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Tesis

Structural Design of a Semiautomatic Position Laser Therapy Equipment

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STRUCTURAL DESIGN OF A SEMIAUTOMATIC POSITION LASER THERAPY EQUIPMENT

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***Abstract*—In the field of health, innovation is positioned as a key element in the development of effective solutions to treat injuries in various areas of the body. The growing need for advanced biomedical equipment capable of addressing these demands is recognized. In this context, the purpose of this article is the design of a semi-automatic laser therapy equipment, a technique whose benefits for rehabilitation have been widely demonstrated. For the research design, a fusion of the VDI 2206 plus MIT methodologies was carried out. The main objective of this article is to design a semi-automatic laser therapy equipment for rehabilitation with parameter regulation. This article seeks to contribute to the innovation and development of biomedical technology, offering solutions adapted to the required needs. Likewise, it is expected that this design and methodological approach can be used as a reference for future semi-automation projects for the development of biomedical equipment. The result of this research is equipment that can be configured for various treatments depending on the injury, this is achieved through the use of programming and structural position control through inverse kinematics.**

***Index Terms*—laser therapy, semi-automatic control, sports injuries, inverse kinematics.**

I. Introduction

Laser therapy, or laser therapy, has become a crucial tool in the field of medicine and physical therapy due to its beneficial effects in accelerating healing and relieving pain. The precise application of low-power laser light beams to specific areas of the body has been shown to be effective in a wide range of medical conditions, from musculoskeletal injuries to dermatological and neurological disorders. The effectiveness of laser therapy lies in its ability to stimulate

tissue regeneration and reduce inflammation, without causing significant damage to surrounding tissues [1].

In the context of technological advancements and increasing demands in the field of healthcare, the need for more efficient and accurate biomedical equipment has become imperative. It is in this context where the importance of designing structures and control systems that allow the application of laser therapy in an even more precise and effective way arises. The automation and semi-automation of this equipment not only optimizes treatment times, but also minimizes human intervention, reducing the possibility of errors and improving the reproducibility of therapeutic procedures [2].

The present article focuses on the structural design of a semi-automatic position laser therapy equipment, with a particular emphasis on the integration of advanced control systems that can improve the delivery of laser therapy treatments. This approach not only contributes to greater efficiency in the clinical environment, but also represents a significant advance in improving the quality of medical care and patient comfort. Throughout this article, we will explore the technical and functional aspects of this emerging technology, as well as its possible applications and benefits in the field of medicine and physiotherapy [3].

A. Importance

The research is carried out with the purpose of innovating the technologies used. Well, new equipment can be implemented and adapted in medical settings, the importance lies in the fact that there are different types of equipment that, when imported, are not compatible with the infrastructure, with environmental factors such as temperature and humidity that affect both the installation and the use and finally the maintenance of the equipment biomedical [4]. Therefore, this research will provide new perspectives on the application of common rehabilitation and physical therapy treatments, the semi-automation of a therapy equipment is carried out, through a new structural design of this focused on laser therapy, in which it adapts the application position according to the information entered by the staff through an interface, finally, the equipment analyzes the parameters and proceeds with the application of the therapy.

B. Background -"Design and implementation of a 4-DOF robotic prototype based on the application of a proposed methodological guide"

This research work explains how a robotic prototype with 4 degrees of freedom has been developed with the aim of helping in practical education and the current technological revolution. Unlike industrial robots, this prototype is smaller and lower cost. Analysis, formulation and simulation have been carried out using SolidWorks, a CAD/ CAE design software, to obtain a simple and modified design with respective specifications [5]. The contribution of this work lies in the information on obtaining relevant graphs such as displacement, speed, torque, trajectory of the end effector.

