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Design of A Low-Cost Wrist Rehabilitation Robot for Home Use

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***Abstract*—The primary objective of this study is to develop a lightweight, compact, and portable medical wrist rehabilitation device. The idea behind the project is that the device will be used by the patient, in the comfort of their home; so the device needs to be easy to wear and use, also safety is a key factor. The target users are patients who need assistance with two specific wrist movements - flexion-extension and radial-ulnar deviation. To achieve this objective, 3D CAD models will be developed to design the mechanical components of the robot. Kinematic and kinetic calculations will be done and simulated using tools like Solidworks Motion. Additionally, finite element analysis using software such as Solidworks and ANSYS will analyze component stresses to ensure safety factors for all parts meet or exceed industry standards. After validating the calculations with simulation, the next steps will involve selecting the electric components. This includes choosing two appropriately sized motors, one for each degree of freedom, that will apply sufficient torque for joint movements, without excessive force to disturb the patient based on torque requirements for wrist rehabilitation. In addition, a controller with sufficient processing properties will be evaluated and selected to interface with the motors/drivers. Testing on people with a healthy wrist movement extent will conclude the objectives. The prototype will be tested to verify its performance through quantitative and qualitative feedback. Key metrics for testing will include a range of motion, torque output, electrical current usage, and safety. The design will also be reconsidered based on user feedback to enhance comfort, usability, and ability to smoothly assist natural wrist motions during rehabilitation exercises. Comprehensive documentation of all aspects of the design, development, and testing process will likewise be provided.**

***Keywords*—upper-limb rehabilitation, wrist rehabilitation, robotic rehabilitation, robot design, medical device.**

I. Introduction

The necessity for wrist rehabilitation is increasing due to several factors, including the prevalence of age-related muscular weakness, occupational injuries, road traffic accidents, trauma sustained in military service, and long-term medical disorders[1]. It is exceedingly challenging to enhance muscular strength and partially or fully restore wrist functionality when dealing with specific wrist abnormalities. For the sake of their well-being, as well as that of their families and close social circle, it is imperative that these individuals restore their capacity to work, maintain good health, and engage in social activities [2]. Consequently, many medical therapies have been developed to address these issues, with a core focus on treatment modalities. The specific characteristics of the patient's wrist condition inform the selection of the most appropriate technique, ensuring a bespoke approach that aligns with their individual rehabilitation goals [3].

This study addresses a critical gap in the rehabilitation sector, specifically focusing on wrist impairments caused by various factors [4]. Individuals affected, including those with conditions like age-related muscle weakness, industrial accidents, traffic events, injuries sustained in the military, and chronic diseases, often find themselves excluded from both work and social life due to the debilitating nature of their conditions. Wrist-related disabilities have a significant impact on daily functioning and general health. Our study, which is exclusively dedicated to wrist rehabilitation, aims to address this issue. It differs from existing solutions in that it is portable and affordable, as evidenced by our review of the literature (Ref. [5], [6], [7], [8], [9], [10], [11], [12]). The shortage of physiotherapists per patient, transportation issues for both the patient and the physiotherapist, the high cost of procedures, and the absence of therapeutic exercise equipment in advanced countries underscore the need for innovative rehabilitation approaches, highlighting the significance of our project. Physiotherapy robots designed for wrist rehabilitation aim to reinstate the previous functions of the wrist through the implementation of specific exercises. Our robot focuses on reinstating wrist flexion/extension and radial/ulnar deviation motion capabilities through specialized exercises designed for the wrist region. Moreover, our design's emphasis on user-friendliness and portability adds an extra layer of importance. Unlike other systems, which are often heavy, complex, and designed for the upper limb or focused solely on the hand, our project is exclusively dedicated to wrist rehabilitation. In essence, our project's efficiency, affordability, and user-centric design make it a valuable contribution to improving the quality of life for those requiring wrist rehabilitation, especially considering the challenges they face in accessing adequate rehabilitation services.

II. Related Studies

In the study conducted by M. M. R. Khan et al. [13] offering upper limb rehabilitation therapy, an intelligent therapeutic

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Fig. 1: Wrist rehabilitation-robots from the literature

robot called iTbot which is shown in Fig.1 a) with 2 - degrees of freedom (DoFs) was designed. This paper introduces the non-linear control of iTbot, which utilizes modified sliding mode control (SMC).

