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Design and Kinematic Modelling Of Slave Manipulator For Remote Medical Diagnosis

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Abstract : This work presents an efficient design for a slave manipulator that can be remotely controlled by a doctor to perform medical diagnosis on his patient. The design is developed as per the application of Ultrasound, however the adaptability of design towards a spectrum of medical operations is the primary motive of this project. A CAD Model developed with the help of design calculations is presented here. The FEA was also performed and results are shown. Moreover, the DH Parameters are provided to give the Kinematic-Model, which can easily be used for path planning and workspace analysis.

Keywords: Utlra-Sound Robotics, Medical Robotics, Robotics Design, Kinematics, Tele-Echography

I. INTRODUCTION

In the past, lots of assistive robots have been designed especially for minimally invasive surgery, laparoscopy, endoscopy, echo-graphy, tomography, etc. In [1] work on tele-presence means for a doctor to remotely diagnose the patient via internet has been presented. The capability of internet in the same very well highlights the usefulness of remote robotic manipulation for medical diagnosis as it proves the entire approach to be practically feasible.

As the research in work [2] has been transformed into end stage prototype and product, it is a perfect example which shows the vision of robot use for remote diagnosis. This vision may as well be further elaborated in [3], where a system is being developed to perform more than one operation remotely.

In [4], special mechanisms like radius guides and 4-bar planer mechanism have been introduced in the design to give more rigidity and aids impedance control method. However, 7-DOF system has been proposed here, whereas in our work the robot is able to reach the targeted dexterous workspace with just 5 DOFs (Degree Of Freedoms) and 1extra DOF which is reserved for precision or user intent.

In [5], a master-slave robotic system assists a doctor to remotely diagnose a patient with the help of Tele-echographic data, that he may receive through internet. In this design, a parallel manipulator has been used which may add to congestion of the environment in human vicinity. In [6], a robotic arm is designed which autonomously follows the trajectory points on a CT image, thus helping a doctor to diagnose easily. These types of works prove that robotic assistance doesn't just extend a doctor's aid to the patient but also makes it more efficient.

In [7] a 4 DOF ergonomic and light weight manipulator is presented, where ultrasound probe is combined with force sensor. In [8] 2 translational DOFs have been added to a similar structure presented in [7], to perform tele-echography at a remote site. In [9], use of planer parallelogram structures in a 5 DOF manipulator, allows for a low gravity action on moving masses, however the approach here is slightly different. Perhaps, the closest to our work is [10], where a 5 DOF manipulator can move linearly along the periphery of the bed.

The above works prove that the use of robots in medicine has increased the success rate of any surgery or operation. Also, it paves the way to a bright future in medicine and healthcare. This work is largely about designing a robot with large and dexterous workspace as required in medical applications. The ability to carry most of the above defined distinct operations on a single system has also been targeted here, thereby increasing cost efficiency and ergonomics.

The following work has been divided as follows, Sec II. Design Summary, Sec III. Materials Used, Sec IV. DH Parameters, Sec V. CAD Model and FEA Results, Sec VI. Conclusion

II. DESIGN SUMMARY

To target the objectives as described earlier, the end effecter of the system must be able to reach any point in Cartesian Space, thus 3 DOFs along x, y and z axes are provided. Also it should be able to orient itself in any position at the end , thus needing 3 rotational DOFs about the same 3 axes at the end-effecter's frame. However, only 2 DOFs in the wrist, have been provided here in the design. The last rotational DOF, which is about the geometrical axis of the last link has been left to the choice of user, as it may be used for any other purpose such as precision placement. Thus, a serial open chain manipulator with 5 DOFs (6th is dependent upon the instrument used at end effecter) which can be fixed along the periphery of the bed, has been designed here.

Also, the last link in the assembly chain here, has an option of easy replacement. It can be replaced with any other type of link or instrument, simply by screwing it out of the threads provided in movable socket. This gives an autonomy to user to perform more number of operations with the single system. The medical operation of remote ultrasound diagnosis is the basis for the presented design. Also, it is designed in principle with the ability to accommodate more number of such operations on a single system, which is also the ultimate goal of our ongoing research. As mentioned in [11], the vertical force on an ultrasound probe is found largest to be nearly 7 N. However, the mechanical design here has been developed with the max payload (in the worst possible loading) of 20 N. The lower limit for the same will be defined when the control laws will be developed, thus the subsequent work on dynamics and control will be aimed at minimizing this value. Due to a higher range and other such features, the design can accommodate a higher variety of instruments and respective operations at the end-effecter.

The worst possible loading for all the links would be when they are all in the cantilever positions with respect to the base link. This stretched out position of the manipulator has been used here to design the assembly components and link cross sections, in a reverse approach of first designing the last link and then solving up to base. This distributes lower weight at the end and higher near the base, thus reducing moments due to gravity and inertia for the heaviest base motors.

