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A short Note on Design Aspect of A Mini Robot for Remote Surgical Operation

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Abstract

A mini robot for operation into the patient body is designed , based on CAD and Solid works that can help surgeons to assist in surgeries, increase their dexterity and assist them with more reliable operations to the patients. The stress analysis was done to arrive at optimum parameters of the design. The robot manufactured has two arms with 4 degree of freedom (4DOF). The robot has 2 arms with each arm consisting of a torso, upper arm and a forearm with end effector (grasper). A 2DOF shoulders joint located between the torso and the upper arm provides yaw and pitch. The materials used were biocompatible. This system will use stainless steel for driver and driven pulleys, similar to a conveyor belt. The belt is cylindrical in shape and is made of Nitinol, which is a biocompatible material. The cost of the robot is found out around $1200.

Keywords: Surgery; Robot; Degree of freedom;

1. Introduction

Since the time when surgical operations began, they have been performed through a large incision. Large incision surgeries causes trauma to the patient. New techniques have been in great demand where the incision is very small; these procedures are called minimally invasive surgeries (MIS) [1]. MIS is replacing the open procedures to the patients due to the significant benefits like fast recovery, less tissue trauma and cheaper cost of operation. This technology will be in high demand, as in future surgeons can perform surgeries from remote locations. This paper discusses the design of the robot with 4 degree of freedom.

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2. Background

Use 170 x 250With the development of medical surgeries, minor operations on localized body parts were done using special instrumentations to change the concept of surgery from traditional open surgery. Laparoscopic surgery although causes various difficulties while operating, due to the various invasiveness of its surgical procedures, but several research and continuous improvement is focusing to reduce its invasions and reduce the size of incision. It has some extremely beneficial effect on operations for the patients, such as less postoperative discomfort, quicker recovery times, shorter hospital stay, earlier return to full activities and much smaller scars. Laparoscopic surgeries are performed by robots for specialized operations.

Researchers have designed a new way to allow individuals with non-medical backgrounds to perform minimally invasive surgery by assembling a millimeter-sized camera robot to record the minor and minute operations taking place. Unlike room-size and expensive surgical robots, mini in vivo robots are extremely mobile and inexpensive. The robotic operations can be performed almost anywhere, right from the most remote area(outer space) to a commercial hospital.

3. Description of the Robot

It is one of the innovations in medical devices with some improved mechanism, which can help surgeons to assist in surgeries, increase their dexterity and assist them with more reliable operations to the patients.

It consists of two 4-DOF arms (fig.1) which can be individually inserted into a single 4cm incision. The main objective of the robot was developed for less procedure with colon resections. TB2 was designed to maximize the joint range of motion. Each arm of TB2.0 consists of a torso, upper arm, and forearm. A shoulder joint with 2 DOF located between the torso and upper arm, provides the yawing and pitch. The end effect is located at the forearm of the robot provides rotational degree of freedom along with open and close actuation. Tyler Bot has a 4 DOF robot arm .Workspace was calculated by finding the maximum and minimum reach and then revolving about the joint axes. The workspace of TB2 has a 95mm square revolved around its torso, the minimum reach of the robot is 50.8mm and maximum reach is 132.2mm. Average forces across the workspace in the X, Y, and Z directions include 10.3N, 14.8N and 25.5N. These were taken from the information provided by the blue dragon data [2-,3]. The torques provided at Joint 1, Joint 2 and Joint 3 of TB2.9 are 264.17Nm, 264.17Nm and 1220.61Nm respectively. The robot has been designed such that the forearm can yaw in the y-z plane of motion. To perform the objective, the Joint 1 of the robot was primarily modified, including the other parts too. The torque of 264.17mNm produced by the motors at Joint 1 was taken as a reference torque to make the forearm yaw in the y-z plane of motion. Motor selection and inserting other components in the design for its improvement were based on this assumption

4. Force and Torque Analysis

A QFD chart filled by a surgeon was used to determine the constraints and prioritize the different functions performed by the robot. From this study the following three different ideas were considered.

