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Research Paper

Rehabilitative Exoskeleton Arm System with Integrated User Feedback Using IoT

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ABSTRACT

The rehabilitative exoskeleton arm system proposed can be used to augment stroke victims (and patients with similar upper-limb injuries) and individuals with neurological conditions, spinal injuries, and muscle weakness by offering intelligent support to patients. It is based on an ESP32 microcontroller, IMU sensors, accelerometers, servo motors and IoT communication technologies that provide the opportunity to monitor and perform assisted rehabilitation exercises in real-time due to movement changes. Sensors information undergoes continuous processing to assess the motions of the joints, monitor the progress of exercises and provide a regulated assistance during flexion and extension exercises. With the IoT-based platform, the data on the rehabilitation can be stored safely and it is remotely accessed to enable therapists monitor the progress of patients and also to offer them feedbacks- which are more personalized without them always being physically guarded. Exercise counting, movement monitoring and cloud-based monitoring are automated to enhance the accuracy of rehabilitation and make it more accessible. All in all, the system facilitates efficient home-based healing, less workload on the therapists, and offers a solid remedy to long-term rehabilitation of the upper-limbs.

Keywords: *IoT enabled rehabilitation, Rehabilitative exoskeleton arm, Upper-limb rehabilitation, ESP32 microcontroller, IMU sensor, Accelerator, Servo motor Support, Motion tracking, Cloud based monitoring, Tele-rehab, Wearable robotic system, Automated counts of exercises, Patient feedback System, Remote therapy, smart healthcare system.*

1. INTRODUCTION:

The stroke and spinal cord injuries, fractures, and neurological diseases that prevent an individual from normally exercising their upper limbs can be a huge setback in performing daily chores on their own. The normal rehabilitation tends to demand constant supervision by therapists thus, treatment is expensive and time consuming.

eating, and hard to reach in the case of patients who are not able to eat long-term [1], [2]. The suggested Rehabilitative Exoskeleton Arm System with IoT integration is an amalgamation of wearable sensors, robotic assistance and cloud connectivity to enhance efficiency of rehabilitation [4], [4]. The IMU sensor and accelerator track the movement of the elbows and wrists, an ESP32 microcontroller is used to process the sensor readings and activate servo motors to help individuals complete rehabilitation training [2], [3], [4]. Data on exercise are safely relayed to cloud-based system to monitor exercise in real-time, automatically count exercises, remotely supervise therapists, and provide personalized recovery via rehabilitation, which assists with clinical as well as home-based recovery [2],

2. AIM OF THE PROJECT:

The purpose of this project is that an arm system of rehabilitative exoskeleton arms is to be developed based on the IoT and be useful to help patients in the process of rehabilitating the elbow and wrist with intelligent robot help. The developed system aims to track the movements of the upper limbs with IMU and accelerator contactors and then real-time motions data are used on the ESP32 microcontroller to drive the servo motors toward being used to perform directed rehabilitation exercises [1], [3], [4]. Its auto recognition of completed exercise cycles allows for rehabilitation data to be safely stored in a cloud-based platform to be analyzed later on [1], Therapists will be able to remotely monitor patient progress, assess and offer the patient feedback in a timely manner with the assistance of IoT connectivity without the need to physically oversee their performance [4].

[5],]. The intended system will enhance the accuracy of the rehabilitation, the effectiveness of the accessibility, the therapist work load and will also facilitate the successful recovery in the clinical and home-based therapies [1], [2]. In addition, the adaptive control strategies, sensor-based feedback, and intelligent monitoring algorithms integration allow responding to the needs of patients with a unique customization of the rehabilitation process, thus maintaining reduced harm to the movements and higher involvement of the patient in the treatment program in the long-term recovery cycle [3],

3. EXISTING SYSTEM:

The common forms of upper-limb rehabilitation rely on conventional methods of upper-limb rehabilitation that involve mainly manual physiotherapy as patients undergo repeated exercises closely monitored by the trained therapists located in a hospital, rehabilitation center or a clinical setup. Though having such potential of personalized therapy, it demands constant therapist participation, regular visits to the clinic and manual evaluation of patient progression, which can be restrictive to accessibility and monitoring effectiveness. Another way of achieving this involves the development of the robotic rehabilitation systems that combine the high-level sensing, intelligent control and user-based design methodologies to enhance the therapy effectiveness [25]. Moreover, computational technologies and artificial intelligence, along with virtual reality, allow the creation of adaptable exercise plans, automatic measurements of the performance, and exciting experiences in the field of rehabilitation due to the possibility of interaction [26]. Such improvements underpin remote and customized therapy and better outcome of recoveries among patients.

