Study of modified Delta parallel robot used for Cardiopulmonary Resuscitation

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Abstract—This review paper briefly explains the concept of a medical robot constructed by parallel mechanisms for chest compressions in rescuing a patient in cardiac arrest. In light of the requirements of cardiopulmonary resuscitation (CPR) from medical aspects, a new translational parallel manipulator (TPM) employing the architecture of a modified version of DELTA parallel robot is used. Literature survey is done on difference between serial and parallel robot. A Parallel manipulator, having various advantages like high speed, better stiffness, better load bearing capacity etc., can be used for different medical applications where all these properties of Delta Parallel robot are well utilized.

***IndexTerms*— cardiopulmonary resuscitation (CPR), translational parallel manipulator (TPM)**

I. INTRODUCTION

In the past two decades, parallel robots have attracted more and more researchers' attention in terms of medical applications, for the irrelative advantages, e.g., high stiffness, high accuracy, low moving inertia, and so on. For such reason, more and more parallel mechanisms with specified number and type of degrees of freedom (DOF) have been proposed.

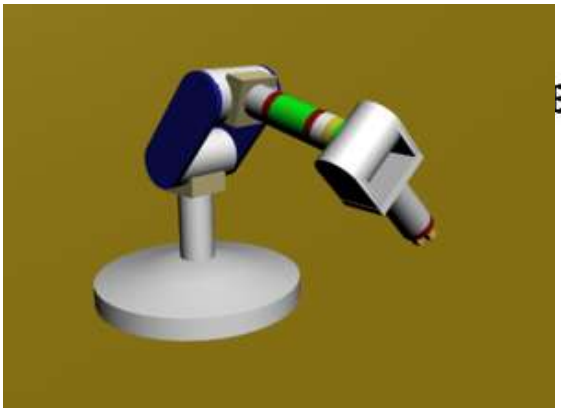
A parallel manipulator is a mechanical system that uses several computer-controlled serial chains to support a single platform, or end-effector. Perhaps, the best known parallel manipulator is formed from six linear actuators that support a movable base for devices such as flight simulators. Also known as parallel robots, these systems are articulated robots that use similar mechanisms for the movement of either the robot on its base, or one or more manipulator arms.

➢ CONCEPT OF SERIAL AND PARALLEL MANIPULATORS

- **SERIAL MANIPULATORS**

  Serial manipulators are the most common industrial robots. They are designed as a series of links connected by motor-actuated joints that extend from a base to an end effector. Often they have an anthropomorphic arm structure described as having a "shoulder", an "elbow", and a "wrist".

Serial robots usually have six joints, because it requires at least six degrees of freedom to place a manipulated object in an arbitrary position and orientation in the workspace of the robot.



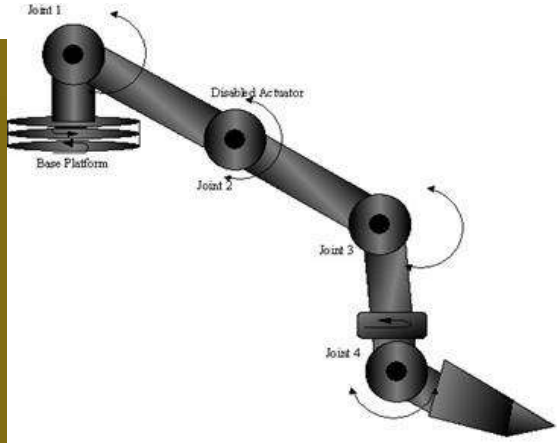


Figure-1 Serial manipulator

- **PARALLEL MANIPULATOR**

Parallel manipulator is a mechanical system that uses several computer-controlled serial chains to support a single platform, or end-effector. Perhaps, the best known parallel manipulator is formed from six linear actuators that support a movable base.