- Adding a motor to actuate the forearm
- Using shape metal alloy as to actuate the yawing motion in forearm
- Using pulley system to perform yawing

Main constraints in selecting the best design were the size (length and width) of the arm, the weight, kinematic design and biocompatibility. Pugh matrix was used to compare these three different ideas and finalize the best. Adding an extra motor was rejected as it would increase the forearm size by almost one third. This will reduce the work space and maneuverability of the robot. Shape Memory Alloy (Nitinol wire) can be used for actuation and it talks almost no space but it operates in on or off mode i.e. the surgeon will not be able to yaw the arm intermediately. Furthermore this SMA works the best only in a controlled environment. At the end it was decided to use the pulley system because it will be more compact, easier to control and more robust The robot was sketched in Computer Aided Design (CAD) using Solid Work. Then the other components were added on the existing sketch. Once getting the initial idea it was important to dive into detailed drawings and calculations. Tthe torque required for elbow yaw was 264.17mNm. Hence the same torque was taken to yaw the elbow in y-z plane. This torque was used to calculate the force required on the joints and the dimensions of the components.

The maximum torque required at Joint J2 and Joint J3 (fig 2) is 264.17mNm to yaw the arms in different planes. Thus the motor installed in those joints were capable of producing that much torque..

The pulley diameter at joint J3 is 9mm. From the torque equation the tangential forces acting at the top and the bottom of the pulleys are calculated and its free body diagram is shown in figure 2. The tangential forces are calculated as 27.78N each side. The tangential forces acting on the pulley becomes the tension of the cable, as the movement of the cable wires causes the pulleys to rotate. The tension in the cable wire is considered constant throughout the system and applied continuously to prevent it from slacking and slipping out of its path. To ensure the pulley system operates as it should, slippage of cable wire at certain areas should be avoided. The critical areas are identified to be at the driving and driven pulley, whereas other component like various idlers, the cable wire can just slide on its surface to ensure smooth motion. For recall, driving pulley is connected to the motor assembly while the driven pulley is attached to the joint of the TB2 forearm. If the slippage occurs at the two identified areas, the cable wire will just sliding over the groove surface of the pulley without driving the both pulley. As a result, yawing motion couldn't be achieved. As the intended design system is using Nitinol wire, the material for the driving and driven pulley should possessed high coefficient of friction (COF). Below is the correlation to use in order to select the material for the two pulleys.

F cable driven < Ffriction ; where Ffriction = μsN

From the force body diagram at the critical area (driving/driven pulley), the normal force, N acting on the surface is identified to be 55.56N and the driven force of the cable wire is 27.78N. The product of the normal force with the COF (also known as μs) should be higher than 27.78N. The table of COF is retrieved from the engineeringtoolbox.com [4]. From the intended design, the material for the pulley is chosen to be steel that fulfilling the biocompatibility features [5]. Hence, the closest available data for the COF is between mild steel and nickel which is 0.64. As nickel is one of the main components in Nitinol [6], the assumption of taking this COF value is valid as the material chooses for the pulleys is steel. In conclusion, the steel ASTM F2229 for the pulley will have enough coefficient of friction to prevent from the slippage of cable wire. For better recommendation, performing surface of modification by increasing the roughness on the surface of the pulley helps to ensure the stability of the pulley system.

5. Design of the Robot

The robot has 2 arms with each arm consisting of a torso, upper arm and a forearm with end effector (grasper). A 2DOF shoulders joint located between the torso and the upper arm provides yaw and pitch [7]. The elbow provides 1 DOF causes yawing in x-y plane. The end effector located at the each arm also provides rotational degrees of freedom with open and close actuation for grasping.

