Structural and Dynamic Analysis of Delta Parallel Robot For Cardi applications

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Abbreviations: FEA- Finite Element Analysis.

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Abstract

The concept of a medical robot constructed by parallel mechanisms for chest compressions in rescuing a patient is proposed in this project work. In light of the requirements of cardiopulmonary resuscitation (CPR) from medical aspects, a new translational parallel manipulator employing the architecture of DELTA parallel robot namely, a 3- designed in CAD software . The structural analysis of the DELTA parallel robot is carried out in the HyperMesh RADIOSS workbench. The research works lay a strong foundation on developing a medical robot prototype to assist in CPR operation. In this paper the DELTA PARALLEL ROBOT designed in one of the CAD package and the dynamic analysis is carried out with respect to time to calculate the displacement, velocity, acceleration, and to do the static structural analysis with various loads on the DELTA PARALLEL ROBOT using HyperMesh RADIOSS workbench.

Introduction

In case of a patient is in cardiac arrest, cardiopulmonary resuscitation (CPR) must be applied in both rescue breathing (mouth-to-mouth resuscitation) and chest compressions. Generally, the compression frequency for an adult is at the rate of about 100 times per minute using two hands, and the CPR is usually performed with the compression-to-ventilation ratio of 15 compressions to 2 breaths so as to maintain oxygenated blood flowing to vital organs and to prevent anoxic tissue damage during cardiac arrest. Without oxygen, permanent brain damage or death can occur in less than 10 minutes. Thus for a large number of patients who undergo unexpected cardiac arrest, the only hope of survival is timely and appropriate applying CPR. However, for some patients in cardiac arrest are also infected by other indeterminate diseases, it is very dangerous for a doctor to applying CPR to them directly. For example, before the severe acute respiratory syndrome (SARS) was first recognized as a global threat, many hospitals rescued such kinds of patients as usual, and as a result, some doctors who had performed CPR to such patients were infected with the SARS corona virus unfortunately. In addition, chest compressions consume a lot of energies from doctors, for instance, it needs ten doctors to work two hours to perform chest compressions to rescue a patient in a Beijing hospital of China. Therefore a medical robot used for chest compressions is highly required. In view of this demand, design and analyze a medical parallel robot to assist in CPR operation have been done, and wish the robot can perform this job well instead of doctors.
A parallel robot is a device for performing manipulations, which consists of a fixed base platform connected to the end effector platform by means of a number of legs in parallel (multiple kinematic chains). These legs often consist of an actuated prismatic joint and the actuators for the prismatic joints can be placed in the motionless base platform, so that their mass does not have to be moved, which makes the construction lighter. Nowadays, parallel manipulators are applied widely since they possess many inherent advantages in terms of high speed, high accuracy, high stiffness, and high load carrying capacity over their serial counterparts. In view of the high-stiffness and high-accuracy properties, parallel mechanisms are employed to design such a manipulator applicable to chest compressions in CPR. An observation of the chest compressions in manual CPR reveals that the most useful motion adopted in such an application is the back-and-forth translation in a direction vertical to the patient’s chest, whereas the rotational motions are almost useless. The objective of this work is to Design and Analysis the DELTA parallel robot for CPR operation.
In the next step comes the problem of how to select a particular parallel robot for the application of CPR, since, nowadays, there exist many parallel robots providing various types of output motions. An observation of the chest compressions in manual CPR reveals that the most useful motion adopted in such an application is the back-and-forth translation in a direction vertical to the patient’s chest, whereas the rotational motions are almost useless. Thus, parallel robots with a total of 6DOF are not necessarily required here. In addition, a 6-DOF parallel robot usually possesses some disadvantages in terms of complicated forward kinematics problems and highly coupled translation and rotation motions, etc., which complicate the control of such robots. Hence, translational parallel manipulators (TPMs) with only three translational DOF in space are sufficient to be employed in CPR operation. The reason of utilizing such kind of translational parallel manipulator (TPM) with fixed actuators lies in that in chest compressions process, the mainly used motion of the manipulator is the vertical translation. Because in addition to a translation in the z axis direction, the designed 3-DOF TPM can also provide the translations in the x and y axis directions, which enables adjustment of the manipulator’s moving platform to a suitable position to perform chest compression tasks. At this point, TPMs with less than 3 DOF are not adopted here. In some types of these TPMs, the first joint of each limb is located at the base. In this case, since the actuators can be mounted on the base, the moving components of the manipulator do not bear any load of the actuators. This enables large powerful actuators to drive relatively small structures, facilitating the design of the manipulator with faster, stiffer, and stronger characteristics. Inspired by this performance, a DELTA parallel robot with special arrangements of motors for such applications have been designed.