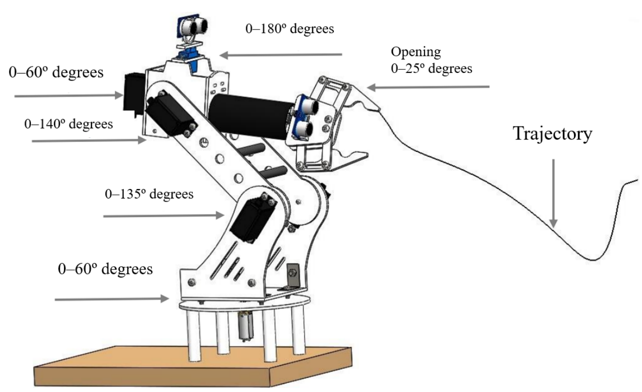

Fig. 1. Isometric view of the trajectory described by the 4 GDL robot.

II. METHODS AND MATERIALS

A. Method applied

In this research, a mixed and non-experimental approach was used to obtain a more complete understanding of the phenomena studied. Quantitative and qualitative methods were combined to enrich the quality of the data and strengthen the conclusions. In addition, this methodology fostered theoretical creativity and allowed the development and strengthening of research skills [6]. The main objective of this research was to collect data and information on the characteristics, properties, aspects or structural dimensions of people, agents and institutions involved in physical therapy operations. Therefore, the scope of this research can be considered descriptive [7].

B. Fusion of methodology

In Figure 2, a fusion of the VDI 2206 methodologies was carried out, for the development and generation of ideas it was implemented taking into account mechanical, electrical and control criteria for subsequent application and future evaluation, synergy with the methodology was sought. MIT to delimit the stages within the VDI methodology.

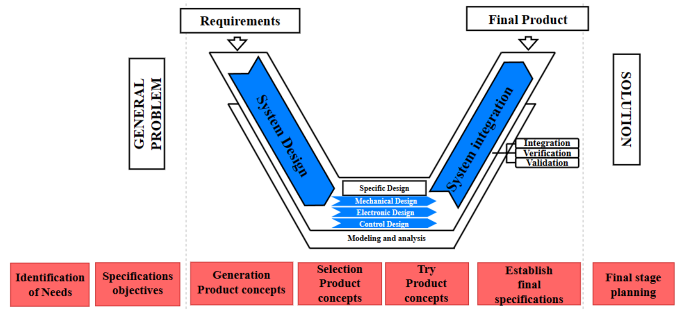

Fig. 2. VDI plus MIT methodology.

C. State of technology

The objective of Figure 3. was to delimit the tentative options of the project in question, establishing differentiating criteria for the selection, in addition to evaluatingthe viability of each one as an innovative solution method, uniting the previously mentioned ideas in a synergistic combination of a final idea, to reach the optimal solution idea.

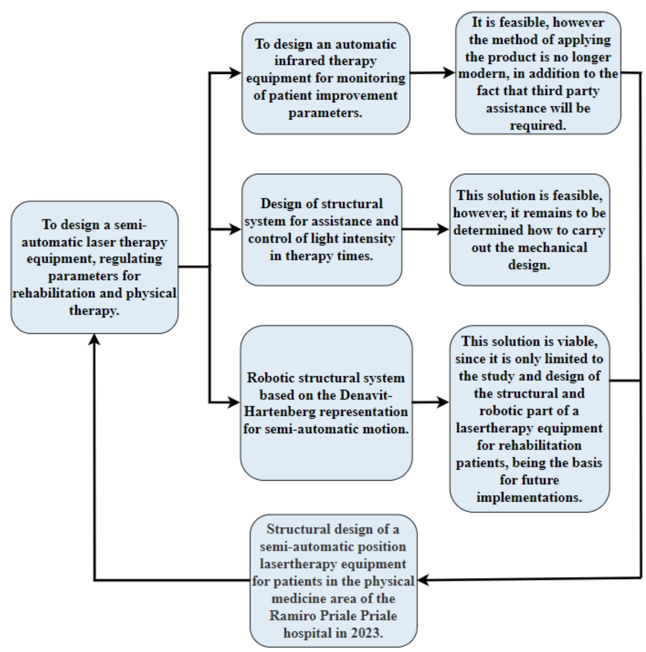

Fig. 3. State of technology.

