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Research Paper

WORKSPACE COMPUTATION USING MOTION ANALYSIS

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Robotic manipulators depending on their type of chain are classified into two categories: Serial and Parallel Manipulators. All closed chain manipulators are parallel manipulators. Parallel manipulators currently are having wide applications in industry, medicine and entertainment. 4D theaters are good examples of application of parallel manipulators. Workspace computation for the tool mounted is an important step when designing the parallel manipulators. Many approaches have been suggested for computing workspace. All the approaches involve mathematical formulation for workspace estimation. This paper proposes the use of motion analysis performed using a CAD package for workspace computation. A modified 3-RPSR manipulator is used for demonstration. Motion envelopes are initially generated for various combinations of motions and are then assembled to get the final workspace. Avoiding of complex mathematical formulation of the workspace is the main advantage with a tradeoff being the number of analyses to be performed to generate the complete workspace.

Keywords: Motion analysis, Motion envelope, Parallel manipulators, Workspace

INTRODUCTION

Robotic manip1ulators can be classified into serial and parallel manipulators depending on the type of kinematic chain they are using. Any manipulator using open chain is a serial manipulator. Any manipulator using a closed chain is a parallel manipulator. The classification of the robots is shown in Figure 1. SCARA, SCORBOT, PUMA are best examples of Serial Manipulators. They have good dexterity. Parallel manipulators on the other hand have a high stiffness and load carrying capability when compared to serial manipulators. This is mainly because of the load being shared among many members. This also helps in achieving higher accuracy and built-in redundancy. But the only disadvantage is that the workspace is smaller when compared to that of serial manipulators. This is mainly due to link interferences, motion

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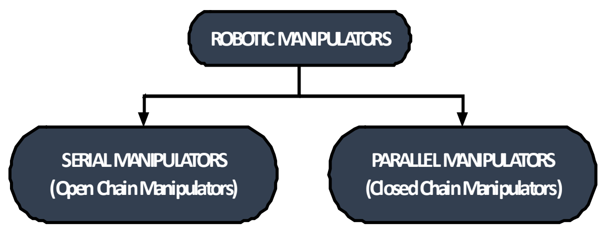
Figure 1: Classification of Manipulators



limitation of actuators and physical constraints of universal and spherical joints.

Many approaches are introduced to estimate the workspace. Bohigas *et al.* (2011 and 2010) discussed the requirements of methods to compute the workspace namely: a) Method should ideally be complete, b) the method should be accurate, c) The method should be as general as possible. The unified method suggested in Bohigas *et al.* (2011) involves the formulation of the equations governing the workspace boundary using kinematic analysis and then computing the total workspace with required resolution. A method for computing workspace of manipulators with lower-pair-multi-body systems was suggested in Bohigas *et al.* (2010). The method by the use of branch-and-prune technique, isolates the set of end effector singularities and then classiûes the points in such set according to whether they correspond to actual motion impediments in the workspace. Kanaan *et al.* (2006) computed the workspace for serial – parallel 5-axis machine tool: the VERNE machine. The equations inverse and direct kinematics for the same machine are discussed in Kanaan *et al.* (2009).

