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Design a Robotic Upper-limb Exoskeleton using CT Images and CAD Software

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Abstract*: *Many people suffer from weakness in the upper or lower extremities, and there were no techniques to compensate for this weakness until not long ago, but with the progress and development of modern technologies, it became possible to provide these people with artificial external structures to help them recover even a small part of the energy of the weak limb called a robotic exoskeleton. In this paper, we studied the manufacturing of an upper exoskeleton which designed to help people with weak upper extremity muscles to rehabilitate and exercise these muscles and help them to carry out activities that they were not able to do, such as lifting weights and using the hand in simple daily activities. The final 3d model of the upper robotic exoskeleton shows a comfortable shape for the patient and static analysis of it illustrates his ability to handle high torque loads.

Keywords: Upper Robotic Exoskeleton – Upper extremities – CAD – Static analysis.

I. INTRODUCTION

As a result of the rapid progress that humanity is experiencing in the past few decades and the rapid change in lifestyle, many health problems have come to the surface and the number of people with them has increased significantly. One of these problems was muscle problems, the most important of which is muscle weakness, which has increased significantly during the last century in general and the past few decades in particular, like the abnormalities in the skeletal muscles resulting from the increase in problems related to stress and psychological causes which varied between muscle, nervous, metabolic, and other causes, the most important of which are strokes [1]. Hence the need for advanced techniques that contribute to restoring hope to those who have suffered muscle weakness and help them overcome their ordeal as much as possible by using means to help them improve their ability to rehabilitate and use their muscles as naturally as possible and increase their ability to integrate into society and serve it and improve their quality of life and life The community in which they live [2].Based on the foregoing, many forms of assistive devices and exoskeletons have emerged for the purposes of treating, rehabilitating, and even exercising the muscles of people with muscular weakness. These devices went through many stages of development, with improved degrees of freedom, flexibility, and ability to move smoothly and comfortably, without neglecting the increased reliability of these devices and their ability to meet patients' demands with the passage of time. The types and shapes of these devices differed, including robotic devices, the most important of which is the HAL series, the last of which is the 5-HAL series, produced in 2008. Among these devices, we also mention contact interfaces, which include an increase in reproducibility, scalability, safety, and control of the conditions of the environment, and finally, we mention the external structures with feedback as Handyman, Hardiman, ARTS or PERCRO are unmatched devices that allow greater movement during contact reactions [3-5]. Upper Exoskeletons (UEs) is one of the most famous and easy to implement among robotics exoskeletons. The research deals with designing a new prototype of (UEs) using 3d reconstruction of CT images so we can use the accurate shape of the upper limbs and uses it inside the fixed parts of (UEs) and makes the patients feel more comfortable.

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II. LITERATURE REVIEW

Ekso Vest is a passive upper exoskeleton was presented by Ekso-BIONICS, the results the tests showed that this device reduce the fatigue on the patients and decrease the load on the shoulders by 10%, also reduce the spine loading [6]. Five-DOF wearable upper exoskeleton, the design shoed a good performance especially using a novel cable-driven mechanism with total weight 4.2 kg [7]. H-PULSE was introduced as a new semi-passive UE, the prototype makes patients feel less strain and more able to do activities also reduce the heart rate that cause of device weight [8]. Recent research work on designing adjustable UE which can be fit on any patient or user using simple design with few actuators [9].

III. METHODOLOGY

The aim of this paper is to propose a novel robotic upper-limb exoskeleton. This design takes into account the accurate dimensions of fixed parts of the device using 3d reconstruction of CT images of an upper limb, modified it, and embedded the actuators with the links and parts. Finally, we will make a static study on this device. The numerical static study will show the efficiency of our robotic exoskeleton.

A. *3D-model of the upper limb*

This stage was achieved by, (1) taking CT images for a patient who suffers from muscle weakness (2) pre-processing these images (slices) so we can detect efficiently the skin and bone positions.

(3) 3D-reconstruction of those slices using special software like DeVIDE or 3D-Doctor and export them into .STL file.

B. Design UE using CAD software

After we obtained a three-dimensional model of the upper limb that will be installed to the supporting device, we divided it to three parts as shown if Fig.1.