D. Function Structure

Once the functional problem of the project has been analyzed, the function structure is established with the objective of having a more detailed vision of the components that will be used in the design of laser therapy. The function structure is represented by a block diagram, as shown in Figure 4. This diagram shows the main components of the system, as well as the relationships between them.

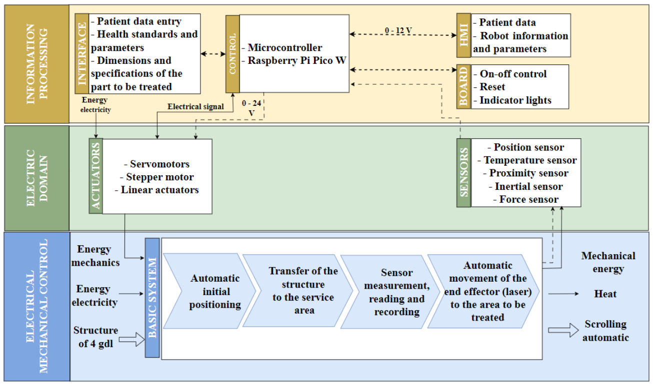

Fig. 4. Function structure matrix.

E. Concept evaluation matrix

The following diagram in figure 5. shows all the interactions of the different components, from the 220 V alternating electric current power input, through the storage banks, then to the circuit power, passing through the stage of signal, where the patient data is recorded, to be processed and structured by using the controller and set the movement parameters of the robot and start the laser therapy treatment.

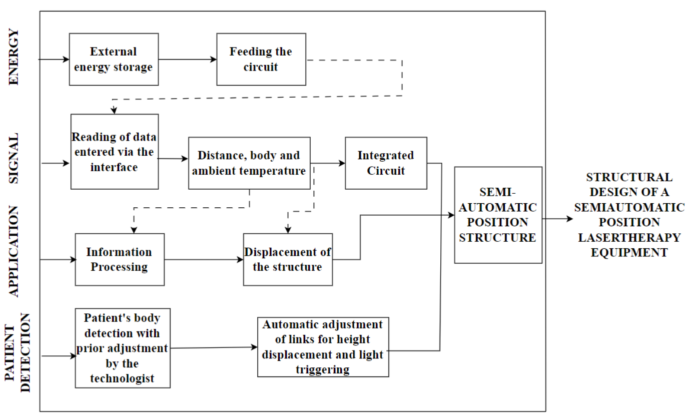

Fig. 5. Concept evaluation matrix.

F. Dimensions, Evaluation and composition of elements and and Static analysis

1) Dimensions: The dimensions of the different parts are as follows: a hollow 304 steel bar with a thickness of 0.1 cm, a length of 60 cm and a diameter of 4 cm. The support structure is cross-shaped and its dimensions are a side face of 5 cm x 6 cm and a length of 50 cm. The rotating base, where the motor that allows a 280° rotation is located, has dimensions of 19 cm high and a diameter ranging from larger than 18 cm to smaller than 5 cm. For the elbows, a cylindrical design with a diameter of 10 cm and a length of 12 cm was selected, which will house the actuators for the links. For the final actuator, which is our laser lamp, the measurements of a surgical lamp were taken as a reference.

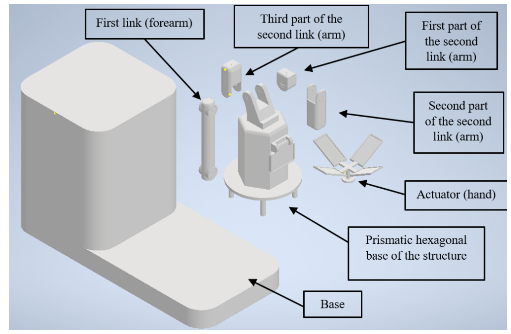

Fig. 6. Parts before assembly.

2) Evaluation and composition of elements: The finite element analysis process of the 3D design was performed in order to evaluate the strength and reliability of the design using a specific material. The base of the robot is established as a reference support point since it supports the weight of the whole structure. The material chosen for the base of the structure is STEEL 304 with a thickness of 17.32 mm, the material chosen for the link parts is ABS and the end effector material is fiberglass.