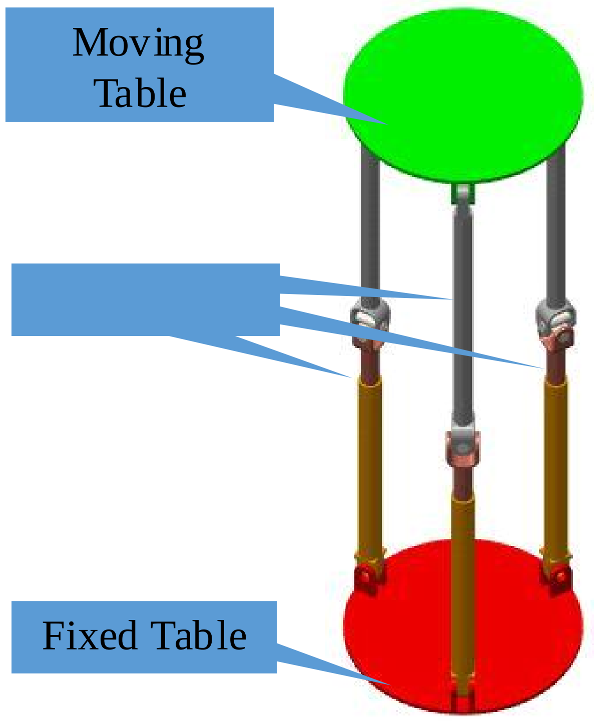
Li and Xu (2009) designed a 3-RRPaR parallel manipulator for chest compression. Screw theory was used for kinematic analysis while numerical search method was used for computing workspace. The total workspace to be computed was generated as a combination of a number of sub-workspaces. Liu *et al.* (2003) computed the workspace of a cube manipulator using simple geometric operations by identifying the workspace of the three legs. Simaan (1999) in his work listed various kinds of parallel manipulators used for medical applications. He performed a detailed kinematic analysis on USR and RSPR manipulators. Workspace was computed based on the kinematic analysis performed. Nawrat and Kostka (2008) discussed the various aspects like workspace, structure etc relating to Robin-Heart, a surgical robot and a serial manipulator. Boschetti and Caracciolo proposed two methods with one based on inverse kinematics while the other making using of symmetry in the mechanical structure for generating equations to compute workspace.

Most of the work described above rely on mathematical formulation of the workspace. The CAD software available currently available in the market have capabilities for generating the motion envelope based the actuation sequences given as input to the assembly model. The work in this paper makes use of Pro/Engineer's mechanism module to compute the workspace of a modified 3-RPSR manipulator without mathematically formulating the workspace. The manipulator is discussed in detail in the next section.

MANIPULATOR DESCRIPTION

The manipulator considered for analysis was a modification of 3-RPSR robot. The model of

Figure 2: Manipulator Considered for Analysis



the manipulator was generated using Pro/Engineer. The assembly was generated out using the mechanism connections pin and cylindrical joints when assembling in Pro/Engineer. Pin joint offers only rotational DOF

Figure 3: Arms of the Manipulator Connected to the Table Using Revolute Joints

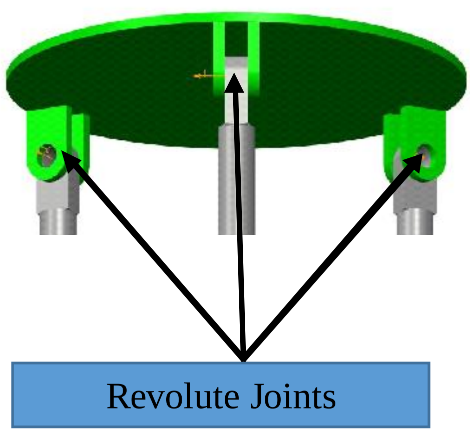
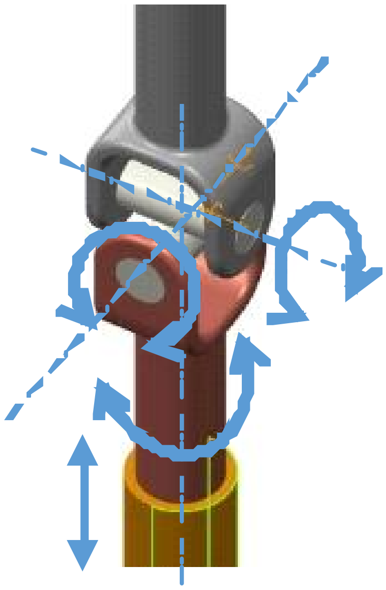


Figure 4: DOF in the Arm



while cylindrical joint offers two DOF, rotational as well as translational. The manipulator considered is shown in the Figure 2. It consists of two tables (one fixed and one moving) connected together using three equispaced arms. Each arm is connected to the table using a revolute joint as shown in Figure 3. The arm consists of a prismatic joint followed by a revolute and universal joint as shown in Figure 4. The revolute and universal joint axes intersect at a single point simulating a spherical joint.

ANALYSIS PROCEDURE

Moving table was considered as end effector during the analysis. Workspace computation for the moving table was made in seven stages. The motion analysis was performed considering the limits of the joint actuators. The limit of each revolute joint to the base considered was 0 to 30° (away from the base). The limit of each prismatic joint considered was 50 mm. Servomotors with profile shown in Figure 5 was applied to each joint axis of the base. For linear axis of each prismatic joint, servomotors with profile shown in Figure 6 was applied. Actuation was performed in seven combination as listed in Table 1. Before each actuation, the configuration is brought to the initial state as shown in Figure 2.