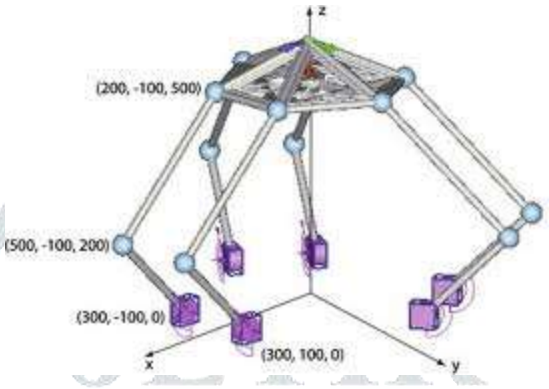


Figure-2 Parallel manipulator

- **CONCEPT OF PARALLEL MANIPULATOR**

(a) A **parallel manipulator** is a mechanical system that uses several computer-controlled serial chains to support a single platform, or end-effector.
(b) In this, the end effector (or 'hand') of this linkage (or 'arm') is connected to its base by a number of (usually three or six) separate and independent linkages working in parallel.
(c) 'Parallel' is used here in the topological sense, rather than the geometrical; these linkages act together, but it is not implied that they are aligned as parallel lines.
(d) A parallel manipulator is designed so that each chain is usually short, simple and can thus be rigid against unwanted movement, compared to a serial manipulator.
(e) These are closed-loop mechanisms that consists of separate serial chains connecting the fixed base to the moving platform.
(f) They are equipped with revolute and prismatic actuators.
(g) They have robust construction and can move bodies of large dimensions with high velocity and acceleration.
(h) It is this closed-loop stiffness that makes the overall parallel manipulator stiff relative to its components, unlike the serial chain that becomes progressively less rigid with more components.[1]

Figure-3 Closed loop structure of Parallel manipulator

➢ ADVANTAGES AND DRAWBACKS OF PARALLEL MANIPULATOR OVER SERIAL MANIPULATOR

➢ ADVANTAGES

1. Higher kinematical precision
2. Lighter weight
3. Better stiffness
4. Greater load bearing
5. High velocity and acceleration

➢ DRAWBACKS OF PARALLEL MANIPULATORS

1. A major drawback of parallel manipulators, in comparison to serial manipulators, is their limited workspace.
2. Another drawback of parallel robots is that they lose stiffness in singular positions completely (The robot gains finite or infinite degrees of freedom which are uncontrollable; it becomes shaky or mobile).

➢ APPLICATIONS OF PARALLEL MANIPULATOR

- In light simulators
- In automobile simulators
- In high speed, high-accuracy positioning with limited workspace, such as in assembly of PCBs
- As micro manipulators mounted on the end effector of larger but slower serial manipulators.
- As high speed/high-precision milling machines
- To assemble automobiles
- In pick and place applications
- In surgical applications

II. WHAT IS DELTA ROBOT?

- A Delta robot is a type of parallel robot. It consists of three arms connected to universal joints at the base.
- It consists of spatial parallel structure with 3 degrees of freedom and is driven by 3 actuators.
- The platform is connected with each drive by two links, forming a parallelogram. It allows only a translational movement of the platform and keeps the platform parallel to the base plane. [2]

Figure-4 Structure of Delta robot

➢ **CONCEPT AND WORKING:-**

- The key concept of the Delta robot is the use of parallelograms. These parallelograms restrict the movement of the end platform to pure translation (only movement in the X, Y or Z direction).
- The robot's base is mounted above the workspace and all the actuators are located on it.
- From the base, three middle jointed arms extend. The ends of these arms are connected to a small triangular platform.
- Actuation of the input links will move the triangular platform along the X, Y or Z direction.

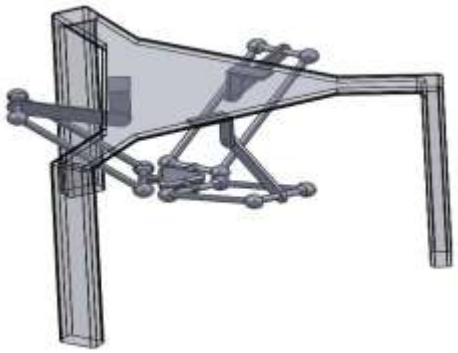


Figure-5 Delta parallel robot with 3 degrees-of-freedom (CAD model)

- Actuation can be done with linear or rotational actuators, with or without reductions (direct drive).
- Since the actuators are all located in the base, the arms can be made of a light composite material.
- As a result of this, the moving parts of the Delta robot have a small inertia. This allows for very high speed and high accelerations.
- Having all the arms connected together to the end-effector increases the robot stiffness, but reduces its working volume.[3]

