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Mechanical Design Procedure and Modelling for 8-DOF Upper Limb Rehabilitation Robotic

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ABSTRACT

Treating muscular medical injuries that impede movement of the human body has become of wide interest because of the importance it holds for improving the lives of people who are exposed to this type of injury. During the past years, several studies have attempted to create a robot that works to rehabilitate the injured upper limbs of the human body. In this research, a curriculum for the procedures will be developed for designing a medical robot by displaying the volumetric tolerances for this robot according to the age and weight of the injured person and the weight and volumetric constants for each part of the robot to be used in the mathematical model that is used to move this robot. Then the design of a robot with 8 DOF will be presented and examined using finite element analysis (FEA) in order to assess its ability to withstand and function in accordance with the load exerted by human weight. The upper limb exoskeleton model is subjected to analysis utilizing the Ansys®software, which facilitates the execution of von Mises stress analysis.

Keywords: Anthropometric, Finite element analysis FEA, Robotic, Upper limp exoskeletons, Von mises stress analysis

Introduction

The application of upper-limb exoskeleton robots encompasses a variety of applications, including but not limited to rehabilitation, mobility aid, and human power amplification, among others.[1] Based on the provided application, they must fulfil distinct criteria. Nevertheless, it is imperative that these various categories adhere to many crucial overarching criteria.

Ensuring safety is a major issue when developing systems that directly interact with human users. To ensure the safe operation of a mechanical system, it is necessary to implement specific controls. These include mechanical breaks to limit range of motion (ROM) regulation, installing software emergency shut-offs, mechanical constrains blocks and ensuring alignment with human joints.[2] Furthermore, in the case that the robot necessitates attachment to a support, it is important that the mechanism remains capable of performing anthropomorphic motion. Deviation from the physiologically right angle of human joints is frequently observed in exoskeleton robots. In essence, misalignment between exoskeleton joints and human joints can result in significant joint injury. Hence, it is important to take into account other mechanisms in order to counterbalance the adverse impact resulting from the mechanism. Alternatively, the exoskeleton of the robot must be securely fastened to the separate body segments to minimize substantial deviations.[3] In addition, it should be noted that the robot is positioned on the surface of the skin rather than along the hypothetical line connecting the joint rotation centers. Consequently, a gap will exist between the rotation center of the robot segments joints and that of the corresponding human segments joints. The mentioned gap necessitates careful consideration while constructing the joints of the exoskeleton, particularly in the case of complex joints that include several degrees of freedom, such as the shoulder.[4]

The shoulder complex is considered to be one of the most intricate anatomical regions inside the human body. Therefore, the process of ball-and-socket joint constructing, such as the shoulder complex, necessitates the include of certain factors. The presence of

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motion singularities resulting from the center offset and the mathematical representation of these joints give a significant challenge in the study of the shoulder joint. The design of a shoulder joint exoskeleton should not only consider the physical ROM required by the joint but also ensure that it does not impede the natural mobility of the joint.[5–7] Additionally, it should be noted that the center of rotation (COR) of the shoulder joint undergoes modifications throughout the motion. The observed motion is contingent upon the characteristics of the scapular motion and the joint surfaces. The influence of joint surface characteristics on shoulder mobility may be deemed insignificant. Nevertheless, as previously mentioned, the impact of scapular motion on shoulder complex might be substantial if it is beyond a certain threshold. Therefore, it is imperative to exercise caution while performing an activity of daily living (ADL) that involves a range of motion exceeding the intended range. This is crucial in order to prevent any additional physical damaging to the shoulder.

The elbow-joint involves three main bones, namely the humerus, radius and ulna. The elbow-joint has been conceptualized as a uniaxial-hinge joint.[8] The robot's rotation axis, situated at the user's elbow-joint, may be represented as a basic revolute joint in the model.

Islam, M.R[9] created a novel upper arm equipped with sensors to accurately detect the forces exerted during interactions with the arm. Both joint-based and end-point workouts were subjected to a PID control approach. The trial findings confirmed the effectiveness of both forms of functionality of the built robot. While, Hairui LIU[10] chose several sorts of elements and created a finite element model after analyzing the results, irrelevant sections were eliminated and simplified, while the essential components were enhanced through parameter definition to optimize and redesign the structure. The static analysis and harmonious response analysis of the updated model demonstrate significant improvements in the structural mechanical characteristics compared to the original design. These modifications successfully meet all design criteria.

