DYNAMIC MODELING OF MRI COMPATIBLE ASSISTANT SURGERY ROBOT (MC ROBOT)

Hashem Yousefi\(^1\), Mostafa Rostami\(^2\), Foad S. Farimani\(^1\)
1-MS student, Biomedical Engineering Department, Amirkabir University of Technology, Tehran, Iran
2-Professor-Biomedical Engineering Department, Amirkabir University of Technology, Tehran, Iran
Ha.yousefi144@gmail.com

Abstract: In the following of development of primary design and fabrication process of MRI compatible assistant surgery robot (MC Robot) for the purpose of diagnose and treatment via placement, injection and aspiration method, in this paper we discuss the dynamic modeling of conceptual mechanism design of the robot. Because of close loop control system and also cable actuated system, results from modeling of proposed robot can be used as an appropriate guidance on control part. We assume in this work that needle has one degree of freedom and needle deflections and the other orientations are zero, and also we have a viscoelastic model for the tissue. Simulation results validate our previous study on transfer of kinematics and kinetics on the robot links to explain the task of manipulator. As this robot works on MRI condition, the user must have good knowledge about the motion mechanism of the manipulator. The result obtained from modeling of robot can be used to instruct operator inexpensively for applying this technology.

Keywords: MRI compatible robot, conceptual design, dynamic modeling, needle insertion.

1 Introduction

One of the most common fields in medical robotics and in biomedical engineering is working on MRI conditions. MCRobot is an effort to link robotics and the usage of MRI in medical science. Therefore in somewhere of the world, scientists want to design and produce mechanisms for this purpose and using robotics in medical sciences. After the development of primary design and fabrication process of MRI compatible assistant surgery (MC) robot for the purpose of diagnose and treatment via placement, injection and aspiration method we want to get the steps of this approach.

It is well known that any arbitrary frame in 3D space could be described by 6 degrees of freedom, 3 for position and 3 for orientation. However since our robot’s end-effector is an axisymmetric needle, clearly the whole system’s degrees of freedom could be decreased to 5. According to this point that the robot is patient-mounted, the first link of the robot exactly has the motion of the patient body, which transfers to mechanism with the ability of image processing. And it will discuss in future works. Here we have the assumption of that the patient have symmetric breathing during a period of time, and we could take it as a sinuous function.

Therefore dynamic modeling is very important for the control of actuators and finally, control of the whole mechanism. Because the dynamic modeling will help us to estimate the magnitude of torques and reacting forces in the joints for a special motion, and then we have good sense how to control the motors.
However at first we want to discuss interventions more that have been studied in MRI compatible robots and also the amount of journal and conference papers about this subject nowadays has great rate of progress. For a few years, the modeling of the interaction forces during needle insertions has become a challenging task. But here we want to simulate a viscoelastic model for soft tissue which is the most classical and popular model for this purpose and also can help unexperienced clinicians to learn needle insertion procedures. And now with the assumption of one direction viscoelastic model for soft tissue, and with a special entrance for the motion of needle tip on insertion, that comes after of its mean task, the dynamical results shows how the operator should control the robot. Between this relations figure 2 shows needle force vs. displacement curves for representative of constant needle velocity. However we neglect needle tissue interaction by the effect of friction between needle shaft and ruptured areas, means needle insertion phases [3, 4] on this condition might change by result of insertion and withdrawal phases.

2 Materials and Methods

For the purpose of dynamical modeling in this case we need to choose an appropriate model for the soft tissue and the force displacement curve for the first link of the robot. So with the solution of inverse kinematic for conceptual design all the rotational and linear of velocity and acceleration vectors of robot could be calculated. But priority of this process is to select the correct Cartesian coordinate from the base to the manipulator, and this needs on Denavit-Hartenberg parameters which is mentioned at table 1.

<table>
<thead>
<tr>
<th>I</th>
<th>α(i-1)</th>
<th>a(i-1)</th>
<th>θ(i)</th>
<th>d(i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>θ(1)</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>h</td>
<td>R(1)</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>90</td>
<td>0</td>
<td>0</td>
<td>θ(2)</td>
</tr>
<tr>
<td>4</td>
<td>90</td>
<td>0</td>
<td>L(1)</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Denavit-Hartenberg parameter

According to coordinates given in the Fig 3, and geometrical property of the links by iterative Newton-Euler dynamics algorithm the inverse dynamic parameters specialized and the problem solves.

2.1 Soft Tissue Modeling

2.1.1. Modeling: To model the interaction during the viscoelastic phase of the needle insertion, we considered a classical viscoelastic model. The linear Kelvin-Voigt (KV) model is certainly the most common model used in the literature. It corresponds to a mass-spring-damper model, as illustrated by Fig 1.