Componente	Material original	Material de anulación
Arm 4 DOF.iam		
Base:1	Genérico	Plástico ABS
Base_Robot:1	Genérico	Plástico ABS
Motor paso a	Genérico	Acero inoxidable
union:1	Genérico	Plástico ABS
Motor paso a	Genérico	Acero inoxidable
Brazo 1:1	Genérico	Plástico ABS
Motor paso a	Genérico	Acero inoxidable
Brazo 2:1	Genérico	Plástico ABS
final:1	Genérico	Plástico PAEK
Motor paso a	Genérico	Acero inoxidable
Efector:1	Genérico	Policarbonato, claro

Fig. 7. Structural composition of materials in Inventor.

Regarding the types of materials used, in the biomedical equipment sector, they are biocompatible and non-toxic. To calculate the tensile strength of the pieces in the case of 304 steel used in the base, different data such as temperature and elastic limit have been taken into account. Therefore, there is a resistance table according to these.

Temperature		0.2% Elastic Limit		Tensile Strength		Elongation
(F)	(C)	(psi)	(MPa)	(psi)	(MPa)	(% to 51mm)
-423	-235	100,000	690	250,000	1725	25
-320	-196	70,000	485	230,000	1285	35
-100	-79	50,000	354	150,000	1035	50
70	21	35,000	240	90,000	620	60
400	205	23,000	160	70,000	485	50
800	427	19,000	130	66,000	455	43
1200	650	15,500	105	48,000	330	34
1500	850	13,000	90	23,000	160	46

Fig. 8. Chart of tensile strength by temperature and elastic limit of steel.

3) Static analysis: The analysis takes into account the gravitational force and the approximate weight of the laser therapy lamp, which is about 50 N. A curvature-based mesh is defined for the analysis. The results show that the highest levels of stress and strain are observed in the end actuator and the end link of the structure. The model has six links, each of which is connected to each other by an actuator. The first link is connected to the base and the last link holds the end effector. The structure of the equipment is symmetrical, with the first three links located in the same plane to perform more precise and fluid movements.

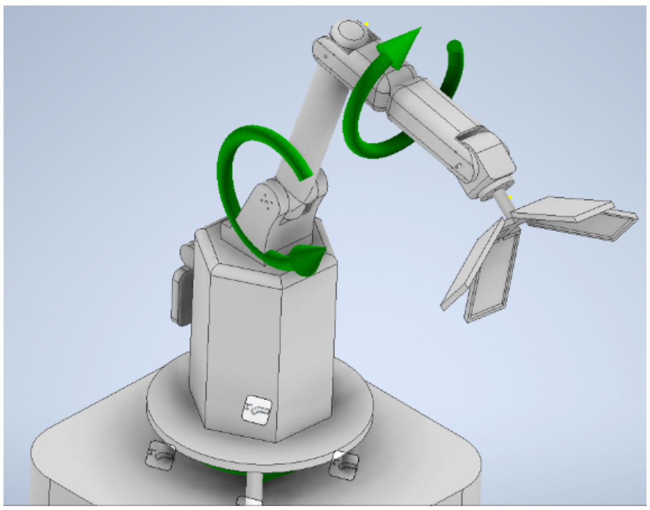

Fig. 9. Finite element analysis.

It is observed and analyzed in Figure 10. that the greatest stress is generated in the final actuator that supports the weight of the lamp, with a maximum displacement of up to 0.0056mm, likewise the final link also presents a maximum deformation of 0.034mm. denoted in yellow in the stress analysis.

