The Collision-free Workspace of the Tripteron Parallel Robot Based on a Geometrical Approach

Z. Anvari[1], P. Ataei[2] and M. Tale Masouleh[3]

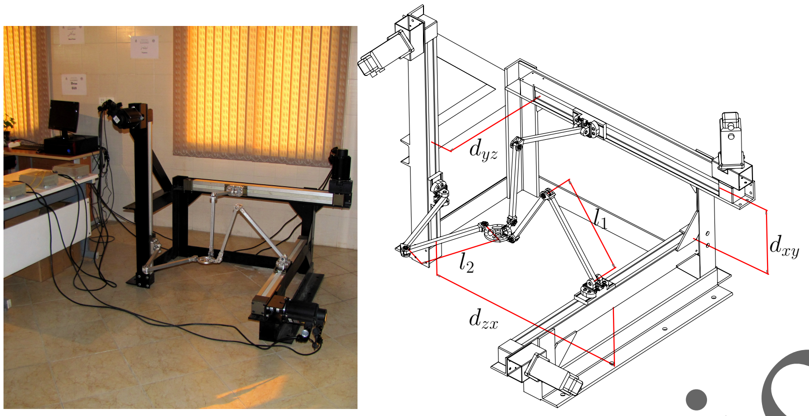
[1,2]*Human-Robot Interaction Laboratory, University of Tehran - Tehran - Iran,*
e-mail: zolfa.anvari@taarlab.com and e-mail: parnyan.ataei@taarlab.com
[3] *School of Electrical and Computer, Human-Robot Interaction Laboratory,*
University of Tehran - Tehran - Iran, e-mail: m.t.masouleh@ut.ac.ir

Abstract. Parallel robots, despite many kinematic features, generally have limited workspace. Therefore, it is paramount importance to obtain the workspace by considering the mechanical interference. In this paper, the mechanical interference, including collision of links, collision of links with obstacles, collision of the end-effector with obstacles, are investigated by using a new geometrical reasoning. For this purpose, a new geometric method is proposed which is based on the segment to segment intersection test. This method can be well extended to a wide range of robotic mechanical systems, including, among others, parallel robots. Moreover, in this paper, an index is introduced which can be used to examine the workspace with respect to mechanical interference. Furthermore, the aforementioned index provides some insight into obtaining a well-conditioned workspace. For the sake of validation, as case study, the proposed method is implemented to a spatial 3-DOF parallel robot, known as the Tripteron.

Key words: Mechanical interference, Parallel robot, Collision-free workspace, Performance index.

1 Introduction

The workspace of parallel robots is more constrained compared to their serial counterparts. Some of the contributing factors rendering a significant amount of workspace useless are collision of links to each other, collision of links with obstacles, collision of the end-effector with obstacles and also mechanical limitations of the joints [2]. Researches conducted on this subject are limited and most of them are concerned with avoiding collision with obstacles, on mobile robots or the end-effector of serial manipulators [4]. Despite its significance, there have been few studies examining the workspace and the mechanical interference among the links and between the links and the end-effector with obstacles; the reason might be that in most simulations the volume and mass of the robot's components are ignored, in order to simplify the problem. The significance of such collisions is highlighted during implementation and use of the robots, where without appropriate collision prevention measures between the components, the robot might sustain serious damages. The present study aims at improving the workspace, by taking into account



(a) Prototype (b) CAD model

Fig. 1: The 3-DOF Tripteron parallel robot, built at the Human and Robot Interaction Labratory, University of Tehran.

the problem of collision-free workspace. This can be achieved by eliminating those parts of the workspace wherein any kind of mechanical collisions might happen. This method is applied to the so-called Tripteron robot, which is a linearly independent 3-DOF parallel robot performing translational motion. The parameters used for implementing the proposed approach are based on the parameters of the actual prototype in the Human and Robot Interaction Laboratory, University of Tehran. The remainder of the paper is organized as follows. In Section 2, the Tripteron parallel robot is introduced. As the main contribution of this paper, a new algorithm is presented in Section 3 which can identify mechanical collisions of the robot. In Section 4, the collisions in the workspace of the Tripteron is examined and the proportion of the practical to theoretical workspace is calculated as an index. Finally, the paper concluded with some remarks and hints as ongoing works.

