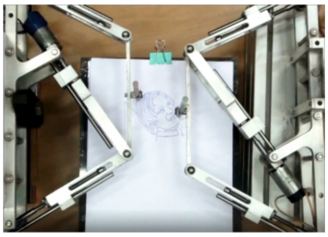
Robotics

3

Parallel Mechanism based Cooperative Robots

T. A. Dwarakanath*[1], Gaurav Bhutani[2], Sumit Kumar Sinha[2] and Hemanta Swain[2]

[1]Former Scientific Officer, Division of Remote Handling & Robotics (DRHR), Bhabha Atomic Research Centre, Mumbai 400085, INDIA
[2]Division of Remote Handling and Robotics (DRHR), Bhabha Atomic Research Centre, Mumbai 400085, INDIA



Trajectories of single caricature with complex geometry shared by two cooperating robots

ABSTRACT

The co-operation among a set of robots is for the purpose of achieving a common goal. The objective is to setup and delegate subtasks to individual robots to complete the task with optimum performance in a cooperative manner. The work presents trajectory planning algorithms based on inter-relationship among robots in achieving a goal in cooperation. Several general tasks are demonstrated in cooperative mode. Further, a novel idea of cooperation in the joint space to generate spatial trajectory using a single actuator is elaborated. The article validates the concept of cooperation through parallel mechanism-based robots, developed at DRHR, BARC.

KEYWORDS: *Robots, Mirror motions, Kinematic structure*

Introduction

To plan and program the participating robots individually towards a common goal at the task space is very complex[1]. The complexity is not only in programming the robots but also in operating and supervising them. This article explains a new trajectory planning scheme based on the inter-relationship that has to exist in achieving a goal in cooperation. The scheme deals with simple ways to divide and delegate the subtasks to the participating robots. Identifying the functional relationship and setting the motion of the cooperating robots on mirror mode would simplify the robot control, user interface and supervision. Many manipulations fall in the category of mirroring the motions at the task space of the cooperating robots. Two schemes of cooperation among robots are discussed. A scheme which serves as a *Cooperating Robots' Programming Interface* (CRPI) simplifies the task space trajectory planning among cooperating robots using mirror motions and its transformation. The other scheme is to cooperate functionally within the actuating axes (joint space) of a parallel mechanism to design a robot based on a single actuator to Generate "6D Trajectories". The key feature of the concept is to enhance the reliability by reducing the complexity.

This article deals with the planning and delegation of tasks among parallel mechanism based cooperative robots. The positional accuracy and stiffness of the parallel mechanism is relatively high in comparison to serial mechanism and hence parallel mechanisms are suitable as participating robots for cooperation in position and force domain. The concept of mirroring manipulation among cooperating robots and to illustrate the several tasks which can be programmed under this framework are explained. The context of the theme is to automate operations that take place in the inaccessible environment. The common tasks that are often encountered are pick and place, trace and cut, grip and hold, align and push, share payload and move. These tasks of cooperation are subtasks in applications like welding, cutting, bending, gripping, pick and place. Mirror motions can function in synchronised manner or can have specific time delay among participating robots. The concept of mirror manipulations can serve to automate several complex manipulations for various applications.

Cooperating Robots through Mirror Motions

The categorization of tasks helps to plan the cooperation. For a cooperation, dividing the work and delegating the work to participating robots become utmost important. The simple option is to look for mirroring the efforts of participating robots in jointly handling the given task. In the following sub-sections, all categories of tasks under the mirror motion scheme are addressed. It is assumed, that for entire planning purposes, the participating robots are identical in their kinematic structure and have a same dynamic capability. Two translations in plane and a rotation about any axis normal to the plane constitute the 3 Degree of Freedom (DOF) of the planar robot. The robot can perform coordinated translation along any line in a plane and a screw driver type rotation about any axis normal to the plane. The architecture of the manipulator is such that the major portion of the end effector is free of structural obstacles and can come face to face with its cooperating robot. Fig.1 shows a schematic of the two planar parallel robots. In a standard setup in the enclosed cell, a coordinate frame, M (X_M,Y_M,Z_M) is established at a point M and $[\hat{\imath},\hat{\jmath},\hat{k}]^T$ are the unit vectors along X_M, Y_M and Z_M respectively. The plane normal to the axis, Y_M and containing the point M is referred as the mirroring plane. Based on the mirroring plane and the workspace of the robot, the base frames, $O_1(X_1, Y_1, Z_1)$ and $O_2(X_2, Y_2, Z_2)$ of the participating robots are fixed. The base frames in mirror symmetry serve as reference co-ordinate frames for the participating robots. The standard setup is shown in Fig.1. In the following subsection, the mirror motion scheme is explained by considering one task. Let us consider that the objective of the task is to generate a circular trace on the job as shown in Fig.1.