Figure 2 is labeled with joint J3 connecting the forearm with upper arm and joint J2 connecting the upper and torso. The joint J3 is modified to add one more degree of freedom to the robot. The designing was implemented such that addition of another DOF does not hinder the workspace of the existing TB2. Previous design of the forearm for TB2 can only yaw in one plane i.e. in the x-y plane. Modification of Joint J3, and addition of a T-joint, along with various components like pulleys and tensioning device, allows it to yaw, in the y-z plane also i.e. (out of the plane of paper). The Tjoint has a pulley attached to it which helps to yaw the forearm using a Nitinol cable wire. The wire runs from the pulley on Joint J3 to the driving pulley. The materials selected for manufacturing the components of the entire system are biocompatible. The pulleys, idlers, joints, shafts and rollers are manufactured by a biocompatible stainless steel ASTM F2229 with an ultimate tensile strength of (Sut) of 1340MPa and yield strength (Sy) of 1180MPa.

6. Biocompatible material and manufacturing of the Robot

The selection of materials for the design process must be biocompatible which mean the capacity of the material to function in the proximity to tissue without evoking an adverse reaction [8,9] while the tissue function is restored or enhanced by promoting the desirable interaction between it and the material (which mean biomaterial). There are two ways that influence on this selection of biomaterial which are either by choosing the bulk material that have properties defined as biomaterials or using surface modification to increase biocompatibility. Here, the design opts to use the material that already is biocompatible rather than coating with chemical modification to non-biocompatible. Hence this can reduce the intriguing of producing or manufacturing the design material, and hassle in applying the surface coating for every surgery procedure.

Material chosen for the belt was biocompatible Nitinol (Ni-Al) wire. This wire is shape memory alloys [10] with high flexibility, and kink resistance crucial to medical device applications, including tensioning wires and guide wires. Since the cable goes through several turns, it is necessary to be kink resistance. Another important reason for Nitinol was the high frictional coefficient of 0.64 with stainless steel, so that the belt may not slip over the pulleys. American Society for Testing and Materials (ASTM), United States Pharmacopeia (USP) and International Organization for Standardization (ISO) had outlining the medical grade standard that fulfilling the regulations governing biocompatibility must be USP class VI or ISO 10993. Hence the selection materials for the design are chose from that class.

The entire assembly is shown in fig. 3. This system will use stainless steel for driver and driven pulleys, similar to a conveyor belt. The driven pulley will be on the forearm to achieve yawing (as the pulley is free to rotate) and the driving pulley will be attached to a motor. The belt is cylindrical in shape and is made of Nitinol, which is a biocompatible material. The coefficient of friction between Nitinol and steel is enough, so the belt will not slip. Between the two pulleys, the belt runs through idlers also made of stainless steel. Robot arm moves and hence the length of the belt changes. To take it into consideration and maintain the tension in the belt, tensioning device is used. Tensioning device consists of a spring which expands and contracts depending on the motion of the arm where it will maintain tension in the wire. Most of the parts will be made using rapid prototyping machine while some will be standard parts.

7. Cost

The cost of the addition of the system will be $1121.04 which includes the cost of all the parts, labor and assembling. This cost is not so expensive considering the relief to the patient and doctors. The patient has to stay in the hospital for 1-2 days as compared to 4-6 days with open surgical procedure. The doctor is more comfortable with the motion as it is similar to that of the human hand.

8. Conclusion

In future the pulley system can be made more compact and the tensioning device can be removed if length of the belt can be kept constant. Other avenue to explore might be to use one actuation device to get two DOF, using a clutch mechanism.