In another study by R. Iandolo et al. [3], the wrist rehabilitation robot was designed as a 3-DoF manipulandum designed for motor control research and rehabilitation presented in Fig.1 b). It allows a full range of motion for the human wrist and is fully backdrivable, enabling the design of experiments where low endpoint impedance was crucial. When a subject attempts to back drive the robot, the interaction forces must be minimal, providing a sensation as if no device were connected. The range of motion (ROM) of the 3-DOFs nearly matches that of a typical human wrist: 65°/70° Flexion(F)/Extension(E), 15°/30° Adduction(Ad)/Abduction(Ab), 90°/90° Pronation (P)/Supination(S) for a typical human subject, versus ±72° (F/E), 45°/27° (Ad/Ab), and ±80° (P/S) for the wrist rehabilitation robot.

Another rehabilitation device available on the market is offered for sale by Company Yıkang Medical [14]. This technology facilitates training across 6-DoF within three-dimensional space, allowing for precise control in this 3D environment. It can accurately assess movements along six different axes (shoulder adduction and abduction, shoulder flexion, shoulder joint external and internal rotation, elbow flexion, forearm pronation and supination, and wrist palmar flexion and dorsiflexion) at the three main joints of the upper limb (shoulder, elbow, and wrist). Real-time analysis of assessment data is possible, aiding therapists in devising treatment plans and thereby improving clinical efficiency. The system incorporates five training modes, including passive training, active-passive training, and active training, and can be utilized throughout the entire rehabilitation process. As illustrated in Fig.1 c), the device's primary disadvantages are its complexity, lack of portability, necessity for expert assistance, and high cost.

Finally, in the study conducted by D. Xu et al. [15], the wrist rehabilitation device, called WReD (in Fig.1 d)) is a reconfigurable device designed for wrist rehabilitation. It can be adjusted for various hand orientation training, including wrist flexion/extension, radial/ulnar deviation, and a combined motion of them. The device utilizes a motor for actuation and includes sensing components such as an angle sensor and a torque sensor. An adaptive forearm holder is also incorporated to compensate for potential misalignment between the human wrist and the rotation axis of the device.

III. Materials and Methods

The robot is equipped with 2-DoF for flexion/extension and radial/ulnar deviation movements. In light of the findings of the literature review, and to ensure that the maximum flexion/extension (70°/60°) movements are carried out within the safe zone, it was decided that these angles should be set at ±50°. The maximum permissible deviation of the ulna is 30-40 degrees, while that of the radius is 15-20 degrees. Furthermore, while the material selection and the measurement values of the component are provided, the objective is to dampen the vibrations during the operation of the robot and to ensure that the requisite strength values are attained for the parts. Accordingly, ABS was selected as the optimal filament type. The use of ABS filament is preferable due to its lightweight nature, enhanced durability in comparison to alternative filament types, and cost-effectiveness. Furthermore, the distribution and accumulation of stress will be examined through the utilization of the finite element method in ANSYS and ABAQUS programs, with modifications to the design or selected materials being implemented to minimize said stress. The motor selected for use in the design will be chosen based on the criteria of enabling the robot to move, avoiding any increase in weight, and ensuring durability in the event of a load. In this regard, the torque, speed, weight, and dimensions of the motors will be taken into account in the selection process.

Using position control as a control method was found appropriate. For this reason, it was tried to work with the IMU sensor. The acceleration data for each axis from the IMU was obtained. We got the acceleration data for each axis from the IMU. By converting the obtained acceleration data into the value of angles, it was tried to estimate the position of the robot. Since the servo motor was used as a motor, the angle data that should go to the servo motor was entered. Since we use a servo motor as a motor, we entered the angle data that should go to the servo motor. We tried to check the correctness of its position via the IMU sensor. The acceleration data was separated from the noise using a 63 Hz high pass filter. We also separated the acceleration data from the noise using a 63 Hz high pass filter.

