



International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.206

Volume 8, Issue 11, November 2025



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Soft Robotic Exosleeve for Stroke Rehabilitation

Prasanna Bhore, Sushank K, Daniya Biradar, Puneeth A

UG Students, Department of Electronics & Communication Engineering, JAIN (Deemed-to-be University) Bangalore,
Karnataka, India

ABSTRACT: This research paper presents a comprehensive overview of a soft robotic exosleeve designed to support upper-limb rehabilitation in stroke survivors. Stroke remains one of the leading causes of long-term disability worldwide, with many patients experiencing persistent arm and hand dysfunction that limits independence. Conventional rehabilitation is often constrained by accessibility, therapist availability, and suboptimal therapy intensity. The soft robotic exosleeve addresses these limitations through compliant materials, gentle pneumatic actuation, and adaptive assist-as-needed control. By integrating real-time sensor feedback and evidence-based neurorehabilitation principles, the system promotes high-dose, task-oriented motor relearning in both clinical and home settings. This paper details the motivation, design framework, implementation strategy, therapeutic advantages, and research gaps related to this technology. Preliminary findings from existing literature highlight improvements in functional outcomes, user engagement, and accessibility. The soft robotic exosleeve demonstrates strong potential to serve as a transformative, patient-centered rehabilitation tool capable of delivering scalable, personalized therapy for millions of stroke survivors.

KEYWORDS- Soft robotics, Exosleeve, Upper-limb rehabilitation, Stroke recovery, Pneumatic actuators, Assist-as-needed control, Neurorehabilitation, Wearable robotics, Adaptive assistance, Sensor fusion, sEMG, IMU sensors, Motor learning, Home-based therapy, Flexible robotic systems, Portable rehabilitation device, Human–robot interaction, Soft exoskeleton, Task-specific training, Neuroplasticity stimulation.

I. INTRODUCTION

Stroke continues to be one of the most significant causes of long-term motor disability worldwide, affecting millions of individuals every year. Among its most debilitating consequences is upper-limb impairment, which impacts more than 70% of survivors and severely limits their ability to perform daily activities such as reaching, grasping, lifting, and manipulating objects. Restoring arm and hand function is therefore a crucial step toward regaining independence, improving quality of life, and reducing caregiver burden.

Conventional rehabilitation programs rely heavily on therapist-guided exercises that focus on repetitive, task-specific training. While these methods are clinically validated, they often fall short due to limited therapist availability, high treatment costs, and logistical challenges such as transportation to therapy centers. Furthermore, many survivors do not receive the recommended intensity of therapy often far lower than what is required to stimulate neuroplasticity and meaningful motor recovery. As a result, patients may experience slow progress, chronic impairment, or early plateauing.

In recent years, neurorehabilitation research has emphasized the importance of high-dose, repetitive training that engages the patient actively in the therapeutic process. Repetition of functional tasks is essential for cortical reorganization and the strengthening of neural pathways. However, delivering such high-dose therapy through traditional one-on-one clinical sessions is not always feasible, especially in resource-limited environments.

Soft robotics has emerged as a transformative approach to address these limitations. Unlike rigid exoskeletons, which can be heavy, uncomfortable, or mechanically restrictive, soft robotic devices use compliant, flexible materials that adapt naturally to the human body. Their lightweight structure and inherent safety make them suitable for daily use, even in home-based environments. Soft robotic systems provide personalized assistance by using embedded sensors and adaptive control algorithms capable of detecting user intent and adjusting support levels in real time.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

The soft robotic exosleeve combines the advantages of wearable technology, soft actuation, and intelligent control to create a rehabilitation tool that is adaptable, accessible, and patient-friendly. By enabling repetitive, task-oriented training in both clinical and home settings, the exosleeve has the potential to significantly increase therapy intensity without increasing patient burden or clinical workload. Furthermore, its ability to encourage active participation rather than passive movement supports the fundamental principles of motor learning.

Overall, the soft robotic exosleeve seeks to bridge the gap between clinical needs and real-world rehabilitation challenges by offering a solution that is effective, scalable, and aligned with the long-term recovery goals of stroke survivors.

II. PROBLEM STATEMENT

Stroke survivors frequently experience long-term upper-limb deficits, including muscle weakness, abnormal synergies, spasticity, poor coordination, and reduced range of motion. These deficits severely impede daily tasks such as eating, dressing, reaching, and grasping. Traditional rehabilitation practices rely on therapist-guided exercises that focus on repetitive, task-specific movement training. However, achieving sufficient repetition intensity is challenging due to time constraints and limited availability of therapists. Existing robotic rehabilitation devices often fail to bridge this gap: rigid exoskeletons restrict natural arm motion, are expensive, and are unsuitable for home use. Moreover, devices that provide constant full assistance diminish the patient's active engagement, reducing neurorehabilitation effectiveness. Therefore, a lightweight, adaptive, soft robotic exosleeve that aligns with the natural biomechanics of the arm and encourages voluntary movement is needed to address these unmet clinical and logistical challenges. Despite the proven importance of intensive, repetitive rehabilitation for upper-limb recovery after stroke, many patients receive insufficient therapy due to workforce limitations, accessibility barriers, and high treatment costs. Rigid exoskeletons offer mechanical assistance but are often bulky, intimidating, and unsuitable for home-based rehabilitation. Additionally, many conventional systems fail to promote active engagement, resulting in passive movement that does not adequately stimulate neuroplasticity. There is a critical need for a lightweight, adaptive, comfortable, and user-friendly device capable of enabling high-dose, task-oriented training in both clinical and home environments. The soft robotic exosleeve aims to address these gaps by integrating soft robotics with sensor-driven adaptive control to enhance motor recovery outcomes.