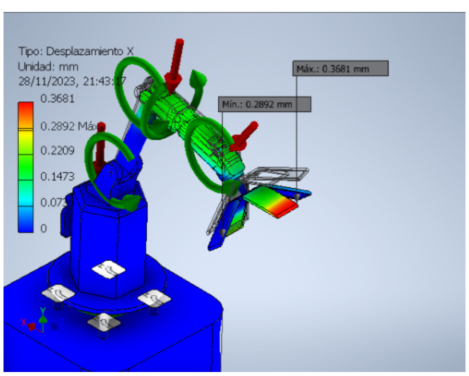

Fig. 10. Displacement analysis.

Likewise, for the analysis of the highest Von Mises stress with maximum values of 82.3 MPa for our model, a predominant light blue color is shown throughout the design with values of 0 MPa denoting little deformation of the system as shown in Figure 11.

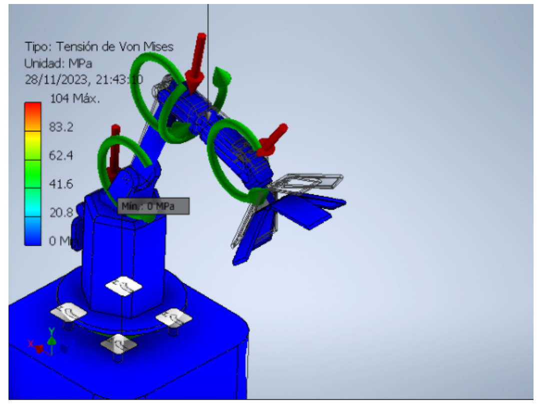

Fig. 11. Analysis Von Mises.

For Figure 12. the values obtained for the first analysis of principal stresses of 83.51 MPa for our model show a predominant light blue color throughout the design that presents values of 0 MPa denoting the little deformation of the system.

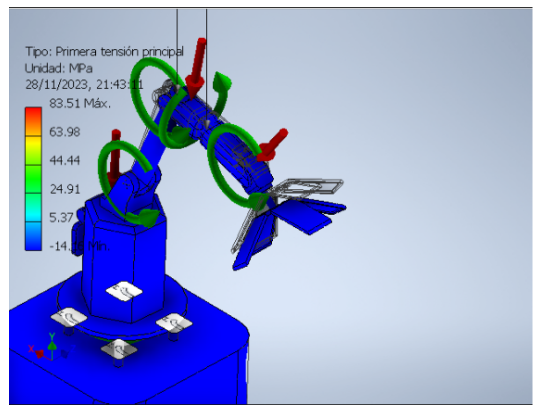

Fig. 12. First principal stress analysis.

G. Control

Controlling movement through inverse kinematics in a robotic arm with 4 degrees of freedom (DOF) involves finding the joint angles to use. This method is ideal for precisely directing the laser head towards specific areas of the patient.

$$\begin{bmatrix} x_{\text{des}} \\ y_{\text{des}} \\ z_{\text{des}} \\ \phi_{\text{des}} \end{bmatrix} = \begin{bmatrix} f_1(q_1, q_2, q_3, q_4) \\ f_2(q_1, q_2, q_3, q_4) \\ f_3(q_1, q_2, q_3, q_4) \\ f_4(q_1, q_2, q_3, q_4) \end{bmatrix} \tag{1}$$

1) Direct design kinematics: Direct kinematics was developed based on the design of four degrees of freedom, making a progressive analysis. To solve it, the Denavit-Hartenberg algorithm will be used, which provides the homogeneous transformation matrices.

a) Coordinate Systems Assignment: Z axes have been assigned to the links, and an arbitrary coordinate system, called system 0, has been selected. From this point, a sequential process has been started using a system i.

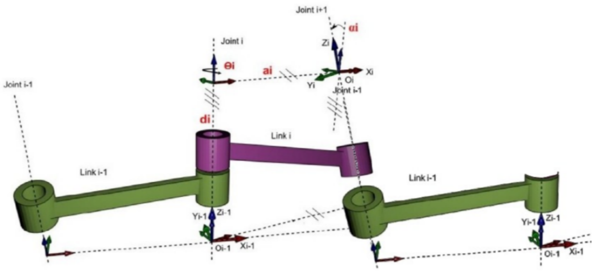

Fig. 13. Coordinate System.