*Author for Correspondence: T. A. Dwarakanath
E-mail: drhroff@barc.gov.in

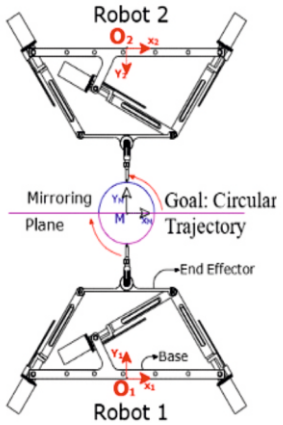


Fig.1: Two robots in mirror symmetry.

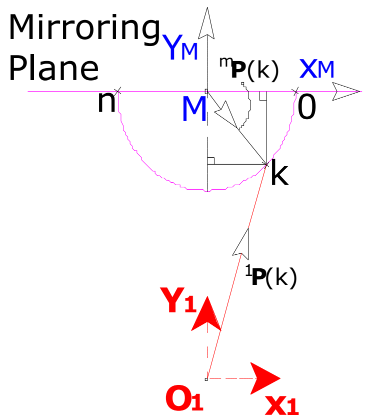
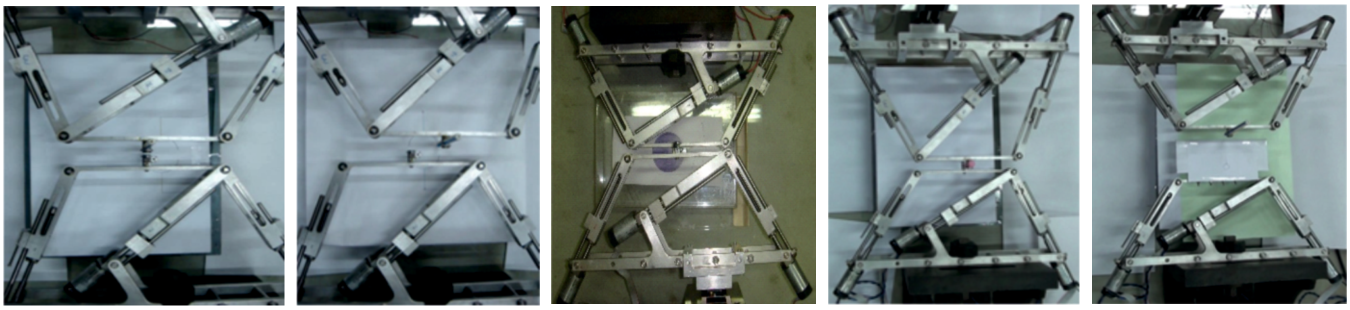


Fig.2: Task point description for Robot 1.



(a) Co. operation in tracing

(b) Trace-Flipping start, and end point

(c) Combined high precision trajectory trace

(d) load sharing while tracing

(e) Ultra-slow relative Motion

Fig.3: Different tasks performed in co-operation by two robots.

Tracing about a mirror plane

A task is shared by both the participating robots and the task is such that the manipulation required from the participating robots is mirror symmetric about a mirror plane (Z_M-X_M, normal to the page and Z_M extending out of the page). It is simple and many operations can be envisaged under this classification. The trajectory sharing about a mirror plane is explained by considering a circular trajectory and the description will hold true for any trajectory that is mirror symmetric to the mirror plane. The circular task space trajectory is divided into two semi-circular trajectories about the mirroring plane.