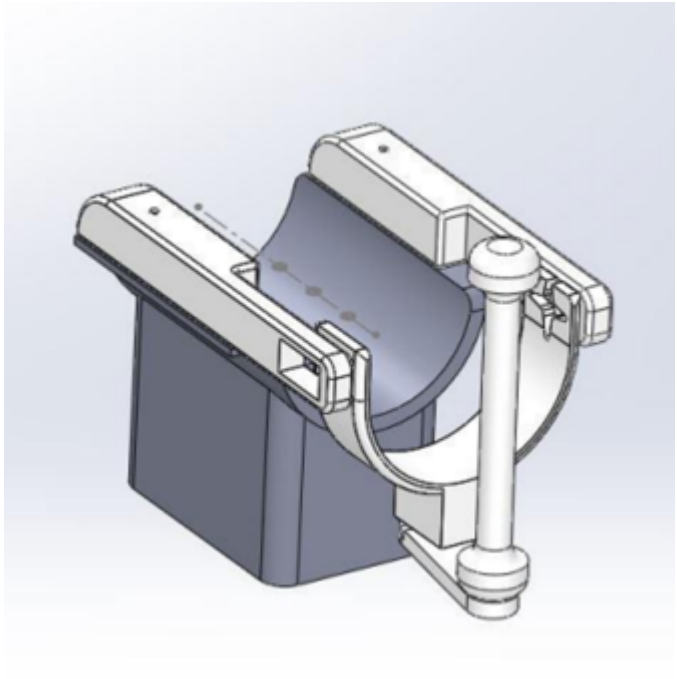


Fig. 2: Preliminary mechanical design

IV. Results and Discussion

The system design exhibits 2-DoF, enabling it to perform precise flexion/extension and radial/ulnar deviation movements. The points to be considered in the design that have been decided are as follows:

- It has been taken into account that the patient, who will use it first, can be easily used and easily transported.
- This Robot weighs approximately 1.5-2 kg. It is a size that any person can easily carry from one place to another.
- This robot is designed according to the hand, arm, and wrist size of an average person.
- The next point to be considered is the cost. Parts of this robot were printed using a 3D printer. For this reason, the production cost is quite reasonable. ABS Filament is used as the material.

Considering the above-mentioned criteria, it was decided that the design shown in Fig.2 was the most suitable.

The use of PLA filament in the 3D printing process was motivated by considerations of lightness, durability, and cost-effectiveness. Furthermore, the design was optimized through the application of a stress analysis. To get more accurate results from the analysis of the project, the design was analyzed in 3 separate parts: the fixed part where the arm is placed, the part that provides the radial-ulnar deviation movement, and the frontmost part that provides the flexion-extension movements. The production of the project was made with ABS filament. ABS has a tensile yield strength of 7 MPa. To be able to say that the part is durable in stress analysis, the value obtained by dividing the material yield stress (in this case ABS) by the stress value of the analyzed part must be greater than 1. As seen in the stress analysis in Fig.3, the stress value of the part

