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Smart Prosthetic Hand Using EMG Signal

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ABSTRACT: Hand injuries are a significant medical concern, often leading to prolonged rehabilitation periods and increased healthcare costs. Traditional physical therapy requires intensive labor and continuous monitoring. To address these challenges, this paper presents the design and control of a portable hand exoskeleton aimed at improving rehabilitation outcomes while reducing costs. The proposed system supports four-finger degrees of freedom and is adaptable to various hand deformities. A soft exoskeleton glove driven by a pneumatic system is controlled using an Arduino Mega 2560 and relay module. The system enables customizable repetitive motion therapy, making it suitable for stroke patients and individuals with finger-specific injuries. The study highlights the flexibility, usability, and potential applications of the device in modern rehabilitation practices.

KEYWORDS: Hand Exoskeleton; Rehabilitation; Soft Actuator; Arduino Mega 2560; Pneumatic Control; Stroke Therapy; Assistive Robotics

I. INTRODUCTION

In modern scientific literature, a wide range of robotic devices has been developed to assist or restore human hand movements, reflecting rapid advancements in rehabilitation and assistive technologies. The design and functionality of hand exoskeletons vary significantly depending on their intended application, resulting in diverse mechanical structures and control strategies. Rehabilitation exoskeletons are typically designed to provide high flexibility and a wide range of motion, enabling patients to perform various therapeutic exercises aimed at regaining motor function. In contrast, assistive exoskeletons used for daily activities prioritize strength, stability, and reliability, often sacrificing flexibility to achieve consistent and predefined grip patterns. These varying requirements have led to the development of multiple power transmission architectures in hand exoskeleton systems. Rigid coupling mechanisms, for instance, offer precise control of joint movement and hand posture but require accurate alignment between the exoskeleton joints and the user's anatomical joints, which can be challenging in practical applications. On the other hand, cable-driven glove systems provide a more flexible and lightweight solution by utilizing the natural movement of human joints, thereby improving comfort and adaptability. However, such systems typically rely on pulley mechanisms and dual-cable configurations to achieve bidirectional motion, which increases system complexity and may limit precise control at intermediate positions. Soft actuator-based exoskeletons, including those using pneumatic artificial muscles or shape memory alloys, represent an alternative approach due to their inherent compliance, lightweight nature, and ease of integration into wearable gloves. These systems enhance safety during human–robot interaction but are often limited in their ability to generate high forces and maintain accuracy under load conditions.

Furthermore, the implementation of closed-loop control systems in hand exoskeletons requires accurate measurement of interaction forces between the user and the device to ensure effective assistance and operational safety. Various sensing technologies, such as torque sensors, strain gauges, bending sensors, and load cells, have been widely explored for this purpose. Despite their advantages, these sensors present several challenges when integrated into compact and wearable exoskeleton designs. Torque sensors typically measure forces at the actuator level and may not capture all interaction forces experienced at the human–device interface, particularly under heavy loading conditions. Load cells, while capable of precise force measurement, are difficult to integrate due to size constraints and the need for proper placement within the limited space of a human hand. Additionally, miniature sensors such as force-sensitive resistors

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are often limited to measuring force in a single direction, whereas sensors capable of bidirectional force measurement are generally too bulky for practical use. These limitations emphasize the need for further research in actuator technologies, sensor integration, and advanced control strategies to improve the performance, reliability, and usability of next-generation hand exoskeleton systems for both rehabilitation and assistive applications.

III. PROBLEM STATEMENT

Hand injuries and neurological disorders such as stroke, spinal cord injury, and nerve damage represent a significant challenge in modern healthcare systems. These conditions often lead to partial or complete loss of hand function, severely affecting a patient's ability to perform basic daily activities such as gripping, holding, writing, and object manipulation. The human hand is a highly complex structure with multiple degrees of freedom, intricate joint mechanisms, and coordinated muscle movements. Any impairment in this system can drastically reduce the quality of life of affected individuals. Consequently, effective rehabilitation methods are essential to restore motor function and improve independence.