As per [12], dimensions of an average hospital bed's sleep surface, were found out to be 2.032 m x 0.914 m, thus the max displacement that the arm can reach up to, is planned to be nearly 1.5 m. However, the dexterous workspace has been restricted up to 1 m only, thus covering the entire width of the bed and half of the length from one base position.

The terminal forces (Payload) are assumed as follows,

- 36 N in vertical plane.
- 36 N in horizontal plane with offset equal to radius.

Both of these forces are assumed to be acting simultaneously. The approach used here is conservative as max payload is 20 N, to accommodate the effects of dynamic forces and offer scope for further modifications.

III. MATERIALS

All the materials used in the manipulator, have been listed in the decreasing order of their volume percentages in assembly. Units Scheme is defined as follows,

- Density : g/cc
- Tensile Yield Strength : MPa
- Ultimate Tensile Strength : MPa
- Young's Module : GPa

Details are given in Table I.

IV. DH PARAMETERS

Units Scheme is defined as follows,

- Alpha : Radians
- Link Length : mm
- Joint Offset : mm
- Joint Angle : Radians

Joint angles are actuated DOFs here, frames are also defined here. Thus frame (i-1) to (i) would indicate DH Parameters required to transform between the same. Details are given in Table II.

TABLE I: MATERIALS USED

S No.	Material	Properties	Application
1	ABS Polymer	Density:1.06 Tensile Yield Strength:46 Ultimate Strength: - Young's Modulus: 2.5	Links
2	En-8 Carbon Steel (R)	Density:7.8 Tensile Yield Strength:450 Ultimate Strength: 750 Young's Modulus: 210	Motor Casings, Connecting Parts, Gears, Shafts, Bolts, Keys
3	Al 6061	Density:7.8 Tensile Yield Strength:450 Ultimate Strength: 750 Young's Modulus: 70	One of the Linkages

TABLE III: DH PARAMETERS

S No.	Frames (i-1) to (i)	Alpha (α)	Link Length (a)	Joint Offset (b)	Joint Angle (θ)
1	Ground to 1	0	0	0	Θ1
2	1 to 2	$+\pi/2$	0	0	Θ2
3	2 to 3	0	+770	0	Θ3
4	3 to 4	$+\pi/2$	0	+650	Θ4
5	4 to 5	$+\pi/2$	0	0	Θ5
6	5 to End Effecter	$-\pi/2$	0	100	0

V. CAD MODEL AND FINITE ELEMENT ANALYSIS RESULTS

The CAD Modelling and Assembly of all the links were done on Solid-Works. The relevant materials were added to each of the Solid Parts. The movable masses of the robotic assembly which are distributed along the length of the link chain i.e. away from the base, weigh around 7 Kgs. This weight is crucial, as described earlier, because it adds to the gravitational moments and varies approximate moment of inertia of the entire assembly, about axes near base. Assembly CAD Models are shown in Fig.1 to Fig. 3.

Post Solid Modelling, Finite Element Analysis of the complicated sections such as motor casing were done. Stress Analysis for these sections are otherwise difficult to evaluate using conventional formulae. However, other parts have been designed using iterative techniques and relevant formulae with the help of MATLAB.

FEA was evaluated on ANSYS with Von Mises Stress Criterion, the details are as follows,

1. Mesh Type : Triangular
2. Min Edge Length : 1.2240 mm
3. Boundary Conditions : Cantilever and 40 Nm, 36 Nm, 28 Nm, as bending moments in 3 axes respectively.

The results are shown in Figures 4 and 5.

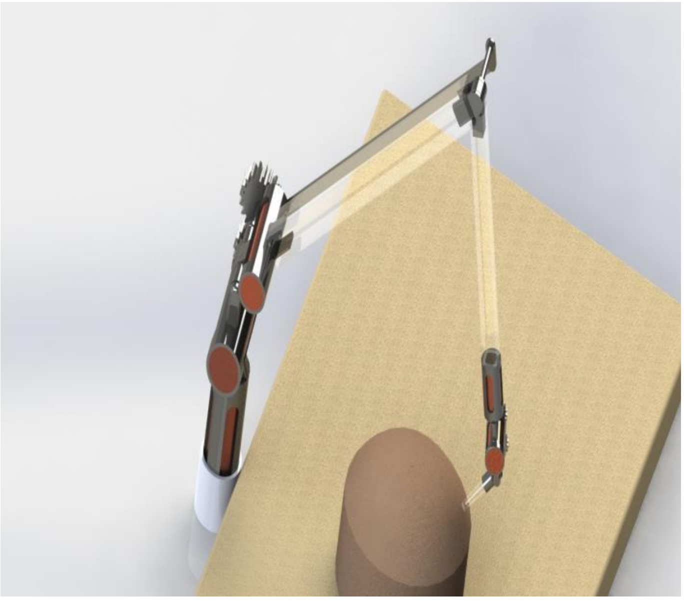

Fig. 1 Slave Manipulator performing Ultrasound.

