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PARALLEL NON-SURGICAL ROBOT USED IN THE MEDICAL FIELD: A REVIEW

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ABSTRACT: This review systematically examines recent technological advancements in medical robotics, with a particular focus on the design, functionality, and clinical integration of non-surgical robotic platforms used across various healthcare applications. Using scientific and medical databases, a literature search was carried out (PubMed and Web of Science) to analyze studies from 2015 to the present. From the chosen literature, details on the kinematic and mechanical characteristics were taken. Previous studies focused on whole-body recovery, limb rehabilitation, and the long-term effects of medical robots and wearable exoskeletons. Parallel rehabilitation robots have been considered and classified according to architectural and design elements. Most rehabilitation robot designs support flexion-extension, adduction-abduction (radial-ulnar deviation), pronation-supination, and internal-external rotation movements. However, with a few notable exceptions, most wearable robots do not support abduction (radial-ulnar deviation). The conclusions of this research are as follows: the use of parallel robots enables complicated and specific spatial movements. Due to its parallel construction, the robot has higher stiffness, a more even dispersion of forces, and a better capacity to adapt to the mechanical characteristics of human joints. Most rehabilitation robot designs support supination-pronation, adduction-abduction (radial-ulnar deviation), flexion-extension, and internal-external rotation motions. However, with a few notable exceptions, most wearable robots do not support the adduction-abduction action (radial-ulnar deviation). Robotic rehabilitation devices have great potential, but very few of them have been made available for purchase. Many ideas are not created to become commercialized or even used for personal purposes.

Keywords: Parallel Robot, Non-Surgical Robot, Rehabilitation Robot, Medical Field Robot

1. INTRODUCTION

One of the leading reasons for an older disability that hurts life quality and independent functioning is stroke. Physical therapists can design patient-centered, individualized therapy using rehabilitation robots to obtain a high level of recovery for lost motor skills. Robots used for rehabilitation might be either stationary or moving. It is offered for stationary devices as end effector-based, exoskeleton-based, or parallel systems. Exoskeleton-based systems are predominantly utilized to provide support for mobile devices, with an extraction error approaching zero [1–6]. Robots operating in parallel have drawn the interest of several sectors and researchers over the past few decades. This is because, as compared to serial robots, they have superior precision, stiffness, dynamic performance, and loading capacity [7]. S. J. Bae, et al. [8] presented a 1-DOF wrist robot for rehabilitation. The robot has only a single powered rotational joint dedicated to wrist movement and it carries out wrist joint flexing and extending motions. The wrist Gimbal [9] is a 2-DOF wrist rehabilitation exoskeleton. It produces motion of wrist flexion-extension. It is intended to carry out a five-force comparison study-torque estimating techniques in physical interactions between humans and robots. L. Yin et al. [10,11] presented a robot-assisted therapy for wrist recovery. With employment of an elastic cable, a double parallel mechanism that can separate rotations and translations performs the wrist flexion-extension motion.

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The principal aim of this investigation is to understand the evolution of parallel non-surgical robots employed in the medical area for therapy following a stroke for the upper and lower limbs and trunk. This research will cover each type's composition, benefits, drawbacks, design concerns, and control system.

2. PARALLEL NON-SURGICAL ROBOT USED IN THE MEDICAL FIELD

2.1 Upper limb rehabilitation

Amna et al [12] the aim of this study is to investigate the theoretical design and fabrication of a parallel robotic system dedicated to the rehabilitation of upper and lower limbs. The proposed system provides a modular and cost-effective solution for neurorehabilitation, exhibiting high precision and repeatability in executing rehabilitation trajectories through its reconfigurable architecture and integrated inertial sensing.

Taheri, et al [13] offer a parallel-actuated end-effector robot with low resistance and good rear-driveability that is intended to help with upper extremity rehabilitation in space. The best design that took into consideration force variation, mechanical advantage, workspace area, and counterbalance was found via gradient-based optimization. According to these requirements (low resistance, high rear-drivability), a beta prototype was constructed, and it underwent fit and function testing in addition to early controller performance testing. Fig. 1 shows the 3D CAD model for the PARTNER robot.

FIGURE 1 The viewer interacted with both the PARTNER (right) and its 3D CAD model (left) [12]

Brahmi et al. [14] present a 7-DOF exoskeleton for restoration of functional ability in the forearm and wrist, elbow, and shoulder. The robot has seven active revolute joints: three shoulder joints, one elbow joint, one forearm joint, and two wrist joints; and it carries out elbow flexion and extension movements, wrist radial-ulnar deviation, forearm flexion and extension, and supination. Target's shoulder abduction muscle, rotation of the shoulder, internal and external.