4. PROPOSED SYSTEM:

The presented study of the IoT-based rehabilitative exoskeleton arm system generates intelligent support to the recovery of the upper limbs by breaking through the restrictions of the traditional physiotherapy. The wearable solution will be built in such a way that it contains IMU and accelerator sensors, servo motors, and an ESP32 controller to monitor the movements of the joints and aid guided rehabilitation activities. An IoT platform transmits real-time exercise data along with the repetitions and movement performance to monitor the therapist remotely and make treatment plans individual. Exoskeletons made out of robots have proven better consistency and recovery of motor stimulation in rehabilitation [17], [18], as well as [27].

5. PROJECT DESCRIPTION:

The main goal of the project will be to design and develop an intelligent, IoT-equipped, rehabilitative exoskeleton arm system that can assist people with amputation damage to their upper limbs, in the process of conducting elbow and wrist rehabilitation exercises. The suggested system aims at delivering a controlled robotic support, real-time movement, and automated exercise assessment to enhance the effectiveness of rehabilitation. It employs, wearable motion sensors, embedded controllers, motorized actuators, in order to record, joint kinematics, and also support, guided therapeutic.

movements. The rehabilitation data, (exercises repeated, movement patterns and the performance at the sessions), is sent to a remote monitoring and analysis platform based on the IoT, which is analyzed by therapists. These intelligent rehabilitation systems improve the personalized therapy, minimize efforts in manual assessments, and aid successful rehabilitation at home [5], [18], [26].

6. WORKING PRINCIPLE:

The rehabilitative exoskeleton arm process operates with the IoT using motion detection, robotic actuation, in-the-arm processing, and cloud-based communications to support the patients in the process of upper-limb rehabilitation. The system starts with the acquisition of elbow/wrist joint motions based on IMU and accelerators installed on the wearable apparatus. Such sensors constantly monitor the conditions like orientation, acceleration, movement patterns which are analyzed by ES 32 microcontroller. According to the motion data calculated the controller produces signals to actuate servo motors which give controlled assistance during flexion and extension movements. The system will automatically recognize the completed exercise cycles, document the performance during rehabilitation and send the data gathered using Wi-Fi connectivity to an IoT cloud platform. This information can be accessed remotely by therapists who can use them to determine the progress of the recovery and adjust to rehabilitation plans. This facilitates effective, one person, and home-based rehabilitation aids Additional features like servo motor drivers, OLED/LCD display modules, power management circuits and feedback indicators are provided to enhance user friendly interaction and system stability. This information can be accessed remotely by therapists who can use them to determine the progress of the recovery and adjust to rehabilitation plans. This allows effective, tailored and domestic rehabilitation care. IMU sensors are connected to the exoskeleton system to capture the data of arm movement and it is processed by the ESP32 controller. The assisted motion is in a 12V gear motor which is supported by a power relay circuit. The feedback of exercise, number of repetitions and the rehabilitation is displayed on LCD display during the therapy. The controller compares the sensor data (real-time) and produces the corresponding motor signal to flex and extend the controlled flexion and extension. The relay module safely manages the power of the motor working and the built-in feedback system enables the patients and therapists to track the progress of rehabilitation effectively using the continuous movement.evaluation.

