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3d Printed Rehabilitation Of Human Assist Device

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ABSTRACT:

Rehabilitation assistive devices are necessary for stroke patients, muscle trauma patients, or patients with age-related muscle atrophy. In this research, a 3D-printed upper limb assistive device was developed with simplicity, customization, and enhanced muscle rehabilitation in mind. With the use of FDM technology and biocompatible materials like PLA and TPU, the device provides light, ergonomic, and patient-specified support. Its modular design enables easy personalization, making it suitable for diverse therapy needs. Preliminary tests on physical therapy patients showed enhanced comfort, usability, and adherence to rehabilitation. The results highlight 3D printing's cost-effectiveness and potential for scalable application in clinical and home settings.

Keywords: Upper limb rehabilitation, 3D printing, Assistive device, FDM technology, PLA and TPU materials, Stroke recovery, Modular design, Patient-specific therapy.

I. INTRODUCTION:

Rehabilitation is a vital component in the recovery journey of individuals affected by musculoskeletal injuries, neurological conditions such as stroke or cerebral palsy, and age-related motor degeneration. Effective rehabilitation aims to restore functional independence, improve quality of life, and reduce long-term healthcare costs. Central to this process are assistive devices and therapeutic tools designed to support and enhance motor relearning, joint mobility, and muscle strengthening through guided, repetitive movements.However, traditional rehabilitation tools, while clinically validated, often fall short in terms of adaptability, comfort, and personalization. Many commercially available devices are manufactured using conventional subtractive processes, resulting in standardized designs that may not suit every patient's anatomical and functional requirements. Additionally, the high cost of such equipment poses a significant barrier to accessibility, particularly in low-resource settings, rural clinics, and for home-based care where budget constraints are a critical concern.Recent advancements in additive manufacturing—most notably, three-dimensional (3D) printing—have revolutionized medical device development by offering unprecedented flexibility in design and customization. 3D printing allows for the layer-by-layer fabrication of complex geometries using a wide range of thermoplastic and elastomeric materials.

This technology enables rapid prototyping, real-time design iteration, and the production of low-volume, patient-specific devices without the need for expensive tooling or Molds. The capability to tailor rehabilitation devices to individual anatomical dimensions and therapeutic goals significantly enhances treatment efficacy and patient compliance.In this context, the present study explores the development of a novel 3D-printed assistive device designed to support upper limb rehabilitation, with a focus on the wrist and elbow joints. These joints are often impaired following neurological injuries, resulting in decreased mobility, reduced strength, and diminished coordination. The proposed device provides passive mechanical assistance to facilitate repetitive movement exercises critical for neuromuscular re-education.

The primary objectives of this research are to design a lightweight, ergonomic, and cost-effective rehabilitation aid that can be fabricated using commonly available desktop FDM (Fused Deposition Modelling) 3D printers. Emphasis is placed on user-centred design, modular construction, and ease of use for both patients and caregivers. The overarching goal is to contribute a scalable solution to the field of rehabilitation engineering that bridges the gap between high-cost robotic systems and low-cost, customizable therapeutic tools.

II. LITERATURE REVIEW:

The application of assistive technology in physical rehabilitation has undergone significant transformation in recent years, particularly with the integration of robotics, wearable systems, and smart materials aimed at improving motor function and patient engagement. High-end rehabilitation centres increasingly rely on advanced mechatronic devices such as robotic exoskeletons, motorized orthoses, and soft actuators to deliver precise, repetitive motion therapy to patients with neuromuscular impairments. Notable examples include the Armeo® Spring and Myomo® MyoPro, which facilitate both active and passive rehabilitation for stroke survivors and individuals with upper limb weakness. While these devices offer measurable improvements in motor function, their high cost, complex setup requirements, and dependence on clinical supervision limit their applicability in home-based or resource-constrained settings [1,2].