Traditional rehabilitation techniques primarily rely on manual physiotherapy, where trained therapists guide patients through repetitive hand exercises. Although these methods are clinically effective, they are time-consuming, labor-intensive, and require continuous supervision. The rehabilitation process often extends over weeks or months, leading to increased healthcare costs and limited accessibility for many patients. Furthermore, the availability of skilled therapists may be restricted, especially in rural or resource-limited areas. As a result, many patients do not receive adequate or consistent therapy, which can delay or even prevent full recovery.

In addition to cost and accessibility issues, conventional rehabilitation methods lack precise control and quantification of therapy parameters. The effectiveness of therapy depends heavily on the therapist's expertise and consistency, which can vary from session to session. It is difficult to maintain uniform repetition rates, controlled force application, and accurate monitoring of patient progress. This lack of standardization can result in suboptimal rehabilitation outcomes. Moreover, patients may experience fatigue or discomfort due to improper handling or excessive manual force during therapy sessions.

To overcome these limitations, robotic and exoskeleton-based rehabilitation systems have been introduced. These systems aim to provide automated, repeatable, and controlled assistance for hand movements. However, existing hand exoskeleton designs present several challenges that limit their practical application. Many systems are based on rigid mechanical structures driven by electric motors. While these systems offer precise control, they are often bulky, heavy, and uncomfortable for users. The requirement for precise alignment between the exoskeleton joints and human anatomical joints further complicates their usage, making them less suitable for patients with varying hand geometries or deformities.

Cable-driven exoskeleton systems have been proposed as a lightweight alternative to rigid designs. These systems use tendon-like cables to transmit forces and enable finger movements. Although they provide improved flexibility and adaptability, they introduce complexities in cable routing, tension control, and maintenance. Achieving accurate and consistent force transmission is challenging, especially during prolonged usage. Additionally, cable-driven systems may suffer from wear and tear, reducing their long-term reliability.

Soft robotic exoskeletons have emerged as a promising solution due to their lightweight, flexible, and compliant nature. These systems use soft actuators, such as pneumatic artificial muscles or shape memory alloys, to generate motion. While they offer improved comfort and safety, they often face limitations in force generation, response time, and precise motion control. Maintaining consistent performance under varying load conditions is also a challenge. Furthermore, the integration of soft actuators with reliable control systems remains an area of ongoing research.

Another critical challenge in existing systems is the lack of effective sensing and feedback mechanisms. Accurate measurement of interaction forces between the device and the user is essential for safe and efficient operation. However, integrating sensors into compact wearable devices is difficult due to space constraints and design limitations. Commonly used sensors, such as torque sensors, strain gauges, and force-sensitive resistors, have inherent drawbacks. Some sensors can measure force only in one direction, while others are too large or complex to be embedded within the exoskeleton structure. This limitation affects the ability to implement advanced closed-loop control systems, which are necessary for adaptive and intelligent rehabilitation.

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Portability and usability are also major concerns in existing hand exoskeleton systems. Many devices are designed for clinical environments and require external support systems, such as large power supplies or compressors. This restricts their use in home-based rehabilitation, where patients need simple, easy-to-use devices for continuous therapy. Additionally, wired control systems limit user mobility and create inconvenience during operation. The lack of wireless communication further reduces the flexibility and practicality of these systems.

Cost is another significant barrier to the widespread adoption of robotic rehabilitation devices. Advanced exoskeleton systems often involve expensive components, complex manufacturing processes, and sophisticated control algorithms, making them unaffordable for many patients. This limits their availability to specialized healthcare facilities and prevents large-scale implementation. There is a need for cost-effective solutions that can deliver comparable performance without compromising functionality and safety.