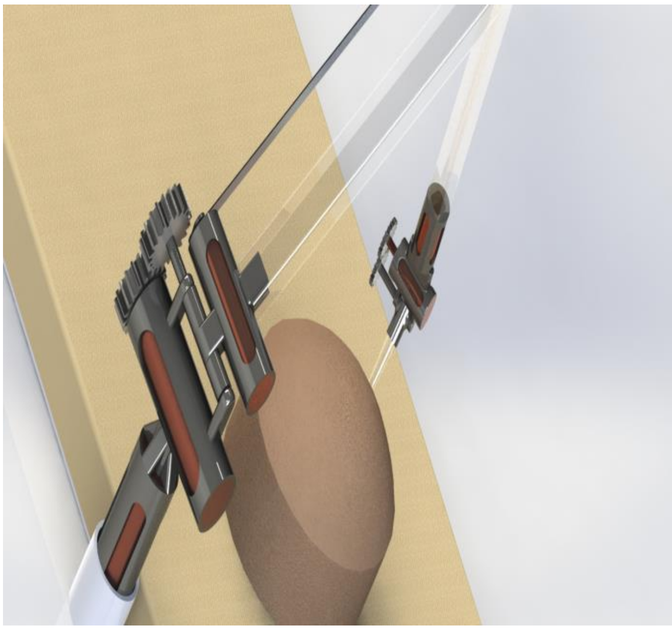

Fig. 2 Slave Manipulator performing Ultrasound (View Of Base)

Fig. 3 Slave Manipulator performing Ultrasound (View Of Wrist)

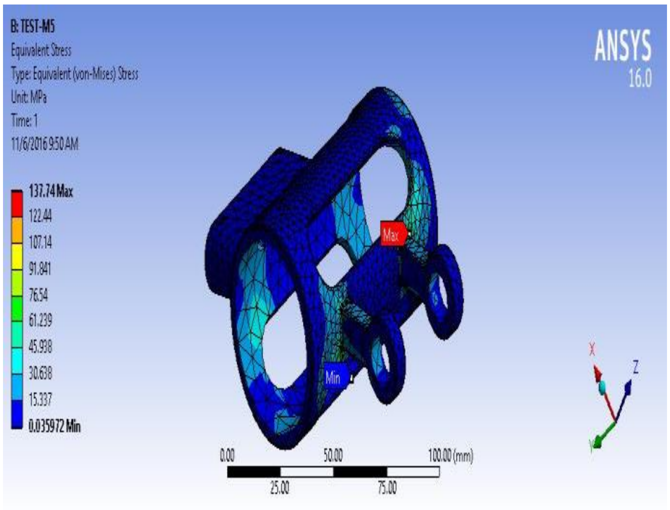

Fig. 4 Motor-5 Casing FEA (Max Stress 137 MPa)

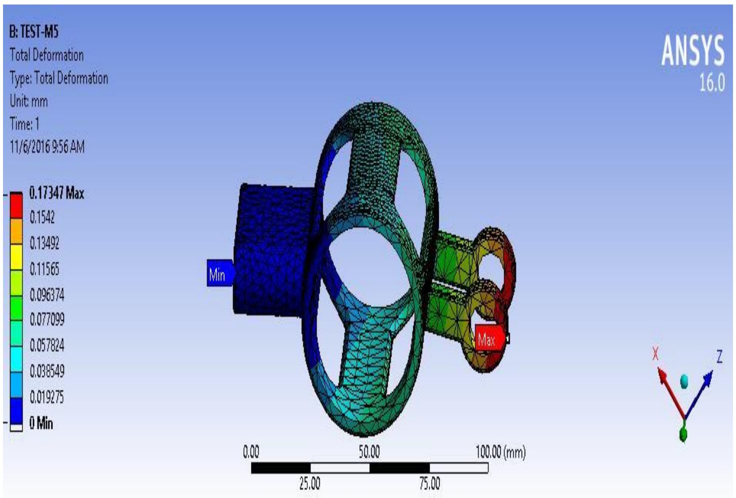

Fig. 5 Motor-5 Casing FEA (Max Deformation 0.17 mm)

VI. CONCLUSION

An efficient design of the slave manipulator for remote medical diagnosis has been developed. FEA results for the same indicate that the design is safe. Design may easily be used for slow speeds, however for fast speeds with heavier payloads stress under dynamic conditions has to be evaluated. The kinematic model for the assembly is also presented in the form of Denevit Hartenberg Parameters.

The future work in this project will focused on Dynamics and Control.

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