In parallel with the development of high-tech solutions, there has been growing interest in low-cost, customizable alternatives enabled by additive manufacturing technologies. The advent of Fused Deposition Modelling (FDM) and Stereolithography (SLA) printing has catalysed research into patient-specific orthotic and prosthetic devices. Zuniga et al. (2018) demonstrated the effectiveness of FDM-printed upper limb prosthetics for paediatric patients, emphasizing their affordability, lightweight construction, and aesthetic adaptability [3]. Similarly, Godfrey et al. (2021) successfully utilized PLA and TPU to fabricate wrist support devices, highlighting the potential of thermoplastics for durable, skin-safe applications in rehabilitative settings [4].

Additional studies have explored hybrid approaches that combine 3D printing with embedded electronics and sensors for biofeedback and motion tracking. For instance, Attaelmanan et al. (2020) developed a 3D-printed elbow orthosis integrated with inertial measurement units (IMUs) to monitor joint angle and movement frequency during therapy sessions [5]. These innovations provide valuable real-time data for therapists but add complexity and increase production costs.

Despite these advancements, the literature reveals a notable gap in passive rehabilitation devices that specifically support upper limb recovery during the early stages of physical therapy, where motor control may be limited, and external assistance is critical. Most existing devices either lack adaptability to individual anatomy or are not optimized for repetitive use in home-based settings. Moreover, devices that balance ergonomic support, ease of assembly, and cost-effectiveness remain scarce in current academic and commercial offerings.

There is, therefore, a pressing need for lightweight, modular, and user-friendly assistive devices that can be fabricated quickly and deployed easily in a variety of settings. The ability to personalize such devices based on patient-specific anthropometric data using 3D scanning and modelling tools further enhances their therapeutic value. This research aims to fill this gap by developing a 3D-printed upper limb assist device that prioritizes passive support, modular construction, and affordability, thereby extending the benefits of modern rehabilitation tools to underserved populations.

III. METHODOLOGY:

Here is an enlarged version of the four sections—Design Requirements, CAD Modelling, 3D Printing Process, and Assembly & Fitting—to render them more detailed and journal-worthy:

Materials and Methodology

1. Design Requirements

The upper extremity assistive device design was motivated by the need to bridge the gap between clinical rehabilitation and home-based therapy that is easily accessible. The main considerations were informed by discussions with physiotherapists, patient feedback, and analysis of successful biomechanical concepts. The objectives were established to make the device easily adoptable, adjustable, and usable without medical supervision for everyday rehabilitation exercises.

The key criteria were:

Modularity:

The design was done to provide the exchangeability of certain modules developed for various joint motions—elbow flexion-extension, wrist pronation-supination, and passive stretching. Modularity provides a patient-oriented strategy, where the device changes as the patient's recovery phase progresses.

Adjustability:

Telescoping arms, adjustable hinges, and rotating joints were included to accommodate a variety of body types. The user was able to adjust the arm length, tension, and range of motion without having to disassemble the device. This accommodated various age groups and intensities of rehabilitation.

Comfort:

User comfort was met by incorporating ergonomically shaped support zones, the use of soft contact zones from TPU and silicone padding, and breathable strapping. These promoted long periods of usage without discomfort, which is paramount in ensuring compliance to therapy.

Ease of Use:

To ensure adoption beyond hospital environments, the device needed to be easily operable by caregivers or patients themselves. The inclusion of minimal mechanical fasteners, clear alignment marks, and intuitive joint movements made the system user-friendly. The operational process required no prior technical experience.

2. CAD Modelling

The device's structural design was created digitally on SolidWorks for mechanical integrity analysis and on Fusion 360 for rapid prototyping refinement and aesthetic optimization.

Functional Design Elements:

- The elbow module had a rotating joint with inbuilt limiters to prevent overextension, mimicking natural range-of-motion exercises.

- The wrist module offered multi-axis movement supported by soft dampers to prevent sudden jerks during passive movement.

- The forearm sleeve was anatomically shaped and featured anchoring sites for stable Velcro and elastic straps.