Hernandez et al. [15] presented a robotic device designed for upper limb therapy driven by cables at the same time. First, the suggested approach can be utilized for enhancing the design efficiency of a manipulator powered by cable for the rehabilitation of upper limbs, and secondly, applied to additional manipulators powered by cables. The robotic structure has many advantages, including: portability, low cost, user-friendly, re-configurable architecture, and a large workspace.

Guang et al. [16] used a PARM robot to decrease inertia and increase rigidity, capability, and accuracy. The parallel mechanism was developed. To help patients train more effectively, the robot utilizes a monitor to show trajectory data and give isometric direct visual feedback. The robot also employs an assist-as-needed technique to enhance patient-robot communication. Fig. 2 shows the PARM robot.

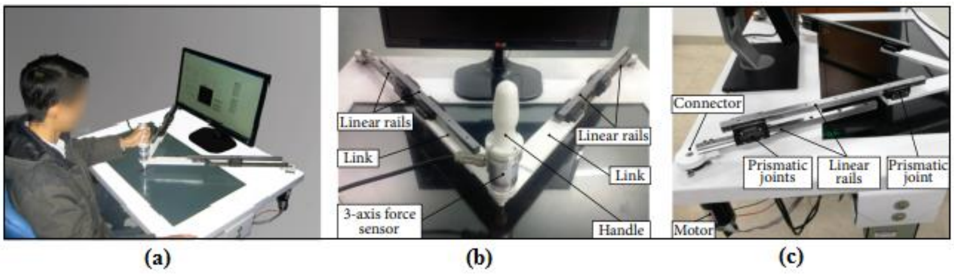


FIGURE 2 The mechanical architecture of PARM [15]. (a) Overview of robot; (b) Robot parallel mechanism; (c) Connections between motors and joints

Gherman et al. [17] designed the ParReEx robot, a 4-DOF elbow and wrist parallel rehabilitation robot. The robot has four active revolute joints: two elbow joints and two wrist joints; It enables the execution of wrist flexion–extension, elbow pronation–supination, elbow flexion–extension, and wrist adduction–abduction, also referred to as radial–ulnar deviation. Pisla et al. [18] the show-off ASPIRE robot is a shoulder spherical parallel rehabilitation robot. This parallel design enables the deployment of additional modules to other spherical joints, including the elbow, forearm, and wrist. This increases the upper limb's motion amplitudes significantly and increases the robot's capabilities. There are two versions of the robot: Fig. 3a depicts the closed form, while Fig. 3b shows the open version.

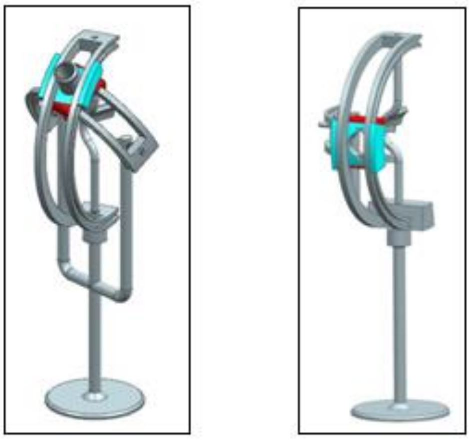


FIGURE 3 The two versions of ASPIRE [18]
(a) Closed version (b) Open version

Plitea et al. [19] studied the ASPIRE robot as a shoulder spherical parallel rehabilitation robot. This parallel architecture allows for the deployment of additional modules to other spherical joints, like the elbow and wrist. A 3D a representation of the ASPIRE robotic system using CAD is illustrated in Fig. 4.