2 Tripteron

The Tripteron, as shown in Fig. 1, is a 3-DOF translational parallel mechanism, whose end-effector is connected by three kinematically identical chains. From the type synthesis performed for this kind of mechanisms, it follows that all the revolute joints and the prismatic actuators have parallel axes in each arm which together form an orthogonal set. One of the remarkable kinematic features of the Tripteron consists in its decoupling properties among its DOF. The latter leads to have an identical Jacobian matrix which results in having a singularity-free workspace [5, 3].

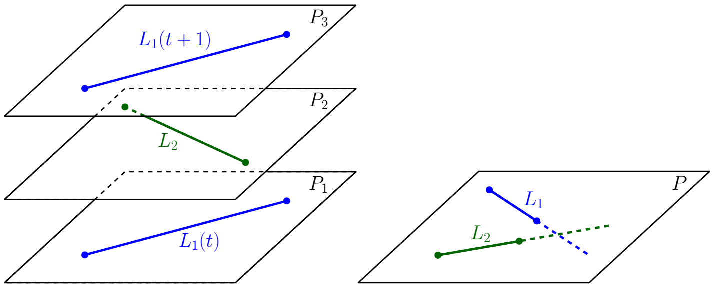
3 A new algorithm based on segments collision

The mechanical collisions depend on design properties, such as dimensions of the links, the fixed frame, and the end-effector. Moreover, if there is an obstacle in the workspace, it can influence the movement of the end-effector considerably. In fact, existence of one or more obstacles in the workspace can limit not only the end-effector but also the movement of the links. Under such circumstances, the detection of collision of links with an obstacle is as important as the collision of end-effector with an obstacle. The obstacles may have different shapes, which they can be inscribed inside a polyhedron.

By dividing the workspace into its constituent parts (meshing), placing the end-effector in all these points, and calculate the inverse kinematics for all these positions, all possible configurations of the robot are obtained. Upon determining the configuration, as shown in the first to the 15th line of Algorithm 1, and after checking the condition of the angel between robot mechanical components, if the angle is not within the allowable range, the robot end-effector is not allowed to go to that part of the workspace and check collision is not necessary, based on lines 16 to 20 of Algorithm 1. However, if the angle is within the allowable range and there is at least one mechanical collision among the links, end-effector, and obstacles, the corresponding coordinate will be considered as a non admissible point for the end-effector. Thus the robot's end-effector is not allowed to go to that part of the workspace, as indicate in lines 22 to 32 of Algorithm 1. By repeating this algorithm for all points of the workspace, a set of coordinates will be obtained for which a collision will take place. Then, this set can be eliminated from the workspace, or considered as an obstacle. From the outset, the geometrical examination of mechanical collisions, can be solved readily using one of the following approaches:

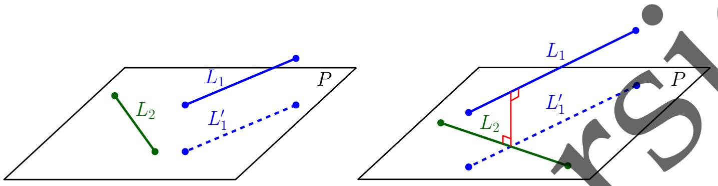
1. Examining the intersection of two line segments in space at any given time;
2. Calculating the common perpendicular of two line segments and comparing it to a permissible value that equals the total radius of the two links.