To provide effective support, it is essential to develop rehabilitation robots to enable them to replicate the normal human motion across different groups of injured cases. To clarify, the complex gait patterns revealed by people could differ on a case-by-case basis due to variations in the range of motion and size specific to each injured case. However, it is important for the robot to possess the capability of adapting to a new motion rang trajectory for ensure the execution of seamless motion while also preventing any potential bodily harm. The objective is accomplished through the process of converting human motion characteristics into biomechanical design standards. This implies that individuals should possess anthropomorphic characteristics and adhere to ergonomic principles.[11]

Exoskeleton structural components measurement and modeling

Anthropometrics properties of the human body

Anthropometric measurements usually are studies used for historical objectives. In the last few years these studies have started to be used for the human body and man-machine, tool, vehicles, etc. interaction, however anthropometrics is considered a branch of anthropology which is defined as "the physical measures of a person's size, form, and functional capacities"[12] and "the science of studying present and past of humans, where the knowledge from the social and biological sciences meet the humanities and physical sciences" in American Anthropological Association definitions.[13]

Segment dimensions

By considering the segments length between joints, it can easily describe the human body size in a detailed manner, which varies with the human gender, body type, age and race. Gull MA & Bai S.[14,15] put the first proposal for the model of estimates of joint locations and segment lengths, while Drillis and Contini[16,17] noted that this average value evaluated from Fig. 1[18] is a segment size of the robot segments parts but not replace real life data from individuals.

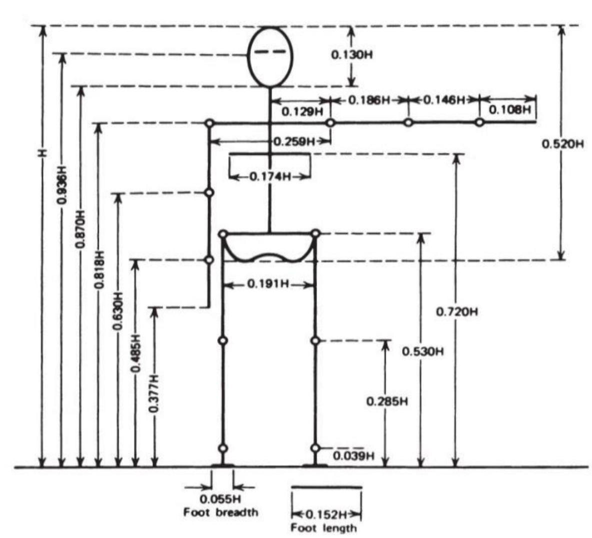

Fig. 1. Segment-length as a function of height.[18]

Table 1. Weight, center of gravity, length, and radius of gyration of targeted limbs of upper extremities.[18]

Segment	Upper Arm	Forearm	Hand	Forearm and Hand
Definition of Segment	Glenohumeral axis/elbow axis	From Elbow axis to Ulnar styloid	From Wrist axis to Knuckle II middle finger	From Elbow axis to Ulnar styloid
Weight Ratio Segment/ Total Body	0.028	0.016	0.006	0.022
Center of Mass Ratio Segment CG (Proximal)/ Segment Length	0.436	0.430	0.506	0.682
Length Ratio Segment/Height	0.186	0.146	0.108	0.254
Radius of Gyration/Segment Length (About CG)	0.322	0.303	0.297	0.468

Segment mass, center of mass

The mass of each segment could be calculated from formula of percentage of the total body mass, in addition to the center of the mass location from the proximal or distal end of the segment can be increased or decreased proportional to the segment length, Table 1[18] describes the relation between the segment proportional ratio for the mass and its center, however, these data value is required for the kinetic and kinematic analyses.

Moment of inertia

Moment of inertia can be calculated by using the radius of gyration of limbs. The center of gravity and average weight and length of targeted upper limbs can be provided in Table 1.[18]

System modeling

The robot manipulator from 8 DOF when each join represents one degree of freedom in the 3D SolidWorks model illustrated in Fig. 2.

The robot structure works in space in three directions (x, y and z) coordinates moved in two of them and rotate about one which means the system configuration on (x, y and θ) parameters, in the real-world application it necessary to describe robot position and orientation on the space a six parameter (x, y, z, yaw, roll and bitch).

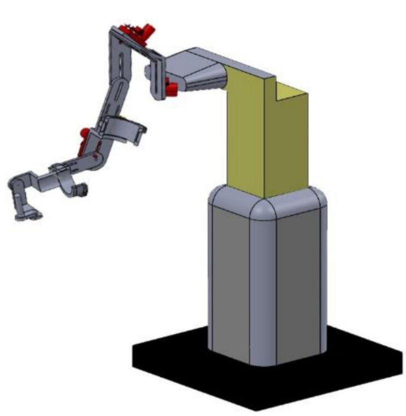

Fig. 2. Upper limb robotic 3D model.

The robot 3D model in Fig. 2 shows the robot consists of links and joints, the links are connected serially to each other by joints, that's means link1 connects to link2 in joint1 and link3 connects to link2 in joint2 eventually, Calculation of movement of each link relative to the main link in the frame.