A point data, $k \in [0,n]$ is the point on the circumference of the semi-circle (see Fig.2) in the task space. The data delegation for the participating robots to trace a semi-circular trajectory is developed as follows.

$$^{m}P(k) = {}^{m}P(k)\hat{\imath},\ {}^{m}P(k)\hat{\jmath} \qquad (1)$$

$$^{1}P(k) = O_1M + {}^{1}{}_{m}R\ {}^{m}P(k) \qquad (2)$$

Where, $^{m}P(k)$ is the kth point with respect to the mirror frame, O_1M is the known vector from O_1 to M. $^{1}{}_{m}R$ is the rotation of frame M with respect to O_1. $^{1}P(k)$ is the kth point data in the task space for the participating robot 1, the parameters are as shown in the Fig.2. An Inverse Kinematic solution on $^{1}P(k)$ gives the joint data for robot 1. Similarly, all data points in the task space and the corresponding joint data for the participating robot 1 can be computed. The joint data and the corresponding instant of time is the control input for the robot motion. The same data serves as the motion input file for robot 2 for the above setup and is as given in equation 3.

$$[I_k]_{R2} = [I][I_k]_{R1} \qquad (3)$$

$[I_k]_{Ri} = [I_{1k}, I_{2k}, I_{3k}]^T_{Ri}$ is the inverse kinematic solution of the kth point of the robot I and [I] is a 3×3 identity matrix. The robots 1 and 2 will start from an initial point, $^{m}P(0)$ and move in a mirror motion in opposite directions to end the trace at a point, $^{m}P(n)$ to accomplish a circular trace in the task space.

Two prototype planar parallel robots are setup in skewed mirror configuration. Fig.3 illustrates different tasks performed in cooperation by two robots. The objective is to achieve simple and reliable ways to bring multiple robots to collaborate and conduct a task.

Ultra slow-motion using mirror algorithm

A single robot to realize an ultra-slow uniform motion at the end-effector is not feasible because the motors exhibit jerky motions at very slow velocity. Two cooperative robots are set to move near around most proficient speeds, yet the relative motion between their end-effectors can be

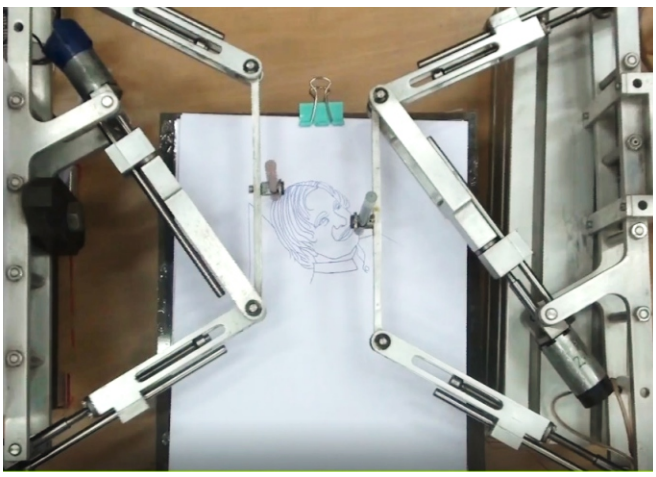
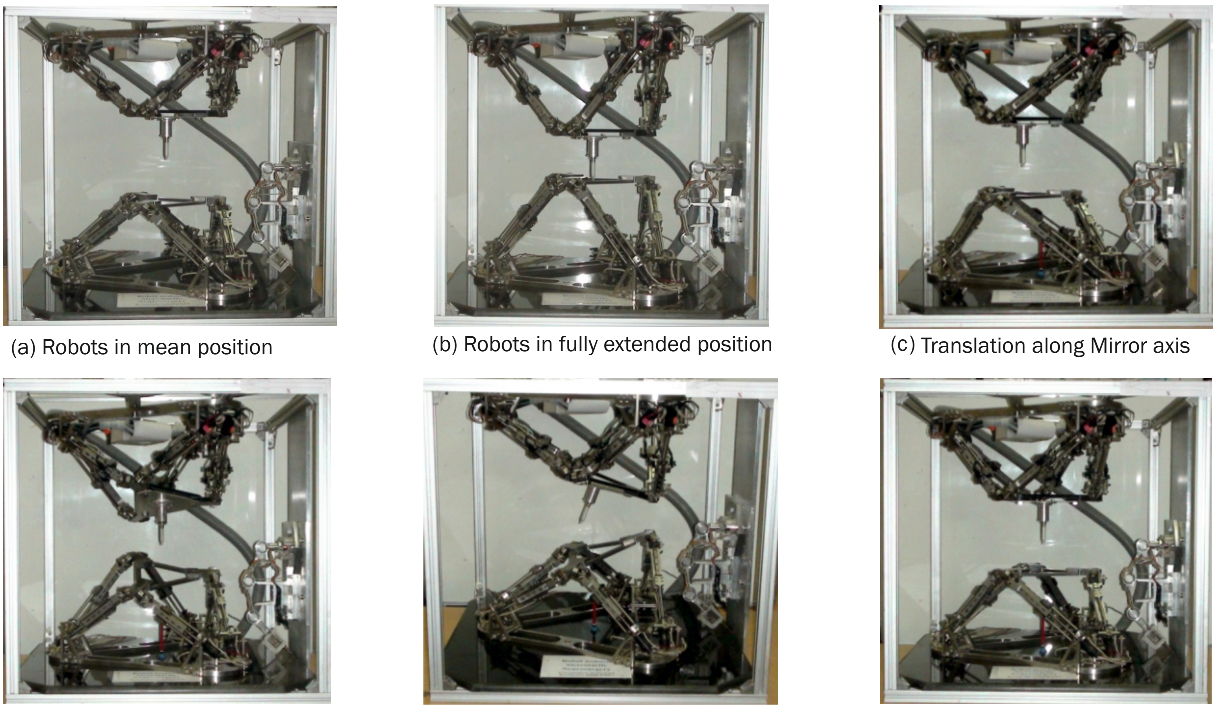