However, since in this method the space is meshed, the configuration of the robot at any moment is one step apart from its next and previous moment. In other words, the positions are discreted. In such a discrete space, it is not possible to calculate all the collision points, because a collision might happen between two selected points. As presented in Fig. 2a, a discrete space will cause L_1 to be on the edge of collision at a given moment t but at the moment $t+1$ it will leave the collision position behind and the collision will not be detected. Moreover, in this case, one cannot take into account the thickness of the links; therefore, the first approach is rejected. The second approach can not be regarded as a comprehensive method. As shown in Fig. 2b, when the line segments are part of the two intersecting lines and do not collide, the length of the common perpendicular is zero, and it seems that there has been a collision. Therefore, it is important to provide a comprehensive algorithm which can be generalized to any line segment in the space, and consider the thickness of the links and other mechanical parts.



(a) Lines position in consecutive times (b) Intersecting lines

Fig. 2: Two failed conventional approaches.



(a) L_1' does not collide with L_2 (b) L_1' collides with L_2

Fig. 3: Two cases which arise by projecting two lines in space.

In the proposed geometrical method, for detecting the collision among the links, the first line segment is projected into a plane that includes the second line segment and is parallel to the first line segment (the surface normal is the common perpendicular of the two lines). Now, two cases arise:

1. The projection of the first line segment does not collide with the second line segment, Fig. 3a, where the two lines do not collide;
2. The projection of the first line segment collides with the second line segment; as shown in Fig. 3b. Obviously, the former situation does not necessarily mean collision of the links and it is necessary to calculate the length of the common perpendicular, if it was less than the permissible value (sum of the thickness of both links), it can be concluded a collision occurs.

As it was claimed and shown in lines 33 to 42 of Algorithm 1, this algorithm can be generalized to all relative positions of the lines. If two lines intersect, the plane in which the collision is examined is their common plane; and if the two line segments are parallel, upon projecting, they should be matched and the second condition(the length of common perpendicular), should be analysed. Therefore, through analysis of the two geometrical conditions, the collision of two mechanical components or lack thereof, with arbitrary thickness and length at any position in the space is obtained. The collision of links is not the only mechanical limitation in robots. For instance, in the prismatic joints, the slider can move in a specified range, and most of the revolute joints do not support 360 degree orientation.

```
input : $l_1$ and $l_2$: Length of links.
        $d_xy$, $d_yz$ and $d_zx$: Distance between axis of prismatic joints and coordinates axis.
        $R$: Radius of end-effector.
        $w$: Allowed threshold between links.
output: modified workspace.

F: Collision matrix.
$i \leftarrow 0$
for Whole of possible space do
    for 3 kinematic chains do
        Check kinematic constraints
        if The conditions holds. then
            $i \leftarrow i+1$
            $[X(i),Y(i),Z(i)]$: Save $(x,y,z)^T$ as the coordinates point of the workspace.
        end
    end
end
for $j = 1 : i$ do
    Solve IK for $X(j),Y(j),Z(j)$.
    Results are: $\theta_1$, $\theta_2$,$\theta_3$ and $\rho_1$, $\rho_2$,$\rho_3$.
    So obtained configuration of robot.
end
Check angle.
Calculate the angle between the segments by using law of cosines.
if Angel isn't in allowable angle range. then
    Save $X,Y,Z$ in a new matrix.
    $F(j,1) \leftarrow X(j)$, $F(j,2) \leftarrow Y(j)$, $F(j,3) \leftarrow Z(j)$.
    else
        Check collision.
        Lines collision detection by using ,collisioncheck, function.
        $[OUTPUT] = collisioncheck(2segment)$.
        Returns $\langle 1 \rangle$ if at least there is a collision. If not, returns $\langle 0 \rangle$ by default.
        Check every 2 segments (include links to each other, links to end-effector,
          end-effector to obstacle and links to obstacle) in robot.
        if There is atleast a collision. then
            Save $X,Y,Z$ in a new matrix.
            $F(j,1) \leftarrow X(j)$, $F(j,2) \leftarrow Y(j)$, $F(j,3) \leftarrow Z(j)$.
        end
    end
end
Function $[OUTPUT] = collisioncheck(2segment)$
OUTPUT $\leftarrow$ 0
$L_1$: First segment.
$L_2$: Second segment.
$L_1$ Project on the plate that is parallel to $L_1$ and includes $L_2$ which is labelled as $L_1'$
if Intersection occur between $L_1'$ and $L_2$ then
    if Common perpendicular $\leq w$ then
        OUTPUT $\leftarrow$ 1
    end
end
```

Algorithm 1: Collision detection algorithm.