Figures

Fig 1 The Surgical Robot

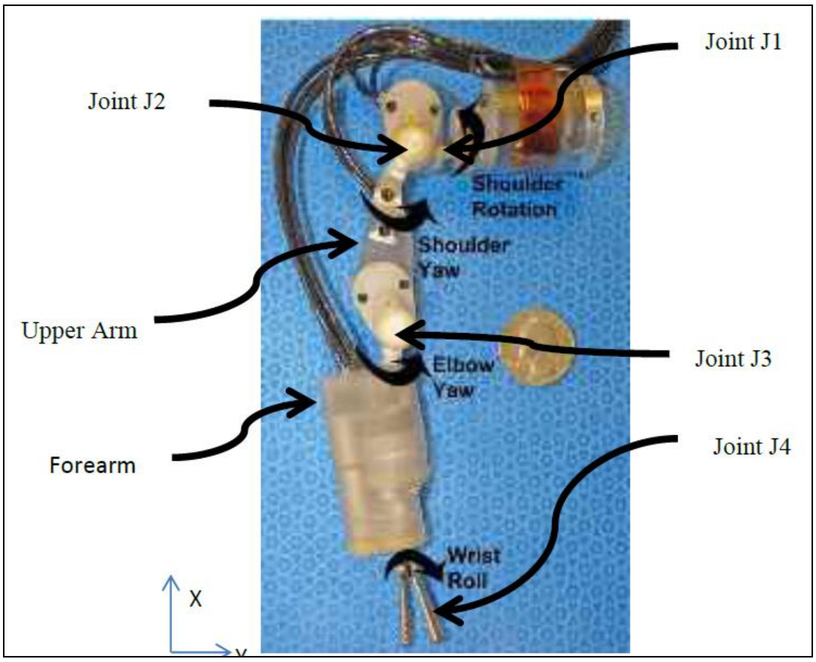

Fig 2 Detail Design of the Robot

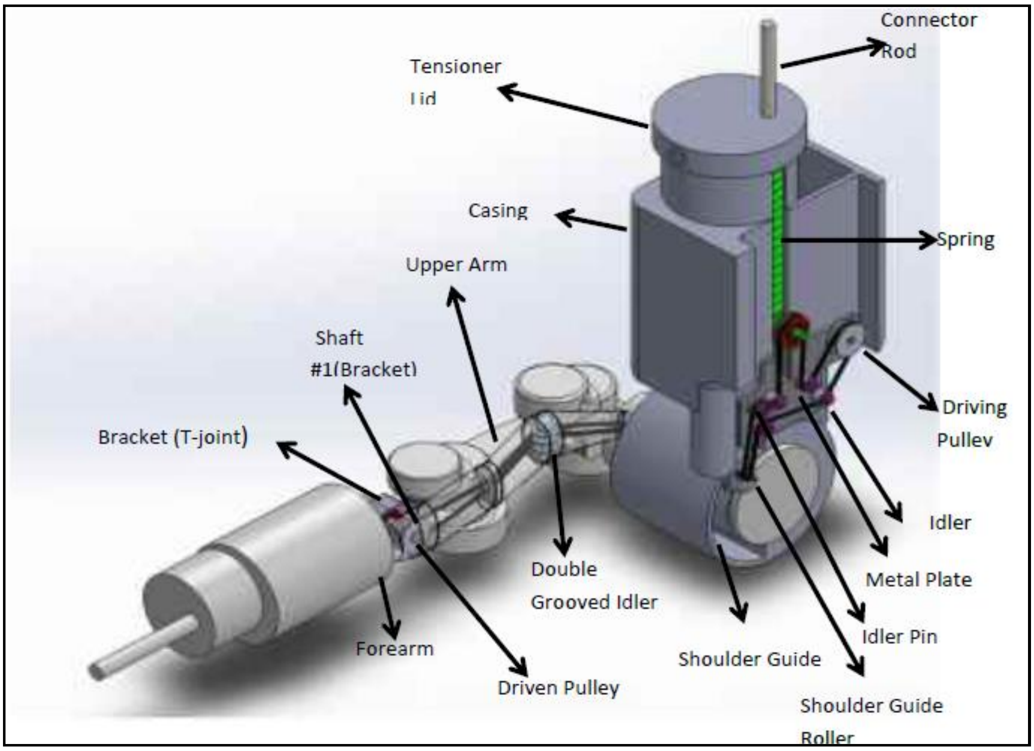

Fig.3 entire assembly of the design system

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