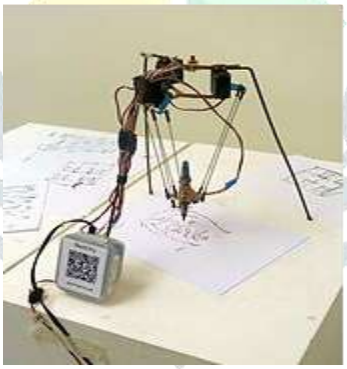


Figure-6 Sketchy (a portrait drawing Delta robot)

III. CONCEPT OF CARDIOPULMONARY RESUSCITATION

- 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.
- It is an emergency procedure which is performed in an effort to manually preserve intact brain function to restore spontaneous blood circulation and breathing in a person in cardiac arrest.
- It is indicated in those who are unresponsive with no breathing or abnormal breathing, for example. It may be performed both in and outside of a hospital.
- CPR involves chest compressions at least 5 cm deep and at a rate of at least 100 per minute in an effort to create artificial circulation by manually pumping blood through the heart.

- Compression-to-ventilation ratio is 15 compressions to 2 breaths, so as to maintain oxygenated blood flowing to vital organs and to prevent anoxic tissue damage during cardiac arrest. [4],[5]

Figure-7 Manual method of CPR

➢ **IMPORTANCE OF CPR**

- CPR alone is unlikely to restart the heart; its main purpose is to restore partial flow of oxygenated blood to the brain and heart.
- Without oxygen, permanent brain damage or death can occur in less than 10 minutes.
- The objective is to delay tissue death and to extend the brief window of opportunity for a successful resuscitation without permanent brain damage.
- Thus for a large number of patients who undergo unexpected cardiac arrest, the only hope of survival is timely and appropriate applying CPR.[5],[6]

➢ **NEED OF ROBOT WHILE APPLYING CPR**

- Since CPR involves chest compressions at least 5 cm deep and at a rate of at least 100 per minute, it's not an easy task to do for a single person.
- Chest compressions consume a lot of energies from doctors, for a very long period of time. For example, 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.
- Some patients in cardiac arrest are also infected by other indeterminate diseases, it is very dangerous for a doctor to apply CPR to them directly.
  For example, before the Severe Acute Respiratory Syndrome (SARS) was first recognized as a global threat in 2003, many hospitals rescued such kinds of patients as usual. And as a result, some doctors who had performed CPR to such patients were unfortunately infected with the SARC corona virus [6].

➢ **CONCEPTUAL DESIGN:**

- When a patient goes in cardiac arrest, the rescuer usually uses two hands instead of only one hand to perform the action of chest compressions.
- During chest compressions action, the two arms of the rescuer construct actually a parallel mechanism.
- Inspired by this performance, we design a modified version of the DELTA parallel robot with special arrangements of motors utilizing only revolute joints for such applications.

USING TRANSLATIONAL PARALLEL MANIPULATOR (TPM):

Figure-8 Parallel structure formed by hands during CPR

- In chest compressions process, the mainly used motion of the he manipulator is the vertical translation.
- In addition to a translation in the z axis direction, the designed TPM can also provide the translations in the x and y axis directions, which enables the adjustment of the manipulator mobile platform to a suitable position for performing chest compression.
- The fixed actuators are provided to TPM which make it possible that the moving components of the manipulator do not bear the load of the actuators.
- This enables large powerful actuators to drive relatively small structures, and facilitates the design of a manipulator with faster, stiffer, and stronger characteristics.
- So, the designed TPM has a more compact structure for medical applications in CPR operation.