System kinematic

The Denavit-Hartenberg (DH) parameters are a set of four parameters used to describe the kinematics of robotic systems with revolute or prismatic joints. The DH parameters were introduced by Jacques Denavit and Richard Hartenberg in the 1950s and are widely used in robotics and computer graphics.

Using these four parameters, the transformation matrix between adjacent joints can be derived, allowing the orientation and position of the end-effector of a robot to be calculated.[19] The DH parameters are typically specified relative to a fixed reference frame, and the transformation matrices can be multiplied together to obtain the orientation and position of the end-effector with respect to the fixed reference frame, by the axis that is referenced on the robot as shown in Fig. 3. Table 2 show the DH parameters for the proposed 8 DOF rehabilitation robotic.

By using DH parameters, the homogenous transformation matrix referred to in Eq. (3) is used for finding the transformation matrix to describe the position and orientation of each joint of the robot with reference to the global coordinate and can be simplified in Eq. (1).

$$T_8^0 = \left[T_1^0 T_2^1 T_3^2 T_4^3 T_5^4 T_6^5 T_7^6 T_8^7\right] \tag{1}$$

$$T_8^0 = \begin{bmatrix} R_8^0 & P_8^0 \\ 0 & 1 \end{bmatrix} \tag{2}$$

Where: R is rotation matrix and P is the position matrix description.

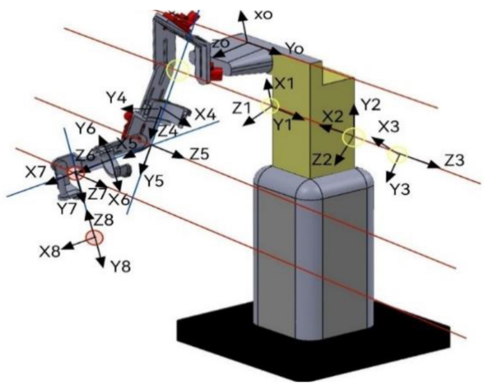

Fig. 3. Upper limb robotic joint referenced axes.

Table 2. DH Parameter for ULERD 8 robot.

Joint	α_{i-1} Twist Angle	a_{i-1} Offset Link	d_i Link Length	θ_i Joint Angle
1	0	0	L_1	θ_1
2	$\pi/3$	L_2	0	$\theta_2 + \pi/3$
3	$\pi/2$	0	0	$\theta_3 + \pi/3$
4	$\pi/2$	0	L_{4-1}	θ_4
5	$\pi/2$	0	0	θ_5
6	$\pi/2$	0	L_{6-1}	θ_6
7	$\pi/2$	0	0	θ_7
8	$\pi/2$	0	0	θ_8

Each joint transformation matrix can be obtained by Eq. (3):

$$T_i^{i-1} = \begin{pmatrix} \cos\theta_i & -\sin\theta_i\cos\alpha_i & \sin\theta_i\sin\alpha_i & a_i\cos\theta_i \\ \sin\theta_i & \cos\theta_i\cos\alpha_i & -\cos\theta_i\sin\alpha_i & a_i\sin\theta_i \\ 0 & \sin\alpha_i & \cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{3}$$

By using the Eqs. (1) to (3) for individual joints of robot that are related in each frame of the robot and after submitting DH parameters in Table 2, the homogenous transformation matrix for the robot frames from 1 to 8 can be obtained:

$$T_1^0 = \begin{pmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & L_1 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{4}$$

$$T_2^1 = \begin{pmatrix} \cos(\theta_2 + \pi/3) & -\sin(\theta_2 + \pi/3)\cos\pi/3 & \sin(\theta_2 + \pi/3)\sin\pi/3 & L_2\cos(\theta_2 + \pi/3) \\ \sin(\theta_2 + \pi/3) & \cos(\theta_2 + \pi/3)\cos\pi/3 & -\cos(\theta_2 + \pi/3)\sin\pi/3 & L_2\sin(\theta_2 + \pi/3) \\ 0 & \sin\pi/3 & \cos\pi/3 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{5}$$

$$T_3^2 = \begin{pmatrix} \cos(\theta_3 + \pi/3) & 0 & \sin(\theta_3 + \pi/2) & 0 \\ \sin(\theta_3 + \pi/3) & 0 & -\cos(\theta_3 + \pi/3) & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{6}$$

$$T_4^3 = \begin{pmatrix} \cos\theta_4 & 0 & \sin\theta_4 & 0 \\ \sin\theta_4 & 0 & -\cos\theta_4 & 0 \\ 0 & 1 & 0 & L_{4-1} \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{7}$$

$$T_5^4 = \begin{pmatrix} \cos\theta_5 & 0 & \sin\theta_5 & 0 \\ \sin\theta_5 & 0 & -\cos\theta_5 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{8}$$