Moreover, many existing systems do not provide sufficient customization options to accommodate different patient needs. Rehabilitation requirements vary based on the severity of injury, stage of recovery, and individual physical conditions. A one-size-fits-all approach is not effective in such scenarios. Systems that lack adjustable parameters for motion control, speed, and repetition may not provide optimal therapy for all users. This highlights the importance of developing adaptable systems that can be tailored to individual rehabilitation programs.

Safety is another critical issue that must be addressed in the design of hand exoskeletons. Improper force application, excessive motion, or mechanical failure can lead to further injury or discomfort for the user. Rigid systems, in particular, pose a higher risk due to their lack of compliance. Ensuring safe human–machine interaction is essential for gaining user trust and acceptance of these devices. Therefore, designing systems with inherent safety features and controlled actuation mechanisms is a key requirement.

Considering all these challenges, there is a clear need for an improved hand exoskeleton system that addresses the limitations of existing methodologies. The system should be lightweight, portable, and easy to use, allowing patients to perform rehabilitation exercises independently. It should provide flexible and natural finger movements while maintaining sufficient force for effective therapy. The integration of simple yet reliable control mechanisms is essential to ensure consistent performance without increasing system complexity.

Furthermore, the inclusion of wireless communication capabilities can enhance system usability by enabling remote operation and reducing physical constraints. A cost-effective design approach is necessary to make the technology accessible to a wider population. The system should also support customization of therapy parameters, allowing users to adjust motion patterns according to their specific needs. Ensuring safety through compliant actuation and controlled motion is equally important. In summary, the problem addressed in this work is the development of an efficient, user-friendly, and cost-effective hand exoskeleton system that overcomes the limitations of existing rehabilitation devices. The proposed solution aims to provide controlled, repetitive, and customizable finger movements using a soft pneumatic actuation mechanism combined with a microcontroller-based control system and wireless communication. By addressing issues related to flexibility, portability, cost, and safety, the system seeks to improve the effectiveness and accessibility of hand rehabilitation for a wide range of users.

III. OBJECTIVES

The primary objective of this work is to design and develop a portable and lightweight hand exoskeleton system that can effectively assist in the rehabilitation of patients with hand injuries or neurological impairments such as stroke. The system aims to provide flexible and controlled finger movements with multiple degrees of freedom, enabling users to perform a wide range of therapeutic exercises. Another key objective is to implement a pneumatic actuation mechanism that ensures smooth, safe, and repeatable bending of fingers, thereby enhancing patient comfort during therapy sessions. The study also focuses on developing an efficient control system using an Arduino Mega 2560, integrated with a relay module and solenoid valve, to regulate motion through adjustable timing parameters. Furthermore, the proposed system seeks to offer customizable rehabilitation programs tailored to individual patient needs, improving recovery outcomes. Emphasis is also placed on ensuring adaptability to different hand shapes, including deformed or partially functional hands, while maintaining ease of use. In addition, the system is intended to reduce rehabilitation costs and minimize dependence on continuous manual physiotherapy. Overall, the objective is to create a reliable, safe, and cost-effective solution that enhances the efficiency of hand rehabilitation and supports its application in both clinical and home environments.

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IV. RELATED WORK

Recent advancements in robotic rehabilitation have significantly contributed to the development of hand exoskeleton systems designed to restore motor function and assist individuals with impaired hand mobility. Early research in this field primarily focused on rigid exoskeleton structures driven by electric actuators, which offered precise control over finger movements and joint trajectories. These systems were effective in controlled environments; however, their bulky design, high cost, and requirement for precise alignment with human joints limited their usability and comfort for continuous rehabilitation.

To address these limitations, researchers introduced cable-driven mechanisms that mimic the tendon-like structure of the human hand. These systems are lighter and more flexible compared to rigid exoskeletons, allowing more natural and adaptive movements. By utilizing cables and pulley systems, force transmission becomes more efficient, and the device can better conform to the user's hand. Nevertheless, cable-driven systems present challenges such as complex routing, difficulty in maintaining consistent tension, and limited accuracy in controlling intermediate finger positions.