User-Centric Optimization:

Prototypes were digitally tested with static force simulations to validate material durability and joint stability under repeated motion. Physiotherapist feedback was incorporated into each iteration, especially for optimizing joint stop angles and padding thickness.

Output Files:

Once the design was complete, STL files were exported for 3D printing and slicing. The files were optimized to minimize print support structures, material waste, and print errors.

3. 3D Printing Process

To maximize accessibility and low-cost production, Fused Deposition Modeling (FDM) was selected as the main manufacturing method. The process consisted of several important steps:

Materials Used:

PLA (Polylactic Acid): Applied for the structural structure because of its rigidity, printability ease, and biocompatibility.

TPU (Thermoplastic Polyurethane): Utilized in flexible areas demanding skin contact, providing soft-touch comfort and flexibility.

Printer Settings:

Layer Height: 0.2 mm for a trade-off between surface finish and printing time.

Infill Density: 25–30% for optimal strength-to-weight ratio.

Shell Thickness: 1.2 mm for increased wall strength.

Post-Processing Steps:

- Light sanding and de-burring were performed to eliminate sharp edges and support marks.

- Hot air guns were applied for light heat treatment to smoothen layer lines and remove micro-roughness in contact areas.

- Foam padding, soft elastic bands, and antibacterial fabric covers were incorporated to increase comfort and hygiene.

4. Assembly and Fitting

The strategy for assembly centered on designing the system to be intuitive, quick, and repeatable, especially for older individuals or those with little physical power Show in Figure 1 And 1.1.

Assembly Features:

Snap-fit joints made it possible to connect the modules securely without using screws or glue.

Guide marks and color-coded parts eased orientation during assembly.

The assembly needed no tools more complicated than hand pressure, which made the system more portable and easier to deploy.

Fitting Strategy:

Patients were able to strap on the device themselves or with the help of their caregivers using adjustable elastic straps and Velcro belts.

Pressure contact points were equipped with silicone padding to spread pressure evenly and prevent circulatory blockage or discomfort.

A step-by-step user guide with images and QR-code-connected video tutorials facilitated proper fitting and reusability.

Maintenance & Reusability:

Materials used were water-resistant and simple to clean.

Modular components were removable for sterilization or replacement.

The design enabled retrofitting with sensors or actuators for future automation in advanced stages of rehabilitation.

Figure 1:3D PRINTED

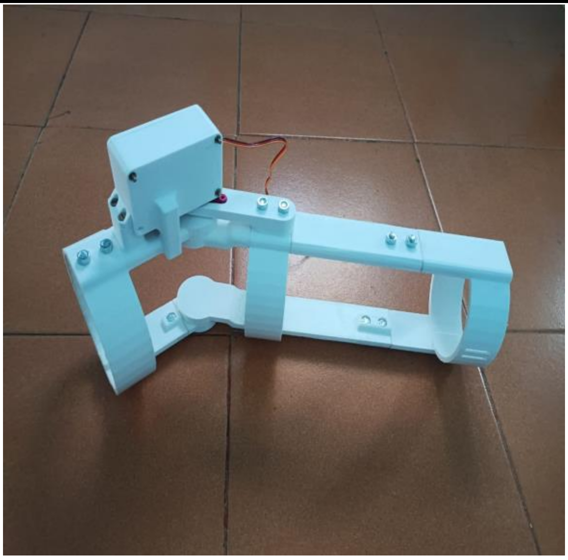

Figure: 1.1 3D PRINTED

IV. RESULTS AND DISCUSSION:

1.Clinical Evaluation:

A preliminary clinical evaluation was conducted with five volunteers, aged 45 to 70, at a local rehabilitation clinic. All participants exhibited limited upper limb mobility resulting from either ischemic stroke or post-surgical musculoskeletal trauma. Prior to the study, each participant underwent an initial clinical assessment to establish baseline motor function.

The device was evaluated over a two-week trial period, during which it was used daily under physiotherapist supervision for routine rehabilitation exercises focusing on elbow flexion-extension and wrist articulation. The following parameters were monitored:

Range of Motion (ROM): Assessed pre- and post-therapy using a goniometer to quantify improvements in joint mobility.