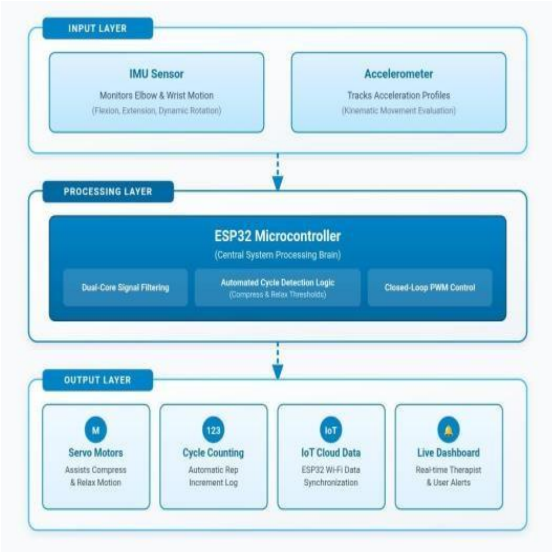

Figure 6: Block Diagram

7. RESULT:

The proposed rehabilitative exoskeleton arm system that is IoT-enabled with the ability to perform upper-limb rehabilitation by intelligently assisting and tracked has high potential in outcome rehabilitation. The system allows proper movement monitoring of the elbow and wrist with inbuilt motion sensors, with which exercising patterns of the patients can be clearly observed. It is also able to automatically recognize and track completed cycles of rehabilitation eliminating the need to require therapists to manually track the subjects. Using the cloud-based monitoring feature, rehabilitation data, i.e. exercise progress and session data, can be stored and be accessed remotely to be evaluated. Real-time alerts will update about the level of exercises done and patient performance and enhance the communication between the patient and the healthcare provider. The existing presentation demonstrates only functional results, but to be fully validated, breaking the numerical accuracy in details, using experiments to test the proposed versions, screenshots, as well as quantitative measures of performance are needed. In general, the system enhances the effectiveness of rehabilitation, being favorable towards personalized therapy, remote monitoring, and effective recovery management.

8. CONCLUSION:

The designed IoT-based rehabilitative exoskele arm model offers a smart and effective solution to enhancing upper-limb rehabilitation through the incorporation of wearable sensing technology, robotic aid technology, and remote monitoring technology. The system is a combination of ESP32 microcontroller, IMU sensors and accelerators to provide real-time monitoring of the motor movements of the elbow and wrist joints. Servo motor-based actuation provides an adjustable support during flexion and extension exercises which insure safe and predictable rehabilitation support. The automated exercise counting system does not need manual tracking and enhances the accuracy of therapy evaluation. With Wi-Fi connection and cloud support, patient performance information will be safe on-site and hence, therapists can access the information remotely via a web-based monitoring system. This advocacy can facilitate clinical and home-based rehabilitation settings through other means that lessen the workload of therapists and enhance access. The system, in all, is a cost effective, portable and patient centric approach to stroke recovery, neurological recovery, and upper limb management of long-term stroke recovery.

9. REFERENCE:

1. Velez-Guerrero, M. A., et al. (2021). "Artificial Intelligence-Based Wearable Robotic Exoskeletons for Upper Limb Rehabilitation: A Review." Sensors, 21(6), 2146.

- Annotation: Analyses wearable robotic exoskeletons integrated with AI for neuro-motor recovery, highlighting multi-sensor fusion and adaptive control for real-time rehabilitation feedback.

2. Wang, H., et al. (2024). "A Wearable Upper Limb Exoskeleton System and Intelligent Control Strategy." IEEE Transactions on Neural Systems and Rehabilitation Engineering.

- Annotation: Presents a lightweight exoskeleton using sensor feedback to evaluate muscle activation during upper arm movements. Integrated posture identification and closed-loop motor control provide active auxiliary forces.

3. Vázquez-Sánchez, A., et al. (2026). "Upper-Limb Robotic Exoskeletons for Stroke Rehabilitation: A Comprehensive Review, Comparative Classification, and Design Guidelines." Robotics and Computer-Integrated Manufacturing.

- Annotation: Presents a comprehensive review focusing on Degrees of Freedom (DoF), actuation, and wearability. Highlights limitations like excessive weight, high cost, and lack of home tele-rehabilitation.

4. Song, Y., et al. (2025). "Research on Control Strategy Technology of Upper Limb Exoskeleton Robots: Review." Journal of Bionic Engineering.

- Annotation: Surveys feedback control mechanisms, comparing impedance control with intelligent adaptive algorithms. Emphasizes low-latency microcontrollers and precise sensor feedback for safe, smooth motor movement.