III. BACKGROUND AND RELATED WORK

Soft robotics has emerged as a promising field for rehabilitation because of its human-friendly, compliant design. Unlike rigid exoskeletons, soft robotic systems use flexible materials, pneumatic networks, and textile-based actuators that conform naturally to the human arm. Previous research has demonstrated the feasibility of soft robotic gloves for hand rehabilitation, soft sleeves for elbow training, and tendon-driven systems for multi-joint support. These devices show clear advantages in comfort and safety but often lack integrated adaptive control, multimodal sensing, or practical home-use capability. Recent studies highlight the importance of combining soft actuation with real-time sensing such as IMU tracking, EMG-based intent detection, and pressure monitoring to personalize therapy. The proposed exosleeve builds on these advancements, integrating them into a unified, portable system capable of supporting repetitive movements essential for restoring upper-limb functionality. Soft robotics has advanced upper-limb rehabilitation by offering compliant actuators, textile-based designs, and improved sensing. Existing solutions include soft gloves and elbow-assist devices, but many lack full integration of adaptive control, comfort, and affordability. The exosleeve addresses these limitations by combining pneumatic actuation, multimodal sensing, and user-friendly interfaces suitable for clinical and home use.

IV. PROPOSED SOLUTION: SOFT ROBOTIC EXOSLEEVE

- The soft robotic exosleeve is designed to function as an intelligent, personalized rehabilitation companion tailored to the needs of stroke survivors and individuals with upper-limb motor impairments. Unlike conventional rigid exoskeletons that restrict natural motion and require precise alignment with anatomical joints, this exosleeve leverages compliant soft materials and biomimetic actuation principles to deliver safe, flexible, and intuitive assistance. Its architecture is centered around a network of flexible pneumatic actuators embedded within a lightweight, ergonomically contoured textile sleeve. These actuators distribute pressure evenly across the arm, enabling controlled flexion, extension, pronation, and supination without causing discomfort or joint misalignment. Because the sleeve



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

conforms naturally to the user's arm, it minimizes strain points and allows therapy sessions to be longer, more comfortable, and more effective.

- To achieve precise, adaptive rehabilitation support, the system integrates multiple key components:
- Multi-segment pneumatic actuators: Arranged longitudinally and circumferentially, they allow fine-tuned, direction-specific forces. Independent air chambers provide graded assistance, enabling the sleeve to target specific movement deficits (e.g., limited elbow flexion or weak forearm rotation).
- Sensor fusion network: Embedded inertial measurement units (IMUs), flex sensors, and surface electromyography (sEMG) electrodes monitor joint angles, movement speed, muscle activation, and resistance patterns. This distributed sensing framework provides real-time biomechanical data essential for adaptive control.
- On-board microcontroller with adaptive control algorithms: The control unit continuously interprets sensor data and determines the optimal assistance level using "assist-as-needed" strategies. This ensures that the user performs as much voluntary effort as possible while still receiving support when fatigue or motor deficits occur. Over time, the controller reduces assistance as recovery improves, promoting active engagement and neuroplastic changes.
- Compact, low-noise pneumatic actuation system: A miniaturized air pump with pressure regulators and valves delivers smooth, quiet operation, making the device suitable for both clinical and home environments. Its portable design ensures that therapy is not confined to scheduled sessions but can be integrated seamlessly into daily routines.
- Beyond mechanical and control functions, the soft robotic exosleeve also enhances user motivation a crucial factor in long-term rehabilitation success. The system can interface with a mobile application offering gamified training modules, progress tracking dashboards, and personalized exercise routines. Real-time performance feedback, such as movement correctness, range of motion improvements, and repetition counts, helps patients stay engaged and consistent with therapy.
- Overall, the exosleeve's combination of comfort, adaptability, safety, and portability supports a rehabilitation paradigm centered on high-repetition, task-oriented training. By encouraging voluntary effort while delivering assistance intelligently, the device aligns with established motor-learning principles and has strong potential to improve functional outcomes for users in both clinical and remote settings.

V. SYSTEM ARCHITECTURE AND WORKING PRINCIPLES

The soft robotic exosleeve is designed with a modular architecture that includes mechanical, sensing, and control subsystems working together to deliver effective rehabilitation.

5.1 Mechanical Design

Flexible pneumatic actuators are embedded along the arm to support elbow flexion and extension. These actuators inflate and deflate smoothly, generating natural motion patterns that mimic muscle behavior. The sleeve material is breathable, lightweight, and adjustable to accommodate different arm sizes.