2) Development of direct kinematics: Firstly, we proceed to write the Denavit Hatrtenverg equations based on the assignment of coordinates. These equations establish a relationship between the angles of the joints and the position and orientation of the end of the arm. This entire procedure is carried out in the collaborative environment.

```
#variables (PARAMETROS DH)
theta_i=Symbol("theta_i")
alpha_i=Symbol("alpha_i")
a_i=Symbol("a_i")
d_i=Symbol("d_i")
```

```
#Matriz DH
A=Matrix([[cos(theta_i),-cos(alpha_i)*sin(theta_i),sin(alpha_i)*sin(theta_i),a_i*cos(theta_i)]
        ,[sin(theta_i),cos(alpha_i)*cos(theta_i),-sin(alpha_i)*cos(theta_i),a_i*sin(theta_i)]
        ,[0,sin(alpha_i),cos(alpha_i),d_i]
        ,[0,0,0,1]])
```

Fig. 14. D-H Matrix Code.

When executing the code, the result was matrix A:

$$A = \begin{bmatrix} \cos(\theta_i) & -\sin(\theta_i)\cos(\theta_i) & \sin(\theta_i)\sin(\alpha_i) & \alpha_i\cos(\theta_i) \\ \sin(\theta_i) & \cos(\alpha_i)\cos(\alpha_i) & -\sin(\alpha_i)\sin(\alpha_i) & \alpha_i\sin(\theta_i) \\ 0 & \sin(\alpha_i) & \cos(\alpha_i) & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

For which, its validation matrix is executed as follows:

$$I = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3)$$

The homogeneous matrix was used to describe the position and orientation.

$$H = \begin{bmatrix} R & d \\ 0 & 1 \end{bmatrix} \quad (4)$$

A specific code is used, equation 5. defines the 4x4 matrix that represents the position and orientation of the end of the effective link relative to its base frame.

$$A1 = \begin{bmatrix} \cos(\theta_i) & -\sin(\theta_i)\cos(90) & \sin(90)\sin(\alpha_i) & 0.05\cos(\theta_i) \\ \sin(\theta_i) & \cos(90)\cos(\alpha_i) & -\sin(90)\sin(\alpha_i) & 0.05\sin(\theta_i) \\ 0 & \sin(90) & \cos(90) & 0.435 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (5)$$

Second joint:

$$A2 = \begin{bmatrix} \cos(\theta_2) & -\sin(\theta_2) & 0 & 0.35\cos(\theta_2) \\ \sin(\theta_2) & \cos(\theta_2) & 0 & 0.35\sin(\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

Third joint:

$$A3 = \begin{bmatrix} \cos(\theta_3) & -\sin(\theta_3)\cos(90^\circ) & -\sin(90^\circ)\sin(\theta_3) & 0 \\ \sin(\theta_3) & \cos(90^\circ)\cos(\theta_3) & \sin(90^\circ)\cos(\theta_3) & 0 \\ 0 & -\sin(90^\circ) & \cos(90^\circ) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (7)$$

Fourth joint:

$$A4 = \begin{bmatrix} \cos(\theta_i) & -\sin(\theta_i) & 0 & 0 \\ \sin(\theta_i) & \cos(\theta_i) & 0 & 0 \\ 0 & 0 & 1 & 1.3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (8)$$

3) Inverse kinematics: The code provides an inverse kinematics algorithm for a four-degree-of-freedom robot. It uses trigonometric calculations and transformation matrices to deduce the servomotor angles from the desired robot end coordinates. This method, based on specific robot parameters, offers a function that determines the angles required to reach various positions.

```
# Inverse kinematics function
def inverse_kinematics(px, py, pz):
    if __name__ == "__main__":
    # Desired final coordinates
    px_desired = 0.5
    py_desired = 0.4
    pz_desired = 0.6

    # Calculate servomotor angles
    theta1, theta2, theta3, theta4 =
        inverse_kinematics(px_desired, py_desired,
        pz_desired)

    print("Servomotor angles:")
    print(f"Theta1: {theta1:.2f} degrees")
    print(f"Theta2: {theta2:.2f} degrees")
    print(f"Theta3: {theta3:.2f} degrees")
    print(f"Theta4: {theta4:.2f} degrees")
```