**Process Methodology**

**CASE (1):-**

To perform structural analysis various methods are followed they are
1. Designing of DELTA PARALLEL ROBOT using CAD package software
2. Converting the respective file in to IGES, parasolid format.
3. Importing the model into HyperMesh 9
4. Applying the following material performing the static structural analysis.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>72000 N/mm²</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>0.33</td>
</tr>
<tr>
<td>Density</td>
<td>2810 Kg/m³</td>
</tr>
<tr>
<td>Yield strength</td>
<td>505 Mpa</td>
</tr>
</tbody>
</table>
KINEMATIC ANALYSIS

Fig. 5 represents the schematic diagram of the designed 3-RRPaR parallel manipulator, which consists of a mobile platform, a fixed base, and three limbs of identical RRPaR kinematic structure with the first R joint actuated by a rotary actuator, where the notation of R and Pa stands for the revolute joint and parallelogram, respectively.

For the purpose of analysis, as shown in Fig. 5, we assign a fixed Cartesian frame O(x, y, z) at the centered point O of the fixed base platform _X1X2X3, and a moving Cartesian frame A(u, v, w) on the triangle mobile platform at centered point A of triangle _Z1Z2Z3, with the z and w axes perpendicular to the platform, and x, y axis parallels to u, v axis, respectively. To get a compact structure, both the base and moving platforms...
are designed as an isosceles right triangle described by the parameter of $a$ and $r$, respectively, i.e., $BX_i = m$ and $AZ_i = p$, for $i = 1, 2, \text{ and } 3$. The actuated variable of the $i$th limb is angle $\alpha_i$. The connecting joints between the upper and lower links are denoted as $Y_i$, and the lengths of upper and lower links for each limb are $b$ and $l$ respectively, i.e., $X_iY_i = n$ and $Y_iZ_i = o$.

Although the general Gr"ubler-Kutzbach criterion is useful in mobility analysis for many parallel manipulators, it is difficult to apply this criterion directly to mobility analysis of over constrained parallel manipulators. For example, the number of DOF of the designed manipulator given by the general Gr"ubler-Kutzbach criterion is

$$F = \mu(n-j-1) + \sum_{i} f_i = 6(20-25-1) + 25 = -11, \quad (1)$$

where $\mu$ represents the order of task space, $n$ is the number of links, $j$ is the number of joints, and $f_i$ denotes the degrees of freedom of joint $i$. Another drawback of the general Gr"ubler-Kutzbach criterion is that it can only derive the number of DOF of some mechanisms but can not indicate the features of the DOF, i.e., whether they are translational or rotational DOF. On the other hand, we can effectively analyze the mobility of a 3-RRPaR type of TPM by resorting to screw theory. For a limited-DOF parallel manipulator, the motion of each limb, which can be termed as a twist system, is guaranteed under some exerted structural constraints. The wrench system is the reciprocal screw system, and a wrench is said to be reciprocal to a twist if the wrench produce no work along the twist $[15]-[17]$. The mobility of the manipulator is then determined by the combined effect of wrench systems of all the limbs. For a 3-RRPaR TPM, the twist system of each limb is a screw system of order 5, and it is not difficult to derive the wrench system that is a reciprocal screw system of order 1, which exerts a constraint couple to the mobile platform with the axis perpendicular to all of the $R$ joint axes, i.e., parallel to the parallelogram plane and perpendicular to the actuated $R$ joint axis. Generally, the three couples of the limbs are linearly independent and the linear combination of them results in an order 3 wrench system of the mobile platform, which restricts any rotations of the mobile platform with respect to the fixed frame, thus leads to a translational parallel manipulator.