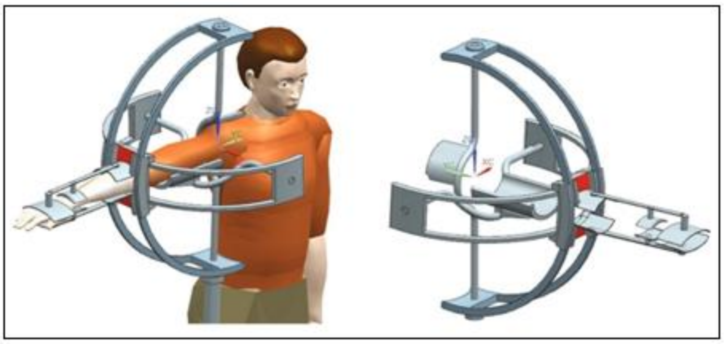


FIGURE 4 3D CAD model of the ASPIRE robot [18]

Hunt et al. [20] presented a shoulder rehabilitation exoskeleton. Other spherical joints, such as the wrist, ankle, and hip, can also use this parallel design. For the wrist, ankle, and hip devices, this may include lifting, jogging, and stair climbing, respectively. The exoskeleton of the shoulder is depicted in Fig. 5.

FIGURE 5 The shoulder exoskeleton [19]

Leiyu et al. [21] proposed a 5-DOF shoulder, elbow, and forearm rehabilitation Co-Exoskeleton. Two modules are included with the robot: a 3-DOF module for shoulder therapy and a 1-DOF module for elbow rehabilitation, see Fig. 6. It performs the following movements: adduction and abduction of the elbow, facilitated through five active revolute joints and four passive sliding joints, and shoulder adduction-abduction. The robot includes a turntable with adjustability, an exoskeleton, and a cantilever beam. The external skeleton may be rotated by the cantilever to accommodate various shoulder types. To accommodate a range of patient heights, the exoskeleton is mounted atop a liftable column.

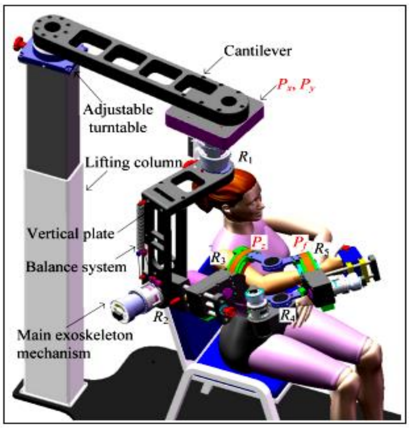
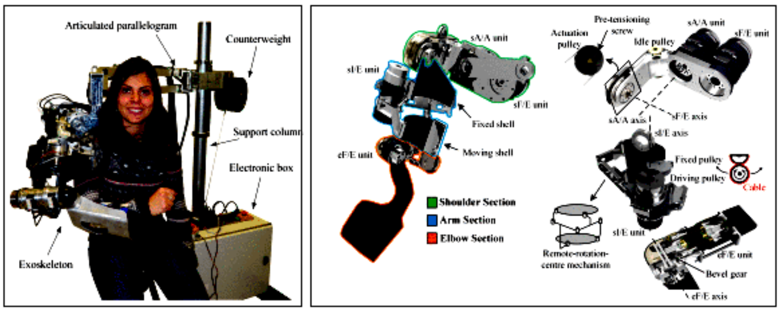


FIGURE 6 Anatomy of the Co-Exoskeleton [20]

Trigili et al [22] proposed NESM robot is a 4-DOF shoulder and elbow rehabilitation exoskeleton. The robot includes three modules: shoulder rehabilitation module, arm rehabilitation module, and elbow rehabilitation module. Three shoulder joints and one elbow joint make up the robot's four active joints. It can flex and extend its shoulders, adduct and abduct its shoulders, rotate its shoulders internally and externally, and bend and extend its elbows. The robot employs two control methods: Robots and patients are in command, see Fig. 7. The robot uses two control strategies: both the robot and the patient are in control. The robotic structure has many advantages, including a complex control system and the ability to adjust to various patient anthropometric characteristics and varied rehabilitation motions.



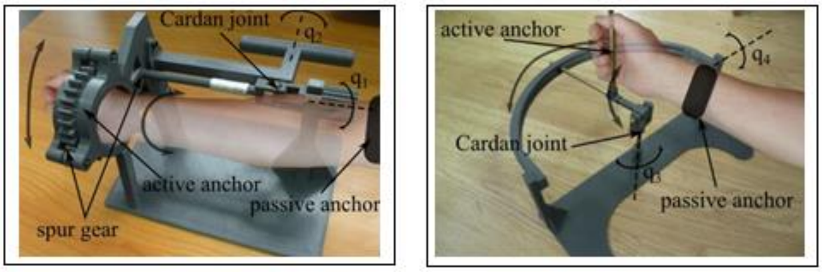
(a) (b)

FIGURE 7 (a)-An overview of the NESM exoskeleton on a healthy individual, as well as information on the NESM actuation units, and (b) the support structure of the device [21].