The Collision-Free Workspace(CFW) index is defined as the ratio of practical workspace to theoretical workspace after calculating the available workspace of the parallel robot in every configuration. the index is used for identification of the most effective factor in designing and ultimately improving the workspace of parallel robots. In fact, this index, η, ranged between 0 and 1 stands for the ratio of collision-free workspace to the theoretical workspace [1]:

$$\eta = \frac{W_p}{W_t} \approx \frac{n_{W_p}}{n_{W_t}} \tag{1}$$

In the above relation, W_p is the practical workspace, W_t is the theoretical workspace, and n is the number of discrete workspaces of the parallel robot.

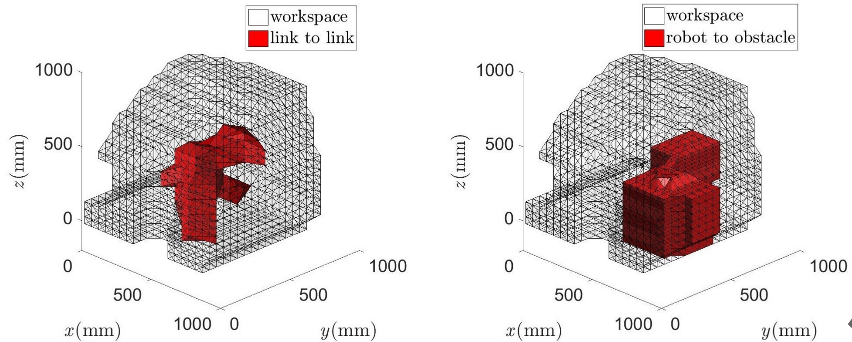
4 Results

In this section, the performance of the proposed collision algorithm is examined for different kinds of mechanical collisions in the workspace, the limitation of revolute joints and the CFW index in the Tripteron robot is presented. Useless parts of the robot's workspace has been detected by collision algorithm. If the end-effector is placed in this space, collision will occur between mechanical components of robot with each other and with obstacle. The 3D appearance of this space in the primary workspace, is illustrated in Fig. 4a and Fig. 4b, respectively. In this case, the considered obstacle is a rectangular cube, located at $P_o(635, 370, 160)^T$, length, width and height of this rectangular cube are 100, 100 and 400, respectively. It should be noted that, from a practical stand point, since a revolute joint can not rotate freely, thus for a given working mode a range of motion is considered less than 160° for all the revolute joints of the Tripteron. The latter leads to have a restricted range of motion for the end-effector, as shown in Fig. 5. The index of practical workspace to theoretical workspace ratio, η, in this case is 0.734 without an obstacle and 0.498 with obstacle.

In Fig. 6, each area represents a type of collision or mechanical limits of the joints in the robot's workspace. Table 1 provides some information about the percentage of collision occurred within the workspace by each components. From the foregoing table 1 it can be inferred that which parts of the robots have a greater percentage of collision and should be subject of further investigation to be improved for an optimum design of this robot.

5 Conclusions

This paper proposed a new geometrical algorithm which can be used for all serial, parallel, and cable-driven robots. Previously, this problem was solved by meshing



(a) Robot components collision to each other (b) Robot components collision to obstacle

Fig. 4: Collision within the workspace of the Tripteron robot.