$$T_6^5 = \begin{pmatrix} \cos\theta_6 & 0 & \sin\theta_6 & 0 \\ \sin\theta_6 & 0 & -\cos\theta_6 & 0 \\ 0 & 1 & 0 & L_{6-1} \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{9}$$

$$T_7^6 = \begin{pmatrix} \cos\theta_7 & 0 & \sin\theta_7 & 0 \\ \sin\theta_7 & 0 & -\cos\theta_7 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{10}$$

$$T_8^7 = \begin{pmatrix} \cos\theta_8 & 0 & \sin\theta_8 & 0 \\ \sin\theta_8 & 0 & -\cos\theta_8 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \tag{11}$$

Dynamic model

For studying the system motion with considering the torque and force and moment, Euler-Lagrange approach are used frequently for dynamic modeling of multi rigid robotic system, Euler-Lagrange contained the kinetic and potential energies of a system described as L = T-V where T is kinetic energy part and V is potential energy part of the system, the function represented by using generalized coordinatesq_i and

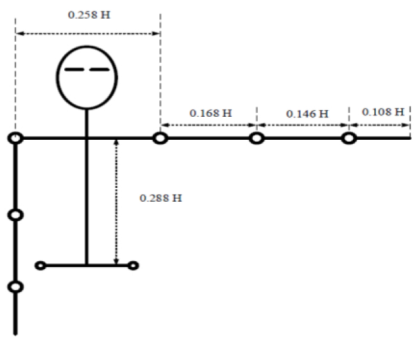

Fig. 4. Upper limb critical segment length.

generalized velocity $\dot{q}_1$ as:

$$L = L(q_i, \ldots\ldots., q_d, \dot{q}_1, \ldots\ldots, \dot{q}_d) \tag{12}$$

Where d is the number of DOF.

Robotic design

In order to develop the wearable robot, it is necessary to take into account several characteristics, including the anthropometry of the intended users, constraints on the weight of the robot, considerations of comfort and ergonomics, the ROM required, and any physical limitations that may exist. Each of these factors will be thoroughly examined and established in the subsequent discussion.

Targeted users and subsequent anthropomorphic data

Adaptation ability is considered to be a fundamental element in the field of design. In essence, the design of an exoskeleton robot should have adaptability to accommodate individuals with diverse characteristics, including variations in weight, height, and other relevant factors. Given that the length of limbs, center of gravity and weight of individuals undergo changes as they mature, it is important to take into account the likely age range of users throughout the design stage. This section aims to establish the specific age range of users and afterwards utilize this range to derive the succeeding metrics associated with different age groups.

Research indicates that age has a significant role in the outcomes of stroke patients. The incidence of stroke exhibits a twofold increase for every decade beyond the age of 55.[20] Therefore, the selected demographic comprises individuals aged 50 to 80 years, as this age group is considered particularly susceptible to stroke. The anthropometric measurements of height and weight among boys across various racial and ethnic backgrounds exhibit variations within the specified age range. These data were collected in the following manner[19] as listed in Table 3.

As indicated in the preceding tables (Table 3), the height range observed between patients aged 50–80 years is 62 to 114.3 kg, while the corresponding height range is 161.3 to 186.8 centimeters. Therefore, it is imperative that the assistive robot have adjustability within this range and the capability to deliver assistive force to patients of varying weights.

The initial parameter assessed pertained (as show in Fig. 4) to the dimensions of the robot as listed in Table 4 below. The measurements essential for determining the size of the robot are presented in the subsequent tables.

Another factor that needs to be taken into account is the limbs weight and the level of required assistive force. Table 1 displays the specified ranges for the weight, center of gravity (CG) listed in Table 5 below, and radius of gyration of the limbs, which are dependent on the weight.

Current actuation technologies

There are several actuating systems technologies existed. Historically, the predominant means of supplying energy to widely utilized actuators has been through the use of electric current, pneumatic pressure and hydraulic fluid. The selection of the energy source has a direct impact on the choice of actuators employed inside the system. In the majority of actuation systems, energy is supplied in the form of electric current. Furthermore, there are occasions in which several actuator systems are selectively mixed to fulfil certain design objectives.

Table 3. Weight (kg)/Height (centimeter) of the targeted age and percentile.[21]

	Percentile									
	Mean	5th	10th	15th	25th	50th	75th	85th	90th	95th
50–59 years	86.0/175.7	63.4/164.5	68.2/167.1	72.0/168.5	75.7/171.1	84.1/176.0	94.0/180.2	100.7/182.5	105.3/184.0	114.3/186.8
60–69 years	83.1/174.1	61.1/162.1	64.5/165.2	67.7/167.3	72.8/169.6	82.4/174.3	92.5/179.0	98.4/181.4	102.0/193.0	107.3/185.1
70–79 years	79.0/171.9	58.5/161.3	62.0/163.4	64.2/164.6	68.8/167.1	77.9/171.9	87.0/176.1	93.5/179.1	96.1/180.4	103.3/183.5

Table 4. Critical dimensions by height range.