Figure 5: Actuation Profile of Servomotor for Base Joint

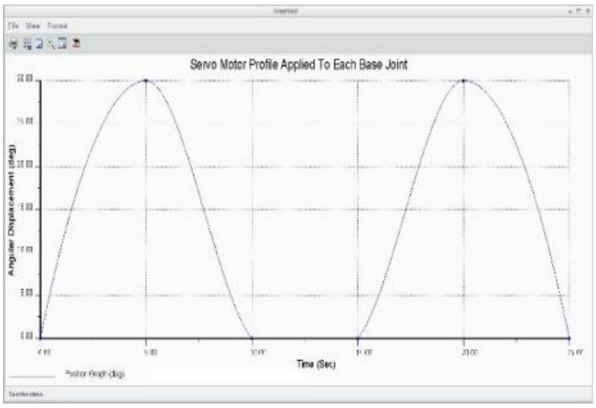
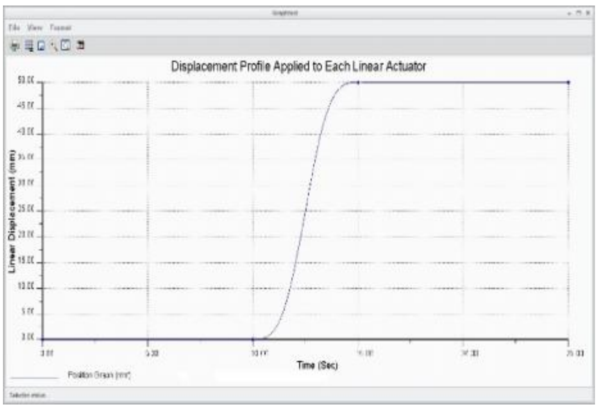


Figure 6: Actuation Profile of Servomotor for Prismatic Joint



RESULTS

As discussed in previous section, different servo motors were applied to various joints and seven motion analyses were performed to generate the complete workspace of the manipulator. The combination of motors for each analysis is listed in Table 1. Motion

Table 1: Joint Motor Actuation Combinations (0 – Not Actuated, 1 – Actuated)

Motor ì Workspace Number í	**Base Motor 1**	**Base Motor 2**	**Base Motor 3**	**Arm Motor 1**	**Arm Motor 2**	**Arm Motor 3**
Work Envelope 1	1	0	0	1	1	1
Work Envelope 2	0	1	0	1	1	1
Work Envelope 3	0	0	1	1	1	1
Work Envelope 4	1	1	0	1	1	1
Work Envelope 5	0	1	1	1	1	1
Work Envelope 6	1	0	1	1	1	1
Work Envelope 7	1	1	1	0	0	0