In recent years, soft robotic technologies have emerged as a promising solution in the design of wearable hand exoskeletons. Soft exoskeleton gloves, often powered by pneumatic actuators or shape memory alloys, provide compliant and safe interaction with the human hand. These devices are lightweight, adaptable to different hand shapes, and reduce the risk of injury during operation. However, their performance is often constrained by lower force output, slower response times, and reduced precision compared to rigid or cable-driven systems.

Another important area of research involves the integration of sensing technologies to enable feedback-based control in exoskeleton systems. Various sensors such as flex sensors, strain gauges, force-sensitive resistors, and torque sensors are used to monitor finger movement, applied force, and user intention. While these sensors enhance system functionality and safety, their integration into compact wearable devices is challenging due to size limitations, placement constraints, and issues related to measurement accuracy, especially in bidirectional force detection.

Despite significant progress, existing hand exoskeleton systems still face several challenges, including high cost, system complexity, limited portability, and lack of adaptability to different users and rehabilitation needs. Many devices are not suitable for home-based therapy due to their size and operational requirements. Therefore, current research is focused on developing cost-effective, lightweight, and user-friendly exoskeleton systems with improved control strategies, better sensor integration, and enhanced performance to support efficient and accessible hand rehabilitation.

V. EXISTING METHODOLOGY

Existing methodologies for hand exoskeleton systems are primarily based on different actuation and control techniques aimed at assisting or restoring finger movements. Traditional approaches commonly utilize rigid exoskeleton frameworks driven by electric motors, where mechanical linkages are aligned with human finger joints to achieve controlled motion. These systems provide high precision and accurate trajectory tracking; however, they require careful calibration and exact joint alignment, making them complex, bulky, and less comfortable for prolonged use. Additionally, their high power consumption and cost limit their practicality for widespread rehabilitation applications.

Another widely used methodology involves cable-driven mechanisms, which replicate the tendon structure of the human hand. In this approach, cables connected to actuators transmit forces to the fingers through pulleys, enabling more natural and flexible movement. These systems are generally lightweight and adaptable to different hand sizes, improving user comfort. However, maintaining proper cable tension, ensuring consistent force transmission, and achieving accurate control at intermediate finger positions remain challenging. The complexity of cable routing and wear over time also affects system reliability.

Soft robotic approaches have also gained attention in recent methodologies, particularly in rehabilitation-focused designs. These systems employ soft actuators such as pneumatic artificial muscles or shape memory alloys integrated into wearable gloves. The primary advantage of this methodology is its inherent compliance, which ensures safe interaction with the human hand and reduces the risk of injury. Despite these benefits, soft systems often suffer from limitations such as lower force output, slower response, and reduced precision in motion control, especially when compared to rigid or cable-driven systems.

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In addition to actuation techniques, existing methodologies incorporate various sensing and control strategies to improve system performance. Sensors such as flex sensors, strain gauges, force-sensitive resistors, and torque sensors are used to monitor finger motion and interaction forces. These sensors enable feedback-based or closed-loop control, which enhances accuracy and safety. However, integrating these sensors into compact and wearable designs poses challenges due to size constraints, placement issues, and limited ability to measure bidirectional forces effectively.

Overall, while existing methodologies have demonstrated significant progress in the development of hand exoskeleton systems, they still face limitations in terms of portability, cost, adaptability, and ease of use. Many systems are not suitable for continuous or home-based rehabilitation due to their complexity and size. These limitations highlight the need for improved methodologies that combine flexibility, precise control, lightweight design, and cost-effectiveness for practical rehabilitation applications.