	Shoulder to Hip	Shoulder to Shoulder	Shoulder to Elbow	Shoulder to Hand
Dimensions as Function of Height	0.288 H	0.258 H	0.168 H	0.254 H
Rang of the Length of the Limbs (cm)	46.5–53.8	41.3–48.2	27.1–31.4	40.9–47.4
CG from proximal (cm)	–	–	11.8–13.7	27.9–32.3

Table 5. Range of weight and moment of inertia of the limbs of targets range.

	Upper arm	Forearm and Hand
Weight (kg)	1.7360–3.2004	1.3640–2.5146
Moment of Inertia about CG ($kg.m^2$)	0.0132–0.0327	0.0501–0.1240

The design objectives include the integration of a variety of movements, velocities, and accelerations while considering power limitations, workspace demands, mobility, and cost considerations. Several commonly used types of actuators mentioned before. These actuators can also be integrated to create configurations with several actuator systems to fulfil design objectives.

When choosing actuators, several selection factors were taken into account, including produced torques, motor size, velocity, acceleration, power consumption, mobility, weight, and the encoder type. The actuator systems most frequently employed in various applications include electric, hydraulic, and pneumatic systems. Each form of actuator possesses distinct advantages and disadvantages. In recent times, there has been a growing research focus on actuators for soft robotics, encompassing many types such as pneumatics, electrical actuation, and chemical actuation systems.[22,23]

Current sensor technologies

The coordination between the human body and mechatronic structures and is facilitated by the use of sensor data, which contributes to the complexity of their interaction. During the design phase, intricate methodologies involve the adjustment of the exoskeleton's behaviors to align with the motions of the patients. This is achieved by utilizing data from several systems, including optical motion capture systems, EMG sensors, IMU sensors, sensors for muscle activation.[24]

Exoskeletons commonly incorporate several types of sensors, including as EMG sensors, IMU sensors, encoders, strain gauges and force sensors to facilitate the collection of real-time data for control objectives. Control algorithms utilize measured data to assess patient movement intentions, as an example. Consequently, the generation of position and motor torque commands is facilitated by the utilization of adaptive control approaches, which rely on patients' exertions and sensory inputs. Furthermore, advanced controllers have the capability to modify the necessary motor torque in accordance with the progress exhibited by patients.

Exoskeleton safety

The significance of safety in the design of upper limb exoskeletons is of utmost importance because of the direct interaction between the robot and the human body. Rehabilitation devices are classified as medical equipment and, as such, are required to conform to high and specific standards throughout the whole process, including design and production.[25] Safety elements are included in three distinct levels, mainly electrical, mechanical and software.[26] In the realm of mechanical design, it is possible to incorporate physical stoppers into each joint. The purpose of these stoppers is twofold: to limit undesired motion and to safeguard against excessive excursions that may lead to hyperextension or hyperflexion of particular joints. Moreover, the design might have electric emergency stop switches strategically positioned in conveniently accessible locations for the user. Moreover, the control programmed has the capability to restrict the maximum torque and velocity of the exoskeleton, thus mitigating the occurrence of unforeseen abrupt movements.

Exoskeleton structure stress analysis

The finite element analysis used to validate the robot structure stress analysis to clarify the chosen material validate used for this application,[27] the maximum force applied calculated on the individual segment is varying according to the segment body weight[28] and robot segments parts weight and can be calculated according to this equation:

$$Avarage\ mass\ of\ upper\ limb = (upper\ arm\ \%\ x\ MH) + (forearm\ \%\ x\ MH) + (hand\ \%\ x\ MH) \quad (13)$$

Where:

MH is Average mass of a male human (male will be considered due to its larger weight than female in same age range) as illiterate in Table 6 below.

Table 6. Average mass body segment.

	Mass %	
Body Segment	Male	Female
Upper Arm	2.71	2.55
Forearm	1.62	1.38
Hand	0.61	0.56

Upper arm segment mass percentage can be calculated from the data obtained from the literature as in the table below.[1]

Robot material using for manufacturing

The process of selecting materials for upper limb rehabilitation robots involves careful consideration of several criteria like strength, weight, flexibility, comfort, and durability.[29] The integration of lightweight metals, plastics, composites, and soft materials enables these robots to deliver efficient and pleasant therapy to persons undergoing rehabilitation for upper limb injuries or impairments, hence helping their progress towards enhanced mobility and functioning.