![Fig 1. Representation of the Kelvin-Voigt model](image)

In our case it writes:

\[
 f = \begin{cases} 
 -(Kp + Bv) & p > 0 \\
 0 & p \leq 0 
\end{cases}
\]

(1)

Where f is the force exerted on the tissue, p and v represent the position and the velocity of the needle tip, K is the stiffness coefficient and also B the damping coefficient. The position p = 0 corresponds to the initial contact point. Characteristic results are presented on Fig. 5. This figure illustrates the quality of the force reconstruction. Force is given as a function of the needle tip position.

![Fig 2. Force profile during a robotized needle insertion into the liver](image)

2.1.2. Remark: According to [8] most living tissues have viscoelastic behaviour, as long as small displacements are taken into account. In
practice, we could observe that the viscoelastic phase during a needle insertion corresponds to relatively large motions. When the needle is inserted in very viscous organs, they trend to slip in the abdominal cavity. However, this is very difficult to model. In practice, it is avoided by the physician, which often tries to minimize the viscoelastic phase of the insertion by piercing the organs with an abrupt motion of the needle.

2.2 Inverse dynamic solution for mechanism

In this part the method of inverse dynamic solution of the robot will illustrated. This time with the result of the direct and inverse kinematics and also with the solution of direct dynamic the inverse dynamic will be available. In this condition the rotational and linear velocity and acceleration vectors of robot are calculated. And now with the iterative Newton-Euler dynamics algorithm the process advances. The complete algorithm for computing joint torques from the motion of the joints is composed of two parts. First, link velocities and accelerations are iteratively computed from link 1 out to link \( n \) and the Newton-Euler equations are applied to each link. Second, forces and torques of interaction and joint actuator torques are computed recursively from link \( n \) back to link 1.

3 Results

In this part and after the solution of inverse dynamic method for robot mechanism with respect to the entrance force-displacement figures for needle tip, and also the breathing model for the purpose of base motivation, the needed results for the control of the mechanism would be given in next parts.

3.1 Figures of the reaction force and torque on joints

After the modeling of soft tissue with a linear one direction viscoelastic model, simulation of robot with MATLAB software shows the process of links management. Result of simulation say that magnitude of reaction torques and forces are much more than the effect of link weights’ on joints. Because of the cable actuated system that mounted on robot, and this point that motors weights’ are at a plate that is far from the surgery site so it’s not exerted on motivation system. From the image processor software the it shows local coordination of three point, first one is the ruptured surface and second is target point and also the tracked line passed by needle which is the needle tip’s coordinate. So the critical point’s coordinates and robot link’s properties, beside assumptions of this study are the entrance of SIMULINK and SIMMECHANIC’s simulation models. Here the results of a standard motion like sin wave for the base are given on blow figures:

Fig 4: reaction torques without the effect of gravity.
The first data is when the effect of gravity on robot link neglected and the all forces are from the conservative terms reaction. The next one will be with the notation of mass considering effectiveness:

Fig5.

So as you could see this diagrams are from three joint of robot link’s and the magnitude of reacted torques are given for a simple test of a motion which is a combination of four ramp block for needle tip path, which the result are in blow:

Fig6.

4 Discussion

This paper presented devices and design considerations for (MC) robot and has enough accuracy to design for impedance control of (MC) robot. The accuracy of our results is relative to our assumptions and to method employed. After the result of modeling in MATLAB, procedure to reach these outputs should be illustrated. From the MRI coordinate system the information of three points are available. Puncture point and target point from the tissue and centre of mass for Base from the robot are available with image processing interface software’s. The results had shown, were for two section of modeling with or without gravity effect. Comparison with these two absolute answers suggests that probably it would be much better to go through the problem straight, and the differences are negligible. The friction forces on joints were taken to reach on better accuracy on links reactions. However with one-direction viscoelastic model for soft tissue, the model’s properties are extracted.

5 Conclusion and Future Work

After this all result it must be mentioned that the effect of the weight and geometry versus needle tissue interaction could be neglected. And from this work the design of the other part and other steps this point could be used. The reason of this is because materials like Plexiglas or polyamide have low density and this approach could better show the dexterity, manipulability and versatility of the (MC) robot. So in the future work the problem is how to show needle tissue interaction which has also friction between needle shaft and ruptured area, and also about the soft tissue modeling that could be better to take the viscoplastic model around the damaged or formed regions. The obligation of future works are also the cable actuated part of the robot, which have effect on dynamical control of system and should link with robot like image processing part that mentioned some in result part, gives the guidance plan for this work.

References