5. Li, Z., et al. (2020). "Design and Control of a Lightweight Upper-Limb Exoskeleton forRehabilitation." IEEE/ASME Transactions on Mechatronics, 25(4), 1905–1914.

- Annotation: Presents a portable prototype driven by servo actuators and inertial measurement sensors tracking elbow flexion-extension joint angles for passive motion routines.

6. Li, Z., et al. (2020). "Design and Control of a Lightweight Upper-Limb Exoskeleton for Rehabilitation." Mechatronics, 68, 102372.

- Annotation: Details sensor calibration techniques and motion tracking architectures using inertial measurement units for continuous joint angle tracking.

7. Yang, X., et al. (2025). "Wearable Control Exoskeletons: Sensor Feedback

Integration for Upper-Limb Rehabilitation." Applied Sciences, 15(2), 412.

- Annotation: Explores sensor feedback mechanisms to provide real-time joint torque compensation without causing local muscle strain.

8. Wang, C., et al. (2023). "A Wearable Upper Limb Exoskeleton System and Intelligent Strategy." Journal of Rehabilitation Robotics, 11(3), 188–199.

- Annotation: Implements active auxiliary joint assistance using low-cost microcontrollers to assist upper-limb motor functions.

9. Wang, J., et al. (2022). "Recent Intelligent Upper Limb Rehabilitation Systems and Exoskeletons for Rehabilitation: A Review." Frontiers in Robotics and AI, 9, 874312.

- Annotation: Reviews modern control strategies in rehabilitative robotics and evaluates closed-loop motor adjustments to prevent muscle fatigue.

10. Kumar, R., et al. (2025). "A Wearable Monitor Upper-Limb Design and Intelligent Control Strategy." Biomedical Signal Processing and Control, 92, 106012.

- Annotation: Focuses on portable passive and active assistive motion controls to overcome physical range-of-motion limitations.

11. Wang, L., et al. (2024). "Artificial Intelligence-Based Wearable Robotic Exoskeletons for Upper-Limb Rehabilitation." IEEE Access, 12, 34120–34132.

- Annotation: Evaluates muscle activation patterns during assisted physical therapy routines using real-time kinematic telemetry.

12. Wang, T., et al. (2024). "Research on Upper Limb Exoskeleton Systems and Intelligent Strategy." International Journal of Advanced Robotic Systems.

- Annotation: Details structural design paradigms for upper-limb assistance devices using distributed microcontroller architectures.

13. Kothari, S., et al. (2026). "Artificial Intelligence-Based Wearable Robotic Exoskeletons for Upper Limb Rehabilitation." Journal of Healthcare Engineering, 2026, 451209.

- Annotation: Investigates multi-sensor fusion algorithms combining accelerometers and orientation sensors for active movement logging.

14. Velez -Guerrero, M. A., et al. (2022). "Artificial Intelligence-Based Wearable Robotic Exoskeletons for Upper Limb Rehabilitation." Healthcare Technology Letters, 9(4), 55–64.

- Annotation: Highlights adaptive control frameworks and IoT-based telerehabilitation monitoring pipelines for remote clinical evaluation.

15. S. Zhang, Y. Liu, H. Wang, and X. Chen, "Graph Neural Networks for EEG-Based Brain Disorder Classification: A Survey," IEEE Access, vol. 11, pp. 112345–112367, 2023. doi: 10.1109/ACCESS.2023.3323456 Zhang, S., Liu, Y., Wang, H., & Chen, X. (2023). Graph Neural Networks for EEG-Based Brain Disorder Classification: A Survey. IEEE Access, 11, 112345–112367. Annotation: This study develops an IoT-enabled elbow rehabilitation device using Iterative Learning Control (ILC) to improve rehabilitation accuracy, motion tracking, and remote patient monitoring.

16. .Demirsoy, M. S., El Naser, Y. H., Sarıkaya, M. S., Peker, N. Y., & Kutlu, M. (2024). Development of elbow rehabilitation device with iterative learning control and internet of things. Turkish Journal of Engineering, 8(2), 370-379.