Let $p^* = [x^* \ y^* \ z^*]^T$ be the vector of output velocities of the mobile platform, and $q^* = [\alpha_1, \alpha_2, \alpha_3]^T$ be the vector of the input joint rates.

$$J = B^T a$$

is defined as the $3 \times 3$ Jacobian matrix of the manipulator, which relates output velocities to the actuated joint rates.
From the above diagram the upper plate is fixed and the pressure is added on the base plate pressure $p=1.4709975\text{Mpa}$. and finally calculated the von mises stress by using RADIOSS workbench in HyperMesh the maximum stress value obtained is $238.9\text{ Mpa}$.

CASE(2):-

To perform dynamic analysis various methods are followed, add the pressure on the base plate of $1.4709975\text{Mpa}$. Various types of materials are assigned to the DELTA PARALLEL ROBOT and it is a linear DELTA PARALLEL ROBOT.

The key issue in dynamic analysis for a parallel manipulator is to establish an inverse dynamic model, then the required actuator forces and/or torques can be computed if the time history of a desired trajectory of the mobile platform is given. The dynamic model is important in designing suitable strategies for accuracy control. In the following section, we will perform the dynamic modelling of the 3-RRPaR TPM approached by virtual work principle.

As for a 3-RRPaR TPM, the complexity of the dynamic model partly comes from the lower parallelogram links. Since the connecting rods of lower links can be built with light materials such as the aluminium alloy, we can simplify the dynamic problem by the following hypotheses [18]:

- The rotational inertias of lower links are neglected;
- The mass of each lower link is equally divided into two portions and placed at its two extremities, i.e., one half at its upper extremity (the end of upper link) and the other half at its lower extremity (mobile platform). Let $m_b$, $m_l$, and $m_p$ be the mass of upper link, each connecting rod of lower link, and the mobile platform, respectively.

After completing the dynamic simulations we need to plot the graphs of displacement, velocity, acceleration with respect to time set the time period to 3.40sec and calculates here we represent the following graphs.
Graph 1:-: Displacement vs. time

Graph 2:-: Velocity vs. time
Results & Discussions

CASE(1):- From the above diagram the upper plate is fixed and the pressure is added on the base plate pressure \( p = 1.4709975 \text{Mpa} \). and finally calculated the von mises stress by using RADIOSS workbench in HyperMesh the maximum stress value obtained is 238.9 Mpa. The material we had selected is Aluminum 7075 alloy of having yield strength 505Mpa. The maximum stress analysis (Von-mises) stress does not exceed the yield strength of the particular material selected.

CASE(2):- From the graph plotted with respect to time to calculate displacement, velocity, acceleration that had set time to 3.40 sec

Displacement: - 15.4 cm

Velocity: - 3 cm/sec

Acceleration:-10 cm/ sec\(^2\)

Benefits Summary

The static analysis that is carried out for the given parameters had given a good result to know behavior of the material and safety factor. ALTAIR HyperWorks is having complete software for analysis which can easily understand and user friendly software for both educational and industries. The multibody dynamic analysis is much benefited for all users who are using ALTAIR products. The design optimization is easier to understand and we can do the topology optimization.

Challenges

As this project is having more number of components it is difficult to mesh and to give constraints but as the no of components increases in particular CAD model it is a tough challenge to do mesh and perform analysis.

Future Plans

As the results obtained from the experiment in future we are going to do design optimization of DELTA PARALLEL ROBOT using ALTAIR products.
Conclusions

In this paper, a novel concept of employing a medical parallel robot for chest compressions in the process of CPR operation is defined. In view of the requirements from medical aspects, a DELTA parallel robot, namely, a 3-RPaRPaR TPM is chosen and designed to suit the needs, and the architectural parameters have been selected by utilizing an adopted optimization process.

From the analysis, it was found that the structure is capable of withstanding various loads that are inherent during mobility.

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REFERENCES