Aluminum or other lightweight metals are commonly employed as major materials in the fabrication of upper limb rehabilitation robots due to their combination of low weight and high durability. These materials provide the requisite structural integrity to effectively sustain the robotic components, while also ensuring that the overall weight of the device remains within reasonable limits. The significance of this matter lies in the fact that an excessive amount of weight might hinder the patient's capacity to utilize the robot in a comfortable manner, particularly while engaging in prolonged therapy sessions.

In conjunction with metallic elements, components of rehabilitation robots frequently integrate high-strength polymers and composite materials. These materials contribute to the reduction of the device's total weight and improve its design flexibility. As an illustration, the arm or joint mechanics of the robot might potentially integrate materials such as polycarbonate or carbon fiber-reinforced composites. These materials possess a combination of strength and flexibility that enables them to imitate the natural motions of joints during therapeutic interventions.

Results and discussion

Finite element analysis

The upper limb exoskeleton assembly model is subjected to analysis under certain conditions utilizing the Ansys® software. The model is generated on the SolidWorks® software. Fig. 2 displays the upper limb exoskeleton model. The concept of materials is initially defined. A comprehensive analysis will be conducted utilizing all three sources.

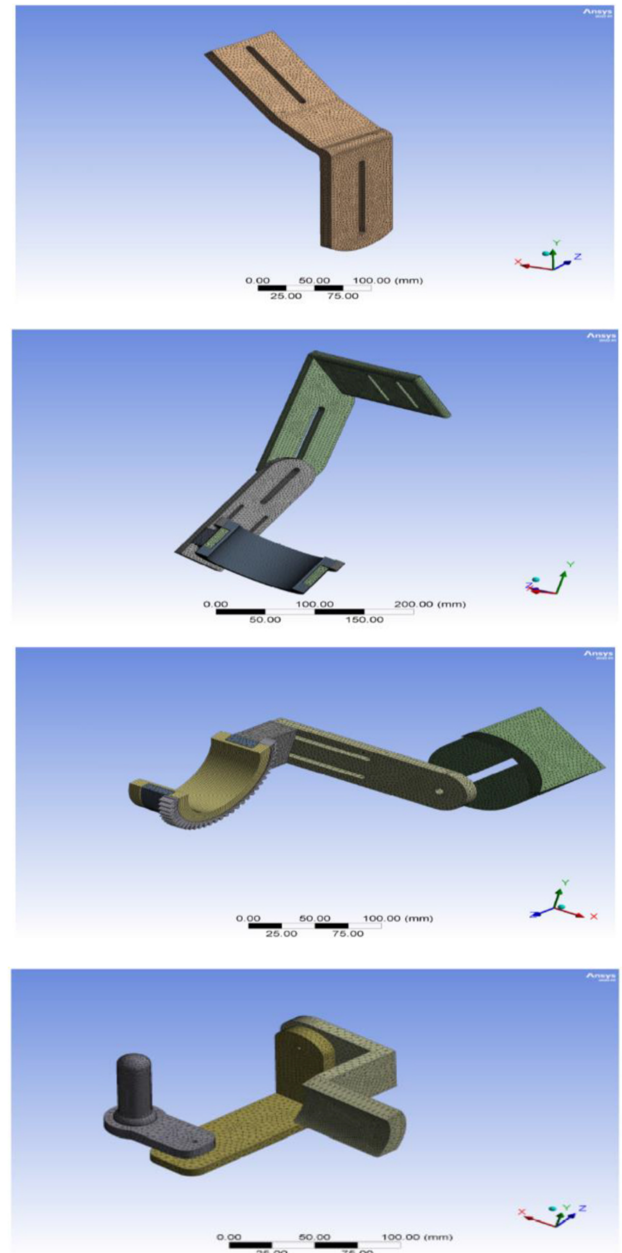

Fig. 5. Robot (back element, shoulder complex, forearm complex and hand complex) meshing.

Constrains, force & meshing

The maximum magnitude of the force utilized for analysis is 106 Newtons. The force provided is determined by the mass of the object. The mass of the subject is 100 kg taking in the account the maximum weight possible, the weight is deferent to each part of robot (back element, shoulder complex, forearm