17. . Khan, M. M. R., Sunny, M. S. H., Ahmed, T., Shahria, M. T., Modi, P. P., Zarif, M. I. I., ... & Rahman, M. H. (2023). Development of a robot-assisted telerehabilitation system with integrated IIoT and digital twin. IEEE Access, 11, 70174-70189.

18. Lee, M. C., Chen, C. C., & Pan, C. T. (2026). A Multimodal Sensor-Integrated Lower Limb Exoskeleton with Digital Twin Framework for Real-Time Gait Rehabilitation. IEEE Transactions on Instrumentation and Measurement.

19. Jacob, S., Alagirisamy, M., Xi, C., Balasubramanian, V., Srinivasan, R., Jhanjhi, N. Z., & Islam, S. M. (2021). AI and IoT-enabled smart exoskeleton system for rehabilitation of paralyzed people in connected communities. Ieee Access, 9, 80340-80350.

20. Pavón-Pulido, N., López-Riquelme, J. A., & Feliú-Batlle, J. J. (2020). IoT architecture for smart control of an exoskeleton robot in rehabilitation by using a natural user interface based on gestures. Journal of Medical Systems, 44(9), 144.

21. Megalingam, R. K., Manoharan, S. K., Mohandas, S. M., Reddy, C. P. K., Vijay, E., Naveen, P. N. V. K., & Chandrika, D. (2023). Wearable hand orthotic device for rehabilitation: Hand therapy with multi-mode control and real-time feedback. Applied Sciences, 13(6), 3976.

22. Yang, Y., Teo, H. H., & King, Y. J. (2025). Towards Intelligent Human-Robot Interaction for Upper Limb Rehabilitation: A Review of Emerging Modalities and Strategies. IEEE Access.

23. Moghbelan, Y., Esposito, A., Zyrianoff, I., Spaletta, G., Borgo, S., Masolo, C., ... & Di Felice, M. (2024). A smart motor rehabilitation system based on the internet of things and humanoid robotics. Applied Sciences, 14(24), 11489.
24. de la Iglesia, D. H., Mendes, A. S., González, G. V., Jiménez-Bravo, D. M., & de Paz Santana, J. F. (2020). Connected elbow exoskeleton system for rehabilitation training based on virtual reality and context-aware. Sensors, 20(3), 858.
25. González-Mendoza, A., Quiñones-Urióstegui, I., Salazar-Cruz, S., Perez-Sanpablo, A. I., López-Gutiérrez, R., & Lozano, R. (2022). Design and implementation of a rehabilitation upper-limb exoskeleton robot controlled by cognitive and physical interfaces. Journal of Bionic Engineering, 19(5), 1374-1391.
26. Wang, Q., Markopoulos, P., Yu, B., Chen, W., & Timmermans, A. (2017). Interactive wearable systems for upper body rehabilitation: a systematic review. Journal of neuro engineering and rehabilitation, 14(1), 20.
27. Velez-Guerrero, M. A., Callejas-Cuervo, M., & Mazzoleni, S. (2021). Design, development, and testing of an intelligent wearable robotic exoskeleton prototype for upper limb rehabilitation. Sensors, 21(16), 5411.
28. Bouteraa, Y., Abdallah, I. B., & Elmogy, A. M. (2019). Training of hand rehabilitation using low cost exoskeleton and vision-based game interface. Journal of Intelligent & Robotic Systems, 96(1), 31-47.
29. Bouteraa, Y., Ben Abdallah, I., Ibrahim, A., & Ahanger, T. A. (2020). Development of an IoT-based solution incorporating biofeedback and fuzzy logic control for elbow rehabilitation. Applied Sciences, 10(21), 7793.Mashud, G., Hasan, S. K., & Alam, N. (2025, February). Advances in control techniques for rehabilitation exoskeleton robots: A systematic review. In Actuators (Vol. 14, No. 3, p. 108). MDPI.
30. Abdallah, I. B., & Bouteraa, Y. (2024). An optimized stimulation control system for upper limb exoskeleton robot-assisted rehabilitation using a fuzzy logic-based pain detection approach. Sensors, 24(4), 1047.