As a result of executing the direct and inverse kinematics of the programming, we had:

- Theta1: 118.85 degrees
- Theta2: 120.69 degrees
- Theta3: 59.93 degrees
- Theta4: 59.93 degrees

4) Denavit-Hartenberg parameters: After completing the kinematics processes, the necessary parameters will be obtained to represent and understand in greater depth the geometry of the laser therapy structure. These parameters include the relative positions and orientations of the different links of the robotic arm, allowing you to accurately visualize how the end of the arm moves and positions based on the joints.

TABLE I
PARAMETERS OF DENAVIT-HARTENBERG FOR A ROBOTIC ARM WITH 4 DEGREES OF FREEDOM

Joint	a_i	α_i	d_i	θ_i
1	a_1	$\alpha_i, 0.05$	$d_i, 0.435$	θ_1
2	a_2	$\alpha_i, 0.35$	$d_i, 0$	θ_2
3	a_3	$\alpha_i, 0$	$d_i, 0$	θ_3
4	a_4	$\alpha_i, 0$	$d_i, 0.3$	θ_4

III. RESULTS AND DISCUSSIONS

A. Results

The developed semi-automatic laser therapy equipment is an effective solution to address the problems identified in the study. In addition to optimizing the time and results of laser therapy, it facilitates the implementation of automated equipment in national hospitals. Its design stands out for its robustness and meets safety and functionality requirements. It features a stable hexagonal base, lightweight and strong ABS links, and an articulated end effector capable of withstanding high temperatures. The control design is efficient and precise, using forward and inverse kinematics to calculate the position and orientation of the end effector. This allows accurate and safe planning of laser motion trajectories, along with D-H parameters. This equipment has the potential to improve the quality of healthcare and reduce costs because it is more precise and efficient than traditional laser therapy methods, and can automate tasks that currently require the intervention of a technologist.

Fig. 15. Complete structural design rendered in Inventor.

B. Discussion

This section highlights the metric components developed for the prototype. It is crucial that the system meets medical standards, which is achieved by using precise materials and performing precise calculations in the control system. To ensure bio compatibility, 304 steel, ABS and glass are strategically used, allowing for effective disinfection, which is essential in medical environments. Payload capacity is validated through static analysis with a 50 N load, ensuring that the system is capable of replacing bulbs within specific intensity and size parameters. This demonstrates not only its reliability, but also its adaptability to different operational requirements. With a maximum working radius of 65 cm and a working area of 1.33 m², the system has a wide operating range that offers essential flexibility and coverage in medical procedures. The use of forward and inverse kinematics demonstrates the system's precision in motion and precise location analysis, ensuring accuracy in treatment delivery, a critical factor in medical applications. Finally, the efficient transport mechanism highlights the practicality and ease of mobility of the system, which improves its usability and applicability in different medical environments.

IV. CONCLUSIONS

The design of the robotic arm base has a hexagonal shape with no corners, made of 304 steel, complying with the biocompatible biomedical equipment. The arm links are composed of acrylonitrile butadiene styrene (ABS). Finally, the end effector of the robotic arm incorporates a ball joint for greater mobility in the treatment area, the end effector gripper is designed with four rectangular faces, each equipped with a laser light spot, allowing it to cover a wider area for treatments in hard-to-reach areas, the gripper is made of fiberglass, a material resistant to high temperatures. The position and orientation of the end effector can be calculated from the angles of these joints. The direct kinematic matrix of the robotic arm is used to calculate the position and orientation of the end effector, which in this case is the laser. The position of the laser can be expressed as a three-coordinate vector (x, y, z) and its orientation as a three-by-three rotation matrix. The code used calculates the matrix transformation of the first link of the robotic arm, which represents the position and orientation of the end effector relative to its base frame.

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