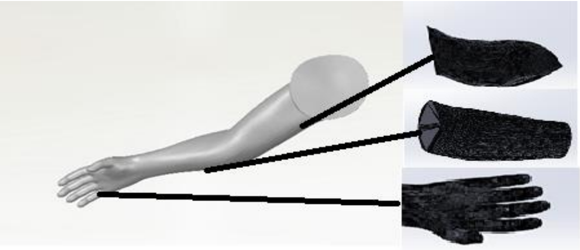


Fig. 1 3D-model of a real arm and its divided parts.

In our project, we will design an external support device (Upper Exoskeleton) with servo motors for the elbow, forearm and palm region. It mainly consists of:

1- Socket items or fixing items (printed with 3D printer).

2- Bearing arms (made of aluminum and chrome).

3- Servo motors, where two MG996R motors were used, because they provided high torque to carry the rest of the parts, and two SG90 motors responsible for lifting the hand area (palm).

Initially the parts was shelled using shell instructions and then the outer surfaces were flattened to ensure good contact with the carrying arms. And also the allocation of holes for placing a fixation tape with the patient's arm Fig. 2.

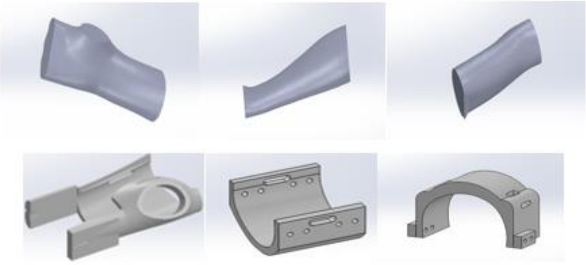


Fig. 2 the real limb parts and modified designs for the Exoskeleton device.

Here, we left an opening for the thumb in order to fix it well in the patient's hand, in addition to the holes for placing a fixation strap with the patient's hand. Bearing links are chrome-aluminum bars and actuaters are MG996R Servo motors. Final design of the proposed (UE) after assembly shown in Fig. 3.

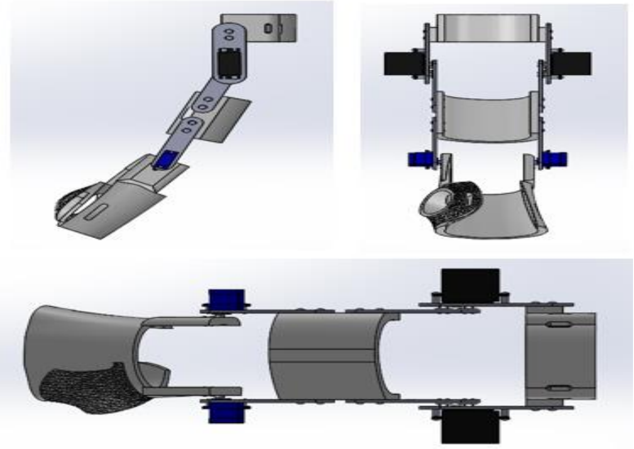


Fig. 3 CAD model of proposed robotic upper exoskeleton.

C. Static simulation parameters

In the beginning, we must first determine the static loads applied to the device, which are:

- The weight of the device, which is related to the type of material it is made of.
- The weight of the hand and forearm that is moved with the device.
- The weight of the hand represents 0.58% of the weight of the full body, and let's assume that the body weight is 75kg, then the weight of the hand equals 0.435kg.
- The weight of the forearm represents 1.65% of the total body weight, and let's assume that the body weight is 75kg, then the weight of the hand equals 1.2375kg.

First case:

Use of ABS PC material for printed fastening elements. Using Chrome stainless steel for carrying arms. Consideration of motors are made of ABS PC material. The rivets are made of Plain carbon steel.

In the case that we have a moving mechanism and want to study the effect of forces on it, we must do one of two steps:

Install the device at its beginning and apply static forces to the final section so that the applied forces do not cause mechanical transmission on the device, otherwise the simulation will fail.

We studied each area separately, taking into account the strength of the deleted areas, and we used this method to achieve simulation.

Second case:

Use of PC High Viscosity for printed fixing elements. Using Chrome stainless steel for carrying arms. Consideration of motors are made of ABS PC material. The rivets are made of Plain carbon steel.

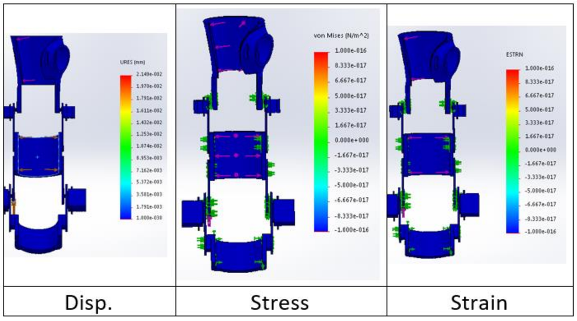
Table. 1. Mechanical properties of ABS and PC.