VI. PROPOSED METHODOLOGY

The proposed methodology focuses on the design and development of a portable, lightweight, and cost-effective hand exoskeleton system intended for rehabilitation applications. The system is based on a soft robotic approach that integrates a wearable glove embedded with pneumatic actuators to assist finger movements. Unlike rigid and cable-driven systems, the proposed design emphasizes flexibility, user comfort, and ease of use, making it suitable for both clinical and home-based rehabilitation. The exoskeleton is designed to support multiple fingers with sufficient degrees of freedom, allowing patients to perform a variety of therapeutic exercises.

The actuation mechanism is implemented using a pneumatic system in which compressed air is supplied to soft bending actuators. These actuators are attached along the fingers and expand or contract when pressurized, producing controlled bending motion. The airflow to the actuators is regulated using a 3/2-way single solenoid valve powered by a 24V DC supply. This approach ensures smooth and safe operation, reducing the risk of injury during repetitive rehabilitation exercises. The lightweight nature of the soft actuators enhances wearability and adaptability to different hand shapes, including injured or partially functional hands.

The control system is developed using an Arduino Mega 2560 microcontroller, which acts as the central processing unit for coordinating the operation of the exoskeleton. A relay module is interfaced with the microcontroller to control the solenoid valve by switching the air supply ON and OFF. The movement of the fingers is controlled by adjusting the ON and OFF delay timing of the relay, allowing precise control over the bending and releasing cycles. This timing-based control mechanism enables the system to generate repetitive motion patterns required for effective rehabilitation.

Furthermore, the proposed system allows customization of therapy sessions based on individual patient needs. By modifying the control parameters such as actuation timing and repetition rate, different rehabilitation exercises can be implemented. This flexibility makes the system suitable for a wide range of conditions, including stroke rehabilitation and single-finger injury recovery. The simplicity of the control strategy reduces system complexity while maintaining effective performance.

Overall, the proposed methodology offers a practical solution that overcomes the limitations of existing systems by combining soft actuation, simple control architecture, and user-friendly design. It ensures safe human–machine interaction, improves comfort, and reduces dependency on manual physiotherapy, thereby providing an efficient and accessible approach to modern hand rehabilitation.

VII. SYSTEM ARCHITECTURE

The system architecture of the proposed hand exoskeleton is designed to ensure simplicity, reliability, and effective rehabilitation performance through the integration of mechanical, pneumatic, and electronic subsystems. The overall architecture consists of three main units: the wearable exoskeleton glove, the pneumatic actuation system, and the control unit. These components work together to generate controlled finger movements required for rehabilitation exercises.

The wearable unit is a soft exoskeleton glove embedded with flexible actuators aligned along the fingers. These actuators are responsible for producing bending motion when pressurized. The glove is designed to be lightweight and adaptable, allowing it to fit different hand sizes and conditions, including injured or partially functional hands. Its soft structure ensures safe interaction with the user and minimizes discomfort during prolonged usage.

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The pneumatic system forms the actuation core of the architecture. It includes an external air compressor or pump that supplies compressed air to the system. The airflow is regulated using a 3/2-way single solenoid valve, which controls the inflation and deflation of the soft actuators. When the valve is activated, compressed air flows into the actuators, causing them to bend and assist finger movement. When deactivated, the air is released, allowing the fingers to return to their original position.

The control unit is built around the Arduino Mega 2560 microcontroller, which manages the overall operation of the system. A relay module is interfaced with the microcontroller to switch the solenoid valve ON and OFF using a 24V DC power supply. The control logic is based on timing parameters, where adjustable ON and OFF delays determine the duration and repetition of finger movements. This enables the generation of cyclic motion patterns essential for rehabilitation therapy.

Additionally, the system architecture allows for future integration of sensors such as flex sensors or force sensors to enable feedback-based control. This can enhance system accuracy, safety, and adaptability by monitoring user interaction and adjusting actuation accordingly. Overall, the proposed architecture provides a modular, scalable, and cost-effective solution that supports efficient and customizable hand rehabilitation.