Figure 7: Workspace Top View

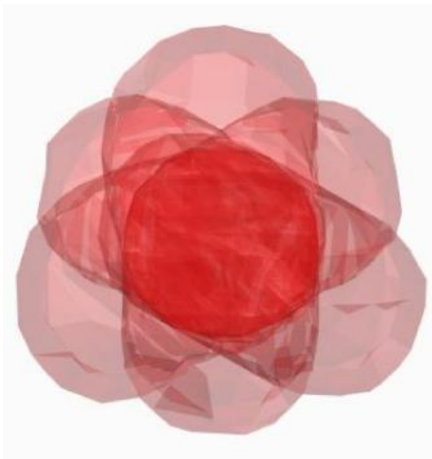


Figure 8: Workspace ISO View

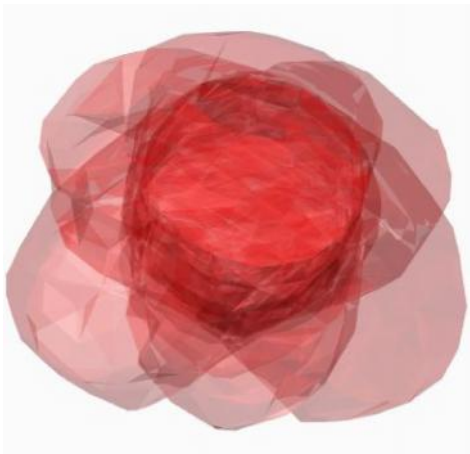


Figure 9: Workspace Front View

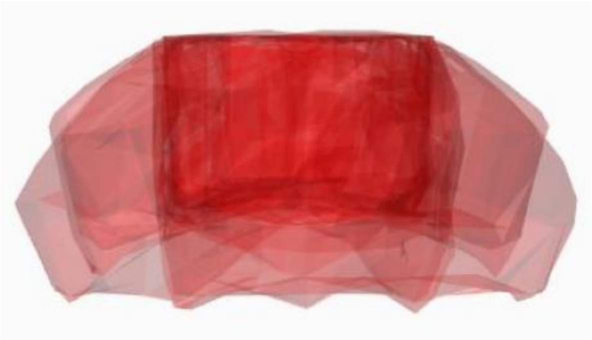


Figure 10: Exploded View of the Workspace Assembly Showing Various Motion Envelopes Generated

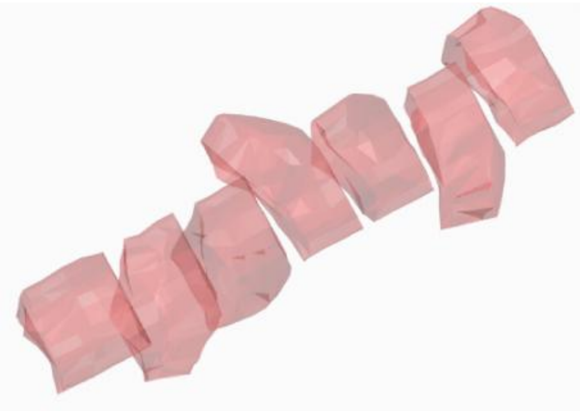


Figure 11: Manipulator with Workspace–Base Configuration

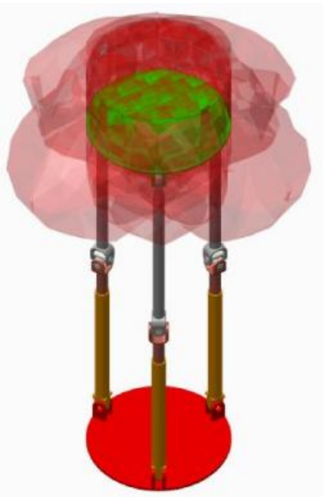
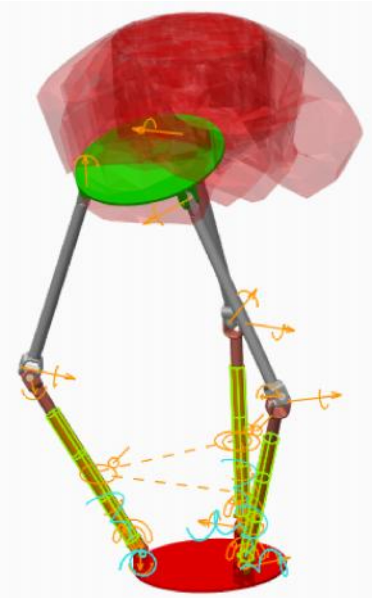


Figure 12: Manipulator with Workspace–Two Base Joints Actuated



envelope in each case was generated. The generated motion envelopes were then assembled together to get the complete workspace of the manipulator. Figures 7 to 10 show images of the workspace generated in various orientations. Figure 11 shows the image of the manipulator with the workspace assembled. Figure 12 shows the manipulator with two of the joints of base actuated.

CONCLUSION

Currently there are many methodologies that were developed for workspace computation. Much work in this area involves mathematically modeling and custom written codes for workspace computation. In this paper, a demonstration of workspace estimation without mathematically modeling was done. This was achieved through a stepwise motion analysis using Pro/Engineer. Seven motion analyses were carried out using for various actuation combinations and motion envelopes are generated in each case. The generated motion envelopes are then assembled together to get the final work volume. The advantage of this methodology is that it offloads the complex mathematical formulation for workspace computation to CAD packages. The requirement of number of analyses for obtaining the workspace should be considered as tradeoff for the aforesaid.

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