Laribi et al [23] mentioned that LAWEX is a parallel rehabilitation robot driven by cables in the upper limb. The robotic structure has many advantages, including small size, portability, low cost, user-friendly re-configurable architecture, large workspace, and minimum cable tension distributions. The robot gathers quantitative information on the patient's prescribed workspace using a motion capture device. The motion-capturing apparatus is depicted in Fig. 8.

FIGURE 8 The motion capture system [22]

Birlescu et al [24] studied the ParReEx is a 4-DOF elbow and wrist parallel rehabilitation robot. The robot has four active revolute joints: two elbow joints and two wrist joints; and it performs motion of wrist movements including flexion, extension, adduction, and abduction of the shoulder, along with elbow flexion and extension, are facilitated."(radial-ulnar deviation). Fig. 9a shows an elbow rehabilitation module. Fig. 9b shows a wrist rehabilitation module.



(a) Elbow rehabilitation module. (b) Wrist rehabilitation module.

FIGURE 9 The robotic system [23]

Hunt et al [25] discuss that the 4B-SPM is a shoulder and elbow spherical parallelism manipulation (SPM)with three 4-bar (4B) substructures. Spherical joints like the wrist, ankle, and hip can also use this parallel design. The robotic structure has many advantages, including: parallel architecture and high acceleration. Fig. 10 depicts the exoskeleton of the 4B-SPM robotic device.

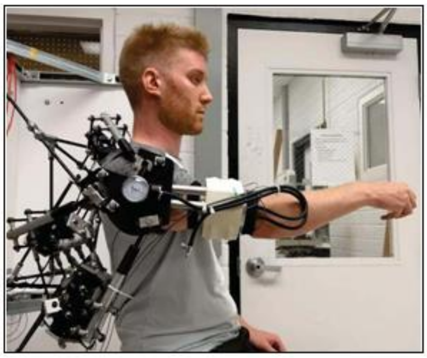


FIGURE 10 **The 4B-SPM exoskeleton [24]**

Zhang et al [26] studied the Parallel Wrist Rehabilitation Robot (PWRR) is a 2-DOF wrist parallel rehabilitation robot that utilizes the 2-SPU/RR architecture. The robot has two active revolute joints: two wrist joints; it performs motion of wrist flexion-extension and wrist radial-ulnar deviation. The robotic structure has many advantages, including lightweight, small size, compact structure, low cost, simple configuration, wearable convenience, superior flexibility, and actuator non-redundancy. A wrist flexion-extension therapy module is depicted in Fig. 11a. A wrist radial-ulnar rehabilitation module is depicted in Fig. 11b.

(a) Wrist flexion-extension rehabilitation module.

(b) Wrist radial-ulnar rehabilitation module.

FIGURE 11 **The robotic system [25]**

Robotic rehabilitation for the elbow and wrist, called ParReEx. The robot includes two modules: an elbow rehabilitation module and a both modules, including the wrist rehabilitation unit, utilize a common control box. For urgent cases, an emergency button is situated at the top of the box. Fig.12 shows the ParReExrobot [27].

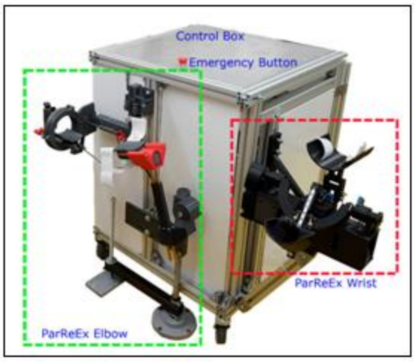


FIGURE 12 **The ParReEx robot [26]**

ASPIRE is a shoulder parallel rehabilitation robot with modular construction. The robot includes two modules: a 3-DOF spherical mechanism the module along with a serial component mechanism module. The 3-DOF spherical mechanism module performs motion of shoulder flexion-extension, shoulder adduction-abduction (radial-ulnar deviation), and shoulder pronation-supination. The robotic structure has many advantages, including the ability to adjust to various patient anthropometric characteristics and varied rehabilitation motions. Fig. 13 shows the ASPIRE robot [28].

FIGURE 13 The ASPIRE robot [27]

Curcio et al. [29] proposed an elbow and wrist parallel rehabilitation robot. The robotic structure has many advantages, including light weight, small size, compact structure, portability, low cost, and home use. A 3D CAD model of the robot may be seen in Fig. 14.