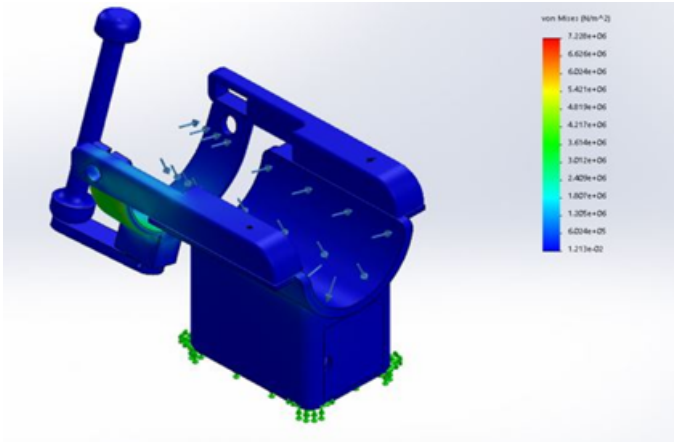


Fig. 3: Finite-Element Analysis of the design

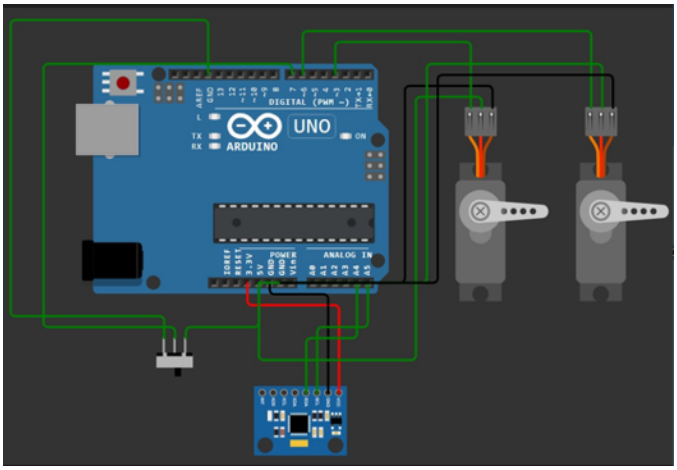


Fig. 4: Hardware components

is 3.21 MPa. $\sigma y(ABS)/3.21 > 1$ (It can be said that the piece is durable.)

The motor was selected based on the torque required by the system. Hardware system presented in Fig.4. It included Arduino Mega, LSM9DS1 9-DOF IMU, GWS S35+XF, and GWS S03N STD. servo motors, and POWER HD CONTINUOUS ROTATION SERVO AR-3606HB components. On the other side software, MATLAB, and Simulink programs have been used for simulation and controller design algorithms. Since Arduino has been used as a microcontroller, C++ language used.

The system was observed to exhibit smooth and light movement within the specified degrees of freedom, with rotation matrices calculated for two different joint points shown in Fig.5. The design was optimized to ensure user comfort and safety, as well as system functionality. A straightforward and dependable control mechanism was devised using the position control strategy.

Our final product design has been altered considerably compared to the project's initial stage. We made a prototype by 3D printing presented in Fig.6, so we could observe and

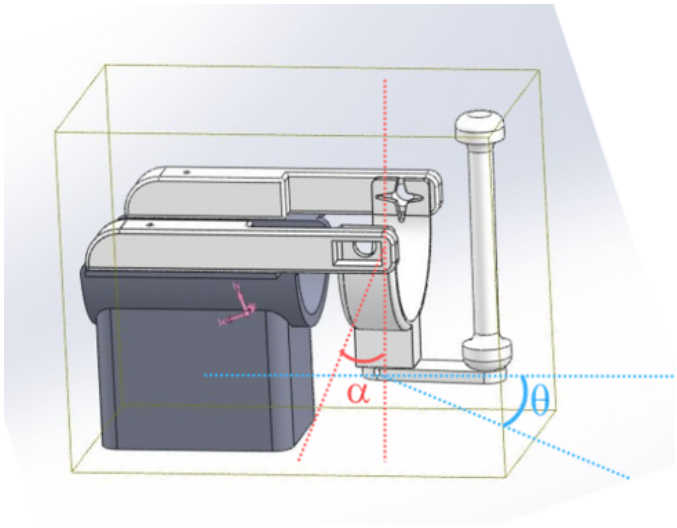


Fig. 5: Robot joint points and dynamic modeling



Fig. 6: Final design and prototype of the study

come up with some drawbacks.

V. Conclusion

In conclusion, the low-budget wrist rehabilitation robot developed in this study represents a significant advancement in the restoration of wrist mobility. The objective of the project is to provide a specialised rehabilitation tool that considers the substantial impact that wrist dysfunction has on the quality of life of individuals. The materials used in the construction of the robot serve to enhance its efficacy by improving durability and functionality. The manufacturing phase is of particular significance to the project, with specific reference to the use of materials such as aluminium, steel and titanium, which are noted for their durability, strength and functionality. An additional option is the use of carbon fibre-reinforced plastics or fibreglass composites, which offer a potential compromise between high strength and lightweight. Further suggestions for future work are welcome, including collaboration with healthcare professionals for clinical validation and continuous optimisation of costs for wider access. The continuous collaboration, integration of user feedback, and strength of the material will be pivotal in shaping a device with the potential to significantly contribute to the field of wrist rehabilitation. Moreover, it is emphasised that improvements to the precision and control mechanisms are essential, which can be accomplished through the incorporation of motors and encoders. It is intended that future developments will enhance the accessibility and motivation of the rehabilitation process through the introduction of innovative features such as a user interface and interactive games. It is anticipated that this project will facilitate effective wrist rehabilitation and provide support for patient recovery processes.

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