VIII. WORKING

The working principle of the proposed hand exoskeleton system is based on the coordinated integration of mechanical, pneumatic, electronic, and wireless communication subsystems to achieve controlled and repetitive finger motion for rehabilitation purposes. The system is specifically designed to assist users suffering from hand impairments, such as stroke or injury, by providing externally controlled movement to stimulate muscle activity and improve motor recovery. The overall operation involves signal transmission, processing, actuation, and motion execution in a synchronized manner.

At the initial stage, the user wears the soft exoskeleton glove, which forms the primary human–machine interface. The glove is ergonomically designed to match the natural anatomical structure of the human hand, ensuring proper alignment with finger joints. Soft actuators are embedded along each finger, allowing the system to replicate natural flexion and extension movements. The glove is secured using adjustable straps, ensuring a stable fit while maintaining user comfort during prolonged usage. The lightweight and flexible design minimizes fatigue and allows continuous rehabilitation sessions.

Once the system is powered on, the control unit initializes its internal parameters. The Arduino Mega 2560 microcontroller serves as the central controller, responsible for executing control algorithms and managing communication between different subsystems. The initialization process includes setting predefined values for actuation timing, repetition cycles, and delay intervals. These parameters can be adjusted based on the patient’s rehabilitation requirements, allowing a customizable therapy process.

A key feature of the system is the integration of wireless communication through RF transmitter and receiver modules. At the transmitting end, control signals are generated using an input interface or controller and are passed to the RF transmitter module. The transmitter consists of four main pins: antenna, data input, ground, and VCC. The data input pin receives encoded signals, which are modulated and transmitted as electromagnetic waves through the antenna. This wireless transmission eliminates the need for direct physical connections, improving system portability and usability.

At the receiving end, the RF receiver module captures the transmitted signals via its antenna. Similar to the transmitter, the receiver includes four pins: antenna, data output, ground, and VCC. The received RF signals are demodulated and converted into electrical signals, which are then fed to the Arduino Mega 2560. The microcontroller decodes the received data and determines the corresponding control action. This wireless mechanism allows remote operation of the exoskeleton, enabling users or therapists to control the device without direct interaction.

The pneumatic actuation system plays a central role in generating finger movement. An external air compressor or pump supplies compressed air to the system. The airflow is controlled using a 3/2-way single solenoid valve, which regulates the direction and flow of air into the soft actuators. The solenoid valve is connected to the microcontroller through a relay module, allowing the controller to switch the valve ON and OFF as required. The relay acts as an interface between the low-power control signals and the high-power pneumatic components.

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When the microcontroller activates the relay, the solenoid valve opens, allowing compressed air to flow into the soft actuators. As air enters the actuators, they expand due to internal pressure. The design of the actuators ensures asymmetric expansion, which results in bending motion. This bending mimics the natural flexion of human fingers, enabling the exoskeleton to assist in grasping or closing movements. The degree of bending depends on factors such as air pressure, actuator geometry, and duration of actuation.

After a predefined ON time, the microcontroller deactivates the relay, causing the solenoid valve to close. This action stops the air supply and allows the pressurized air inside the actuators to escape through the exhaust port. As the air is released, the actuators return to their original shape, resulting in finger extension. This inflation and deflation process forms a complete motion cycle, which can be repeated continuously for rehabilitation exercises.

The timing of the ON and OFF cycles is a critical factor in determining the effectiveness of the therapy. The ON duration controls the extent of finger bending, while the OFF duration provides relaxation time between successive movements. By adjusting these parameters, the system can generate different motion patterns, such as slow stretching or rapid repetitive movement. This flexibility allows the system to adapt to different stages of patient recovery.

Another important aspect of the working principle is selective finger actuation. The system can be configured to control individual fingers independently, enabling targeted rehabilitation for specific injuries. This feature enhances the versatility of the device and allows customized therapy sessions for different patients.

Safety considerations are incorporated throughout the system design. The use of soft actuators ensures compliant interaction between the device and the human hand, reducing the risk of injury. The pneumatic system inherently limits excessive force due to the compressibility of air, providing an additional safety mechanism. Furthermore, the control system can include predefined limits to prevent overextension or prolonged actuation, ensuring safe operation.