FIGURE 14 3D CAD model of the robot [28]

2.2 Lower Limb Rehabilitation

Geonea and Tarnita [30]. The goal of this effort is to create and numerically characterize a novel exoskeleton system for the assistance and rehabilitation of human leg movements. The exoskeleton solution is easy to use, inexpensive, anthropomorphic, and adaptable to human subjects. The exoskeleton mechatronic structure is the subject of the design aspect. accomplished in the virtual SolidWorks environment. In MSC, numerical simulation is carried out. ADAMS model-building environment.

According to Tucan et al. [31], the robotic structure in parallel to the anthropomorphic characteristics of the human body, and design specifications were taken into account when creating RAISE. This is a robotic framework designed to assist individuals who are bedridden. It is made up of two distinct modules: one for the rehabilitation of ankle flexion, extension, adduction, and abduction, and another for the rehabilitation of hip and knee flexion and extension. Fig. 15 displays the RAISE robot's 3D CAD model.

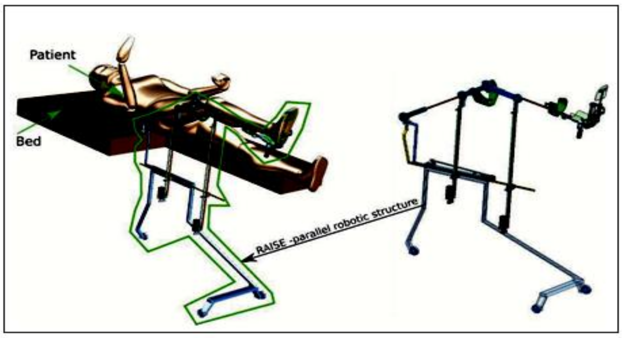
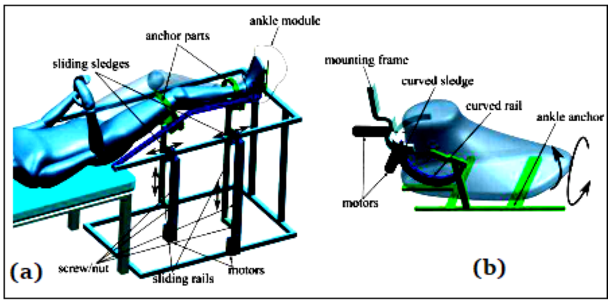


FIGURE 15 3D CAD model of the RAISE robot [30]

Vaida et al. [32] Fig. 16 displays the initial schematic design and key elements that make up the parallel robotic system RAISE. Since the ankle module has two degrees of freedom, the joint can be positioned along two axes to create the flexion/extension and abduction/adduction motions (Figure 16b). The RAISE robotic system can simultaneously rehabilitate every joint in a tree because of the coupling between the limb and ankle rehabilitation modules.



(a) The module for hip-knee rehabilitation. (b) Ankle rehabilitation module.
FIGURE 16 Robotic system 3D CAD model [31]

Gherman et al. [33] the study examines the workspace characteristics of RECOVER, a parallel robot intended for lower limb therapy. The kinematic model was developed to directly relate the anatomical joint angles to the robot's active joints. The robot's task-specific workspace is free from singularities, as shown by the examination of the unique features of the robotic system about the medical task and anatomical limitations. Comparing numerical simulations with experimentally recorded gait cycle data shows that the RECOVER parallel robotic system is a feasible solution for gait rehabilitation. It has the ability to move the ankle, knee, hip, and ankle inversion or eversion. This type of robot is displayed in Fig. 17.

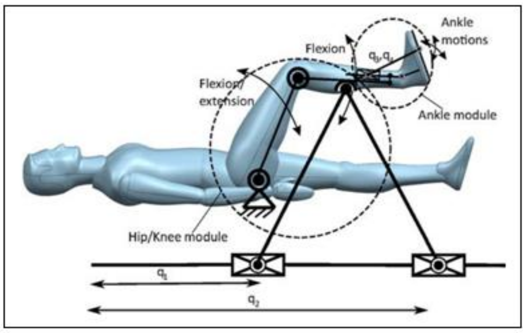
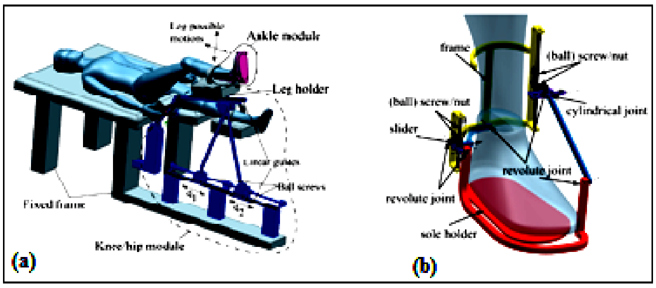