Patient Comfort: Rated on a Likert scale from 1 (poor) to 5 (excellent), considering fit, skin contact, and thermal comfort.

Ease of Use: Feedback was collected from both patients and caregivers regarding the simplicity of wearing, adjusting, and removing the device.

Device Integrity: Physical inspections were carried out daily to detect signs of material fatigue, joint wear, or structural deformation.

2. Key Findings;

The clinical testing yielded positive and encouraging results across all metrics:

Range of Motion (ROM): On average, participants experienced a 15–20% increase in joint movement capability during assisted exercises. Improvements were particularly noted in flexion angles of the elbow and active wrist extension.

Patient Comfort: The average comfort rating was 4.5 out of 5. Most users reported minimal pressure points, good alignment with their limb anatomy, and little to no skin irritation despite extended daily use.

Ease of Use: All participants were able to don and doff the device with minimal assistance. The modular strapping system and lightweight construction contributed to a high usability score, especially among older participants with limited hand dexterity.

Durability: Over the two-week testing period, the device exhibited no structural failure. The materials (PLA and TPU) maintained their mechanical integrity, and joints retained smooth articulation. Minor cosmetic wear was observed at high-friction interfaces, but this did not affect functionality.

3.Discussion:

The outcomes of this pilot evaluation highlight the clinical and practical potential of 3D-printed rehabilitation devices in augmenting early-stage recovery for upper limb impairments. The modular, patient-specific design allowed for precise anatomical fit and comfort, which are critical for patient adherence and therapeutic efficacy. The success of this prototype underscores several key advantages:

Rapid Prototyping: Feedback-driven iterative design was implemented effectively. Minor changes in wrist support curvature and strap placement were integrated between sessions using short turnaround times (less than 24 hours).

Cost-Effectiveness: The total production cost per unit was under $20 USD, excluding labour. This low-cost model presents significant advantages for deployment in resource-limited healthcare systems or for home-based therapy.

Customization and Ergonomics: The ability to digitally tailor the device using patient-specific measurements (taken manually or via 3D scanning) led to high levels of comfort and better biomechanical alignment.

However, several limitations were identified:

Material Breathability: PLA, while structurally sound, can retain heat and cause mild sweating. Future iterations should explore porous lattice designs or integrate ventilation holes to enhance thermal regulation.

Long-Term Wearability: Although short-term durability was proven, extended use over several months may lead to material fatigue. Trials involving advanced polymers (e.g., PETG, Nylon, or medical-grade TPU) are planned for further testing.

Sensor Integration: The current prototype operates passively. Incorporating flex sensors or IMUs could provide real-time feedback on joint angles, enabling data-driven therapy progress tracking and remote clinician monitoring.

V. CONCLUSION:

This research has been able to prove the viability of designing and creating a 3D-printed assistive device for rehabilitation of the upper limb. The application of additive manufacturing provides some of the advantages of being cost-effective, rapid prototyping, and customized design. The lightweight and modular nature of the device facilitates ease of use and the ability to accommodate individual patient requirements, making it extremely appropriate for both clinical and home-based rehabilitation environments.Preliminary testing in a small population of patients yielded positive results, such as ROM gains and high user satisfaction with respect to comfort and ease of use. These results highlight the promise of this device to be a low-cost, accessible alternative to higher-priced robotic rehabilitation systems, particularly in resource-limited environments where cost and infrastructure are high hurdles.The research points to the wider benefits of 3D printing in rehabilitation technology. High rates of design iteration provide ongoing product optimization, and low costs favor broad accessibility. Perhaps most importantly, tailorability makes it possible to produce patient-specific solutions that standard mass-manufactured devices cannot provide. Future development will target upscaling clinical trials, developing greater mechanical strength, and the incorporation of smart features such as motion sensing to optimize rehabilitation outcomes further.

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