The system architecture also supports future integration of sensors for advanced control. Sensors such as flex sensors, force sensors, or pressure sensors can be incorporated to provide real-time feedback on finger position and applied force. This would enable the implementation of closed-loop control systems, allowing the device to adjust its operation dynamically based on user interaction.

Energy efficiency is another important consideration in the working principle. The pneumatic system consumes power primarily during actuation, reducing overall energy usage compared to continuous motor-driven systems. The use of RF communication further enhances efficiency by reducing wiring complexity and enabling a compact design.

The proposed system is suitable for both clinical and home-based rehabilitation environments. In clinical settings, therapists can configure the system parameters to suit individual patient needs. In home environments, the user can operate the device independently using wireless control, reducing dependency on continuous supervision.

In conclusion, the working principle of the proposed hand exoskeleton system involves a coordinated interaction between RF-based wireless communication, microcontroller-based control, and pneumatic actuation. The system generates controlled and repetitive finger movements through timed air pressure modulation in soft actuators. This approach ensures safe, efficient, and customizable rehabilitation, addressing the limitations of traditional therapy methods and existing robotic systems.

The modular architecture of the system allows easy integration of additional components such as sensors for future enhancements. Sensors such as flex sensors or force sensors can be incorporated to measure finger position and interaction force. This would enable closed-loop control, where the system adjusts its operation based on real-time feedback, thereby improving accuracy and responsiveness.

Another important aspect of the working principle is energy efficiency. Unlike traditional motor-driven systems, the pneumatic mechanism consumes power only during actuation, reducing overall energy usage. The use of RF communication also minimizes wiring complexity, contributing to a compact and efficient design.

The system is designed for both clinical and home-based rehabilitation environments. In clinical settings, therapists can configure the system parameters according to the patient’s needs. In home-based scenarios, patients can use the device independently with minimal supervision, thanks to its simple operation and wireless control capability.

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In summary, the working principle of the proposed hand exoskeleton system is based on a synchronized interaction between wireless communication, microcontroller-based control, and pneumatic actuation. The system generates controlled and repetitive finger movements through timed air pressure modulation in soft actuators. The integration of RF modules enhances usability and flexibility, while the soft robotic design ensures safety and comfort. This comprehensive approach provides an effective and practical solution for modern hand rehabilitation, addressing the limitations of conventional therapy methods and existing robotic systems.

IX. CONCLUSION

The Electrical Power Steering (EPS) system represents a significant This paper presented the design and implementation of a portable hand exoskeleton system intended for effective rehabilitation of patients with hand injuries and neurological disorders such as stroke. The proposed system integrates a soft wearable glove with a pneumatic actuation mechanism, controlled by an Arduino Mega 2560, to generate smooth and repetitive finger movements. The use of soft actuators ensures safe and flexible interaction with the human hand, improving user comfort and reducing the risk of injury during therapy.

The incorporation of a simple time-based control strategy using a relay module and solenoid valve enables precise control of finger motion while maintaining low system complexity. Additionally, the integration of RF transmitter and receiver modules provides wireless communication, enhancing system portability and allowing remote operation. This feature makes the system suitable for both clinical and home-based rehabilitation environments.

Compared to conventional rehabilitation methods and existing exoskeleton designs, the proposed system offers advantages such as reduced cost, ease of use, adaptability to different hand conditions, and minimal dependency on manual physiotherapy. Although the current design focuses on basic motion assistance, it provides a strong foundation for future enhancements, including sensor-based feedback control and intelligent rehabilitation programs.

Overall, the developed hand exoskeleton demonstrates a practical and efficient solution for improving hand mobility and supporting recovery. The system has significant potential to contribute to modern rehabilitation technology by making therapy more accessible, customizable, and user-friendly.

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