FIGURE 17 RECOVER robot's 3D CAD model [32]

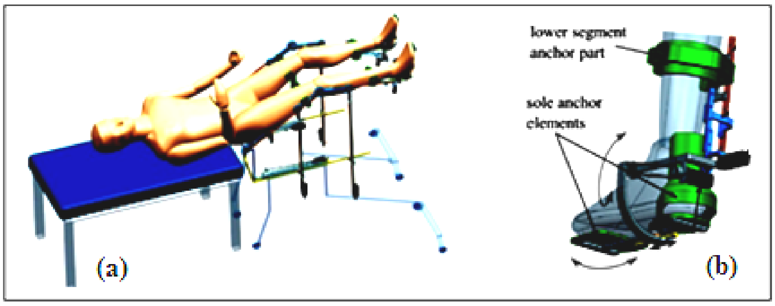
Gherman et al. [34] A therapy robot designed for hip, knee, and ankle rehabilitation was presented. The robot performs ankle flexion-extension, hip flexion-extension, knee flexion-extension, and ankle abduction-adduction movements. It consists of two modules: a 2-DOF hip-knee rehabilitation module and a 2-DOF ankle rehabilitation module. Figure 18a illustrates a Computer-Aided Design (CAD) model of the hip-knee rehabilitation module. Fig. 18b displays a 3D CAD representation of the ankle rehabilitation module.



(a) Hip-knee rehabilitation scheme. (b) Ankle rehab modules.
FIGURE 18 3D CAD model of the robot [33]

Vaida et al. [35] Illustrations have been provided for the RAISE parallel rehabilitation robot, designed to assist in the treatment of the ankle, knee, and hip. The robot is capable of performing knee flexion–extension, ankle abduction–

adduction, ankle dorsiflexion–plantar flexion, and hip flexion–extension movements. Its structural design offers several advantages, including ease of use, adaptability, well-positioned control points aligned with anatomical joints, and a compliant mechanism for the limb segments. Figure 19a presents a 3D CAD model of the hip–knee rehabilitation module, while Figure 19b depicts a 3D CAD model of the ankle rehabilitation module.



(a) The module for hip-knee rehabilitation (b) The module on ankle rehabilitation.
FIGURE 19 shows the robot's 3D CAD model [34]

Diaz-Caneja et al. [36] designed a torso parallel rehabilitation robot. Instead of having joints powered by motors, the robot has flexible bars that flex to absorb motor torque and deliver it to the patient's jacket. Fig. 20 shows the robotic system.

FIGURE 20 The robotic system [35]

3. Conclusions

After mentioning previous studies, a set of conclusions was obtained:

i- The robot will be used as a test platform to look into motor learning and assess how well control schemes work in post-stroke movement rehabilitation.

ii- A novel inverse kinematics approach was developed and described to address the redundancy of a 7-DOF exoskeleton robot, enabling the generation of a passive rehabilitation path that closely mimics natural human motion. The inverse kinematics algorithm was directly inspired by the biomechanics of human arm movement.

iii- To maximize the range of rehabilitation movements possible for the cable-driven structure, the methods suggested in [14] can be used with other cable-driven manipulators in addition to the initial one.

iv- An isometric screen included in the interface could enhance motion perception and engagement. To remove the frictional and inertial influence, in addition to the mechanical design, the derivative of the Jacobin matrix and the notion of virtual work were introduced.

v- ASPIRE is a new type of spherical robotic system. It combines a broad range of motion for the shoulder joint with a straightforward kinematic architecture. The motion simulation and workspace analysis show how well the robot performs in shoulder rehabilitation.

vi- The mechanism's action can help with rehabilitation and human mobility; similar variation graphics are produced when the angular motion of the exoskeleton's knee and hip joints is contrasted with those of a human person in good health.

vii- Gait data from healthy volunteers, combined with their anthropometric measurements, were utilized to design the gait challenge. Subsequently, the RECOVER parallel robotic system was simulated to accomplish the intended objective.

viii- The simulation demonstrated that the RECOVER technology is feasible for gait rehabilitation.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest

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