266 microcontroller as the control unit.A 12V linear actuator to provide physical motion.An L298N motor driver for current amplification and motion control.Limit switches for safety boundaries.An OLED display for real-time session monitoring.Manual push buttons for user control.



Working Principle

The system is powered on and initialized by the NodeMCU, which reads preset parameters such as cycle time and motion direction. Upon start command, the microcontroller sends PWM signals to the L298N motor driver, controlling the actuator's movement. Limit switches serve as end-stops to prevent overextension. The OLED display shows current motion status and cycle count.

SYSTEM FLOW

The operational sequence for the therapy device begins with the user powering on the system, which starts the microcontroller and initializes all connected hardware components, such as sensors, the display, and the motor driver. Once initialized, the device displays a default therapy introduction message to guide the user. The user then selects therapy parameters, including the speed of movement, range of motion (ROM), and session duration. With these settings, the microcontroller sends commands to the motor driver to control the linear actuator accordingly. During operation, the system continuously monitors the actuator's motion and makes real-time adjustments if necessary, displaying an error message if a fault is detected. The actuator continues to operate until the session timer expires or the specified duration is reached. Finally, the actuator stops, and the system displays a message confirming the completion of the therapy session.

RESULT

The CPM-based therapy device was successfully designed and implemented to provide controlled, automated motion for rehabilitation purposes. The microcontroller system accurately executed user-defined parameters such as speed, range of motion, and duration. Testing confirmed smooth actuator operation, effective error handling, and consistent therapy delivery. The device demonstrated reliability and user-friendliness

DISCUSSION

The integration of embedded technology in the proposed CPM device demonstrates significant potential in enhancing the accessibility of physical rehabilitation. The use of off-the-shelf components ensures affordability and replicability. While the prototype does not yet incorporate feedback from the patient's muscular response, future work can integrate sensors like EMG or FSR to create adaptive, real-time therapy systems.

CONCLUSION

This paper presents a functional prototype of a Smart CPM device tailored for hand rehabilitation. It bridges the gap between costly hospital-based systems and the need for affordable, home-use therapeutic devices. Through embedded control, user safety mechanisms, and real-time feedback, the device offers a scalable solution for consistent, effective rehabilitation in resource-limited settings.

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