IV. CONCEPTUAL DESIGN OF A CPR SYSTEM:

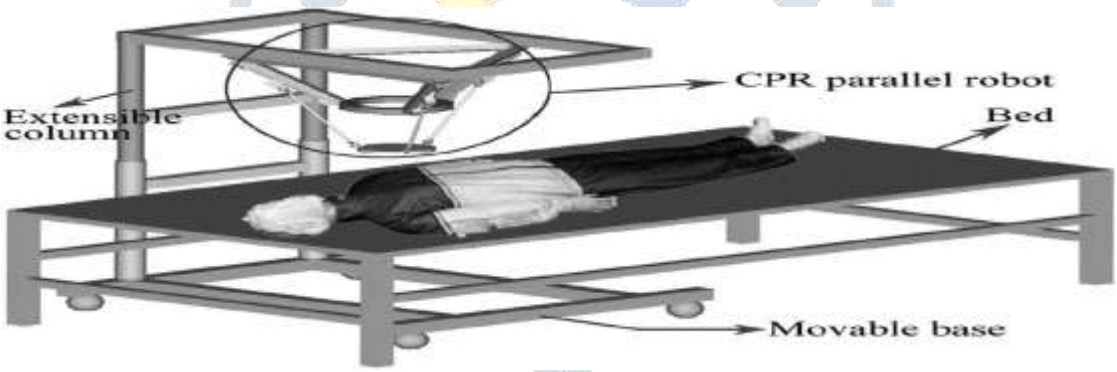


Figure-9 Conceptual design of a CPR medical robot system.

- The patient is placed on a bed beside a CPR robot, which is mounted on a separated movable base via two supporting columns and is deposed above the chest of the patient.
- The movable base can be moved anywhere on the ground, and the supporting columns are extensible in the vertical direction.
- Thus, the robot can be positioned well by hand such that the chest compressions may start as soon as possible, which also allows a doctor to easily take the robot away from the patient in the case of any erroneous operation.
- CPR robot is located on one side of the patient, thereby providing a free space for a rescuer to access the patient on the other side.
- 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.
- This idea is motivated from the reason why the rescuer uses two hands instead of only one hand to perform the action of chest compressions.

- sThe main disadvantage of parallel robots is their relatively limited workspace range. Fortunately, by a proper design, a parallel robot is able to satisfy the workspace requirement with a height of 4–5cm for the CPR operation.

HOW TO SELECT A ROBOT FOR CPR

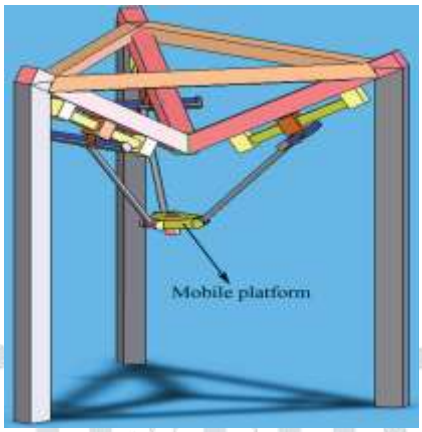


FIG 10 Translational Parallel Manipulator

- 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.
- 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.

FIG 11 - Medical parallel robot applying in CPR operation

- Hence, translational parallel manipulators (TPMs) with only three translational DOF in space are sufficient to be employed in CPR operation.
- Because in addition to a translation, vertical to the chest of the patient, a 3-DOF TPM can also provide translations in any other direction, this enables 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 view of the complexity of the TPM topology, including the number of mechanical joints and links and their manufacture procedures, a 3-PUU TPM is finally chosen.

V. ARCHITECTURE DESCRIPTION OF TPM:

- The 3-PUU TPM consists of a moving platform, a fixed base, and three limbs with identical kinematic structure.
- Each limb connects the fixed base to the moving platform by a prismatic (P) joint followed by two universal (U) joints in sequence, where the P joint is driven by a linear actuator.
- In view of the cost effectiveness, the linear actuator is implemented by using a lead screw actuation system driven by a dc servomotor in this paper.
- For safety reasons, the selected screw should satisfy the condition of self-locking, so as to ensure that the nut is self-locking when the lead screw is not actuated.
- It should be noted that if other types of linear actuators are selected, they should not be back-drivable for safety reasons as well.

VI. CONCLUSION:

In this paper, the concept and working of Delta parallel robot is studied. Along with that, 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 modified Hence it is concluded that, a parallel robot can be easily used in the application like Cardiopulmonary Resuscitation (CPR) by keeping the structure of Delta parallel robot simple like a Translational Parallel Manipulator (TPM).

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