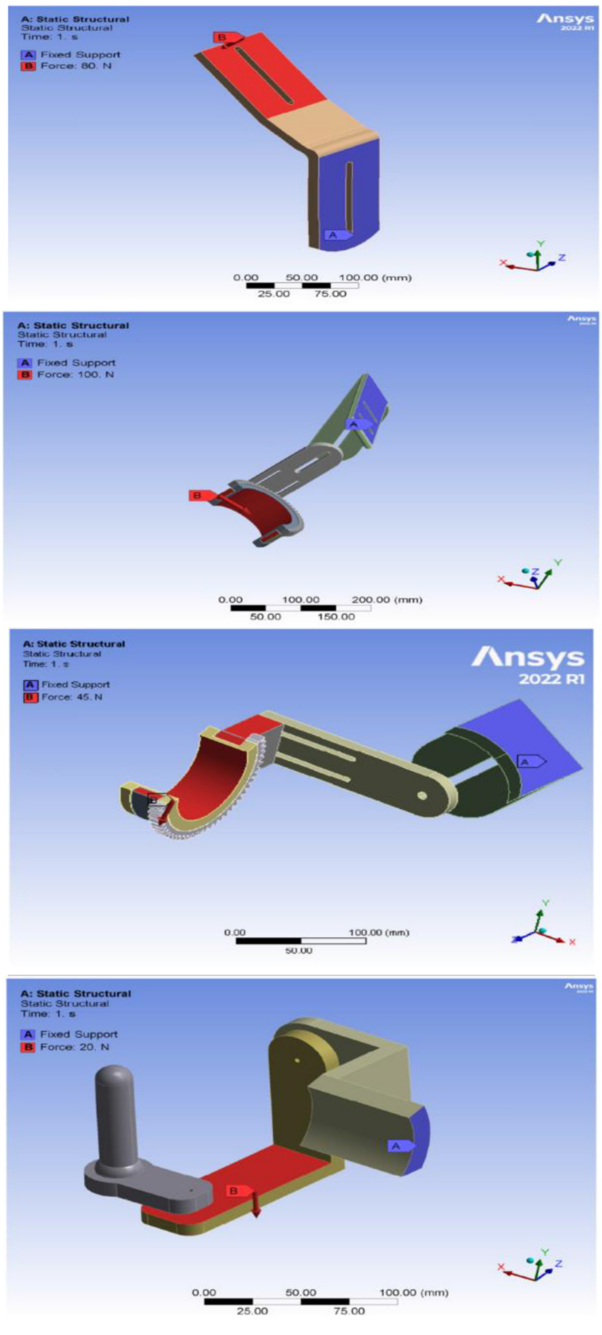

Fig. 6. Applied force constrain.

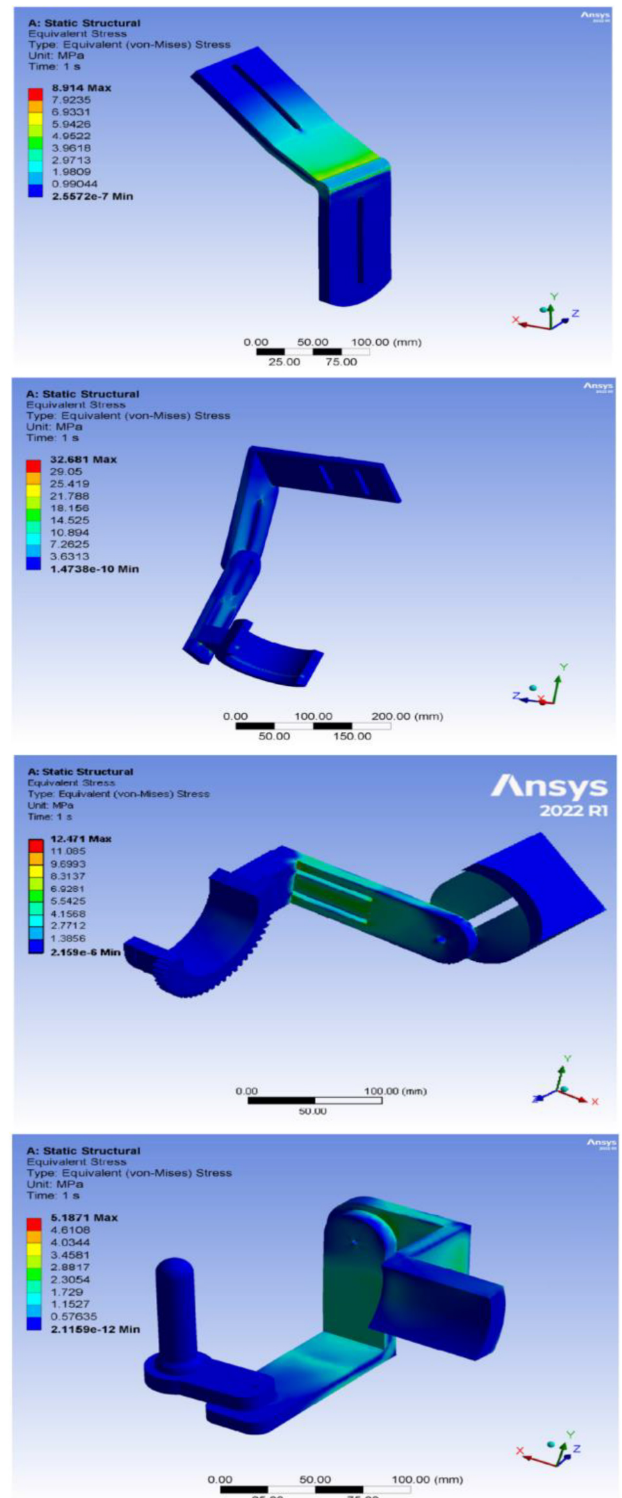

Fig. 7. Von-mises stress analysis of exoskeleton.