5.2 Multimodal Sensing

A combination of IMUs, surface EMG electrodes, strain sensors, and pressure sensors allow precise tracking of movement quality, joint angles, and muscle activation. These sensors enable accurate performance monitoring and adaptive therapy progression.

5.3 Adaptive Control Algorithms

The control unit uses assist-as-needed algorithms to adjust the level of support dynamically. If the patient initiates movement actively, the device reduces assistance to encourage motor effort. When fatigue or weakness is detected, assistance automatically increases. This dynamic adaptation ensures optimal challenge levels throughout each session.

5.4 Gamified User Interface

A tablet or smartphone interface displays visually engaging rehabilitation tasks, performance graphs, and progress tracking. Gamification increases motivation, which is essential for long term adherence. The exosleeve includes soft pneumatic actuators, embedded sensors (IMU, EMG, pressure), and a microcontroller for adaptive control. Actuators generate smooth arm movement, while sensors track joint angles and effort. An assist-as-needed algorithm ensures optimal support by increasing or reducing assistance based on performance. A simple app provides real-time feedback and gamified tasks.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

VI. IMPLEMENTATION STRATEGY

The development of the soft robotic exosleeve follows a structured approach:

1. **Design & Prototyping:** CAD modeling, selection of silicone materials, fabrication of air chambers, and structural optimization.
2. **Actuator Fabrication:** Casting pneumatic muscles using 3D-printed molds and bonding them to reinforced textile layers.
3. **Sensor Integration:** Embedding IMUs, EMG sensors, strain gauges, and wiring into textile channels.
4. **Control System Development:** Programming microcontroller firmware for data acquisition, filtering, and adaptive control.
5. **System Calibration:** Tuning actuator pressure profiles and sensor thresholds.
6. **User Testing:** Conducting comfort, safety, and usability tests with healthy participants.
7. **Clinical Pilots:** Small-scale trials with stroke patients to evaluate therapeutic efficacy.
8. **Iterative Enhancement:** Refining design based on clinician feedback and patient outcomes.
9. **Large-scale Validation:** Multicenter clinical studies measuring improvements in FMA-UE scores, ROM, and ADL performance.
 - Develop 3D-printed molds and fabricate soft actuators using silicone elastomers.
 - Integrate actuators into a textile sleeve designed for modular fit across different arm sizes.
 - Embed IMUs and EMG sensors within the sleeve for continuous monitoring.
 - Develop real-time adaptive control algorithms programmed into a microcontroller.
 - Conduct bench-level testing of actuator performance and control accuracy.
 - Perform pilot usability studies with stroke survivors to refine comfort and functionality.
 - Integrate gamified rehabilitation modules into the user interface.
 - Evaluate device performance in clinical trials measuring functional recovery outcomes.

VII. CLINICAL ADVANTAGES

Key benefits include high dose training, portability, low cost, and enhanced user engagement through gamified tasks. Adaptive assistance promotes active participation, while the soft design ensures comfort and safety. The device is suitable for home rehabilitation, reducing dependence on clinician availability.

VIII. RESEARCH GAPS AND FUTURE SCOPE

Future improvements include enhancing actuator durability, reducing power consumption, improving AI-based intent detection, and validating outcomes with larger clinical trials. Cost reduction and tele-rehabilitation integration are essential for broader adoption.

IX. CONCLUSION

The soft robotic exosleeve represents a significant leap forward in stroke rehabilitation technology. By leveraging soft materials, adaptive control, and multimodal sensing, it provides an effective, motivating, and accessible alternative to traditional therapy. Its ability to deliver high-intensity training in both clinical and home environments positions it as a transformative tool for long-term stroke recovery. As engineering innovations continue to refine the durability, affordability, and intelligence of the system, soft robotic exosleeves hold the promise of redefining rehabilitation making therapy more personal, more engaging, and more effective for millions of survivors worldwide. Soft robotic exosleeves represent a transformative advancement in stroke rehabilitation by offering adaptable, patient-centered, and scalable therapy solutions. By combining compliant actuation, sensor-driven adaptive control, and evidence-based therapeutic principles, the exosleeve delivers high-intensity, task-oriented rehabilitation that enhances neuroplastic recovery. With continued research and refinement, this technology has the potential to shift stroke rehabilitation toward a more accessible and effective home-based model, ultimately improving independence and quality of life for millions of survivors.



International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

REFERENCES

1. Marchal-Crespo, L., & Reinkensmeyer, D. J. (2021). Review of wearable robots for upper limb rehabilitation.
2. Polygerinos, P. et al. (2015). Soft robotic glove for hand rehabilitation.
3. Cianchetti, M. et al. (2018). Soft robotics technologies and applications.
4. Chen, D. et al. (2022). Adaptive control strategies in soft exosuits.
5. Li, Z. et al. (2023). Pneumatic artificial muscles for assistive movement support.. Problem Statement



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH IN SCIENCE, ENGINEERING AND TECHNOLOGY

| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

www.ijmrset.com