Property	**ABS PC**	**PC High Viscosity**	**Unit**
Elastic Modulus	24575.011	23657.27	kgf/cm^2
Poisson's Ratio	0.3897	0.3912	N/A
Shear Modulus	8791.93962	8454.415	kgf/cm^2
Mass Density	0.00107	0.00119	kg/cm^3
Tensile Strength	407.884	639.358	kgf/cm^2

Thermal Conductivity	0.000625717	0.000451721	cal/(cm·sec·°C)
Specific Heat	454.111	366.874	cal/(kg·°C)

IV. RESULTS AND DISCUSSION

The simulation was done using each case alone, after selecting the fixing joints, we select the static loads, where we applied force 0.55kg (hand weight with machine weight) on hand + 1.3kg (forearm weight with machine weight).



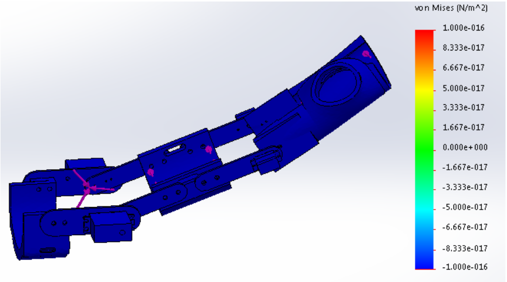
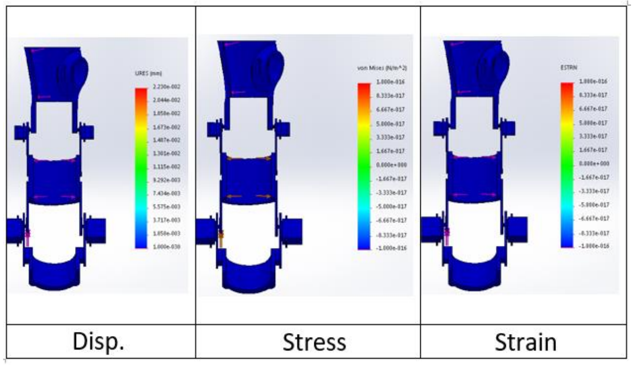


Fig. 4. First case static study results.

First case results in Fig. 4 illustrate that the device can handle the maximum loads without any distortion or future failure. Second case also did the same response and efficiency as shown in Fig. 5.



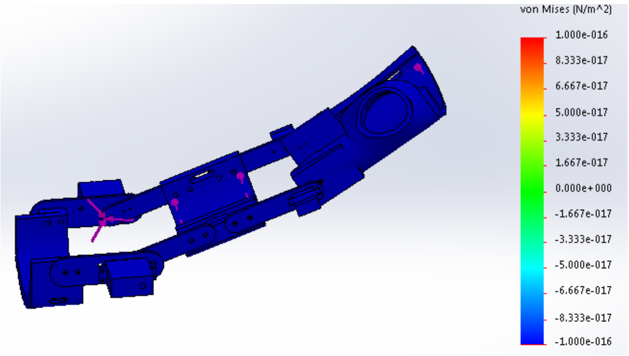


Fig. 5. Second case static study results.

We can use ABS PC and PC materials in these kinds of Exoskeletons because they offer good performance, long-term execution time, and rapid manufacturing using 3D-printing. The benefits of using CT images were clear in the accurate shape of the positioning of the fixing parts. We can just scale the parts a little bit and add some of the canvas layers on the internal face of the printed parts so we can ensure that patients will like it more.

V. CONCLUSION

After all that has been dealt with in this research, including a quick summary of the topic of external support devices, and a presentation of the most famous types of external support devices that are internationally recognized. In the end, in the practical section, we were able to collect the important points and benefit from them in studying the mechanism and requirements of building an external support device for the facility in proportion to what is available in the local market in terms of mechanical and electronic parts in order for the cost to be acceptable in terms of circuits, motors and mechanical designs.

ACKNOWLEDGMENT

This research belongs fully self-made and represent a novel design methodology of the robotic upper-limb exoskeleton. This research doesn’t relate to any labs or research team or company. Solidworks was used for designing and simulation without any commercial usage of the results.

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