complex and hand complex) and the calculated weight is (10.814, 9.814, 4.166 and 1.06 kg) respectively. Once the prerequisites have been established, the process of meshing becomes crucial. Meshing is a fundamental procedure that involves the subdivision of a continuous geometric structure into several smaller shapes, often numbering in the thousands or more. This subdivision is undertaken with the purpose of accurately delineating the physical form of the item in question. The accuracy of a simulation model (FEA) is directly proportional to the level of detail included in the mesh. The meshing technique employed in this study is automated method meshing. The Fig. 5 displays the meshed exoskeleton. The robotic element constrains (boundary condition) shown in Fig. 6.

Von-mises stress for the upper limb exoskeleton

Fig. 6 illustrates the comprehensive stress output of the upper limb exoskeleton. The stress ranging from 4.6108 MPa to 29.05 MPa is reported effect on the inner and anterior regions of components. Fig. 7 illustrates that the shoulder complex sliding connection part are caring a maximum stress value of 29.05 MPa that's is shows a suitability of this design for implementation by using the available bio compactable polymer material like PMMA and PLA and Perlon.[30]

Conclusion

This study presents a proposal for the creation of an upper limb exoskeleton intended for the purpose of proceeding with a physiotherapy rehabilitation program. The analysis of the skeletal strength of exoskeletons using the finite element method is a topic of significant scholarly interest. Based on the analysis given in the previous part, it can be inferred that the following conclusion may be drawn:

The successful development of an upper limb exoskeleton design for physiotherapy rehabilitation has been achieved by introducing an adjustable light weight design. The simulation indicate that the exoskeleton design is considered safe for providing physiotherapy rehabilitation ordinary loading conditions. In the future, research will be conducted to enhance the dependability and efficiency of this technique for optimizing structures. This will involve including other objectives such as compliance and volume, as well as addressing restrictions like as stress and natural frequency. The computational cost is a significant obstacle when implementing topology optimization techniques for the lightweight design of the collaborative robot will be also challenge in the future.

Authors' declaration

- Conflicts of Interest: None.
- We hereby confirm that all figures and tables in the manuscript are ours. Furthermore, figures and images, that are not ours, have been included with the necessary permission for re-publication, which is attached to the manuscript.
- No animal studies are present in the manuscript.
- No human studies are present in the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at Al Nahrain University.

Authors' contribution statement

Both authors M.A and A.M.T contributed in the design and implementation of the research, the analysis of the results and in the writing of the manuscript.

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اجراءات التصميم الميكانيكي والنموذج الرياضي لروبوت تأهيل الطرف العلوي لجسم الانسان ذي 8 درجات من الحركة

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الخلاصة

علاج الاصابات الطبية العضلية التي تعيق الحركة لجسم الانسان اصبحت ذات اهتمام واسع لما تحمله من اهمية لتحسين حياة الناس التي تتعرض الى هكذا نوع من الاصابات ، خلال الاعوام السابقة دراسات عدة حاولت ان تصنع روبوت يعمل على اعادة تأهيل الاطراف العلوية المصابة من جسم الانسان ، في هذا البحث سوف نقوم بوضع منهج لإجراءات تصميم روبوت طبي من خلال عرض المساحات الحجمية لهذا الروبوت حسب عمر ووزن الشخص المصاب والثوابت الوزنية والحجمية لكل جزء من الروبوت لاستخدامها في النموذج الرياضي الذي يستعمل لتحريك هذا الروبوت ومن ثم سوف يتم عرض تصميم روبوت ذو ثمانية درجات من الحركة وفحصه باستخدام تحليل العناصر المحدودة (FEA) من أجل تقييم قدرته على التحمل والعمل وفقًا للحمل الذي يمارسه وزن الإنسان .يخضع نموذج الهيكل الخارجي للطرف العلوي للتحليل باستخدام برنامج®Ansys ، مما يسهل تنفيذ تحليل الإجهاد بطريقة (von Mises).

الكلمات المفتاحية: القياسات البشرية، تحليل العناصر المحدودة، الروبوتات، الهياكل الخارجية للأطراف العلوية، تحليل الإجهاد فون ميزيس.