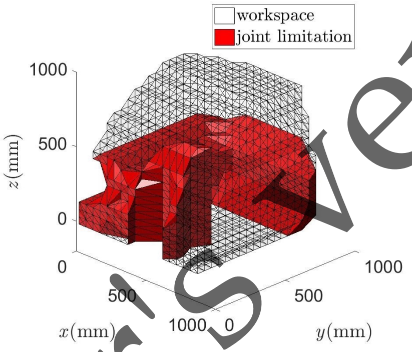


Fig. 5: Joint limitation in the workspace of the Tripteron robt.

and final elements, which was far more complicated, required large quantities of data for comparison and was slower. The provided CFW index is very useful for design stage. For instance, measuring the value of this index for each component of the robot, provides a clear understanding of the relation between these variations and the collision-free workspace of the robot which can be regarded as a definite asset in practice. In this way, an optimum design for workspace could obtained. In addition, the forbidden coordinates can be used as fixed obstacles in the obstacle avoidance algorithms. As ongoing work, this approach will be merged with optimization algorithms to synthesis collision-free workspace parallel robot for a prescribed workspace.

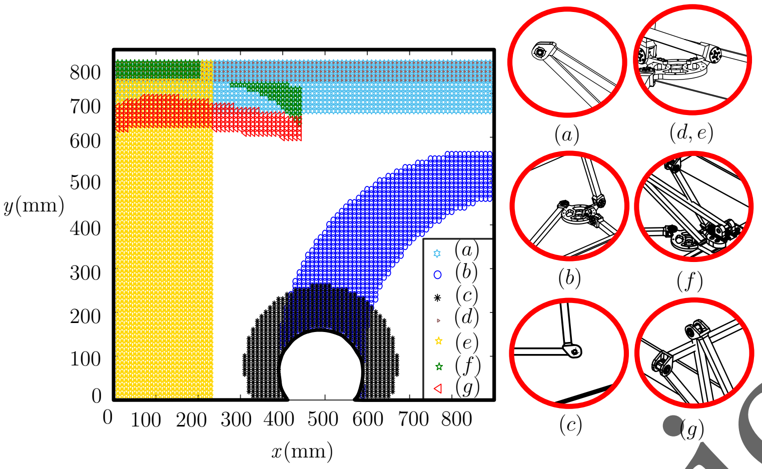


Fig. 6: All types of collisions in a horizontal section at $z = 0$.

Table 1: The effect of collisions in the useless space of the Tripteron in $z = 0$. in link(i, j), i and j stand for the number of link and kinematic chain, respectively.

	Involved Components	Percentage
a	link(1,1) to link(2,1)	26.94
b	link(2,3) to EE	25.55
c	link(3,1) to link(3,2)	11.22
d	link(2,1) to EE	13.39
e	link(2,2) to EE	44.67
f	link(1,1) to link(2,2)	3.68
g	link(2,1) to link(2,1)	6.60

References

1. Danaei, B., Karbasizadeh, N., Tale Masouleh, M.: A general approach on collision-free workspace determination via triangle-to-triangle intersection test. Robotics and Computer-Integrated Manufacturing **44**, 230–241 (2017)
2. Gosselin, C.: Determination of the workspace of 6-dof parallel manipulators. ASME J. Mech. Des **112**(3), 331–336 (1990)
3. Gosselin, C.M., Tale Masouleh, M., Duchaine, V., Richard, P.L., Foucault, S., Kong, X.: Parallel mechanisms of the multipteron family: kinematic architectures and benchmarking. In: Robotics and Automation, 2007 IEEE International Conference on, pp. 555–560. IEEE (2007)
4. Merlet, J.P.: Parallel robots, vol. 74. Springer Science & Business Media (2012)
5. Tale Masouleh, M., Gosselin, C.: Kinematic analysis and singularity representation of 5-rprrr parallel mechanisms. In: ASME 2007 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, pp. 1125–1132. American Society of Mechanical Engineers (2007)