Fig.4: Photograph depicting high precision cooperation. Trajectories of single caricature with complex geometry shared by two cooperating robots.



(a) Robots in mean position (b) Robots in fully extended position (c) Translation along Mirror axis

(d) Rotation about a mirror axis (e) Rotation a mirror axis (f) Rotation, normal to mirror plane

Fig.5: Categories of subtasks of application under cooperation participating robots.

programmed to have ultra-slow velocity. Certain applications require a uniform, ultra-slow relative velocity. A typical application is laser cutting where ultra-slow velocity is required between the laser beam and the job being cut. In cooperative mode, the laser beam is manipulated by robot 1 and the job which has to be cut is manipulated by robot 2. The arrangement of co-operative robots is through mirror motions as discussed above. To realize ultra-slow uniform velocity at the interface of the beam and the job, both of them are set to motion along the same direction. It is like a laser beam following the job along the trajectory.

Let the task space velocity of robot 1 and 2 be T_1 and T_2 respectively. If the task space ultra-slow velocity between the interface of the beam tip and the job is ΔT.

The CPRI code should achieve $(T_1 - T_2) = \Delta T$

The task space velocities of robot 1 and 2 in terms of the components are written as

$$\{T_1\}=[v_{x1}\ v_{y1}\ \omega_1]^T \ ; \qquad \{T_2\}=[v_{x2}\ v_{y2}\ \omega_2]^T$$

The Jacobian, relating the task space velocity to the leg velocity for robot 1 and 2 is given as

$$\{v_1\} = [J_1]^T \{T_1\} \ ; \qquad \{v_2\} = [J_2]^T \{T_2\}$$

where, $\{v_i\} = [v_{1i}\ v_{2i}\ v_{3i}]^T$ is the vector containing leg velocities of the robot i [i=1,2]. $[J_1]$ and $[J_2]$ are the 3×3 Jacobian matrix of robot 1 and 2 respectively. The relationship between $\{V_1\}$ and $\{V_2\}$ can be obtained as discussed above for the cooperating robots.

Six DOF Parallel Robots in Cooperative Mode

The CPRI discussed above is extended to the in-house developed 6 DOF parallel mechanisms-based robots. Three translations and three rotations constitute the 6 DOF for the robot. A representative arrangement of the 6 DOF parallel mechanisms for mirror manipulation in cooperative mode is shown in Fig.5. All the categories of subtasks of applications mentioned in the earlier section can be performed in spatial mode.

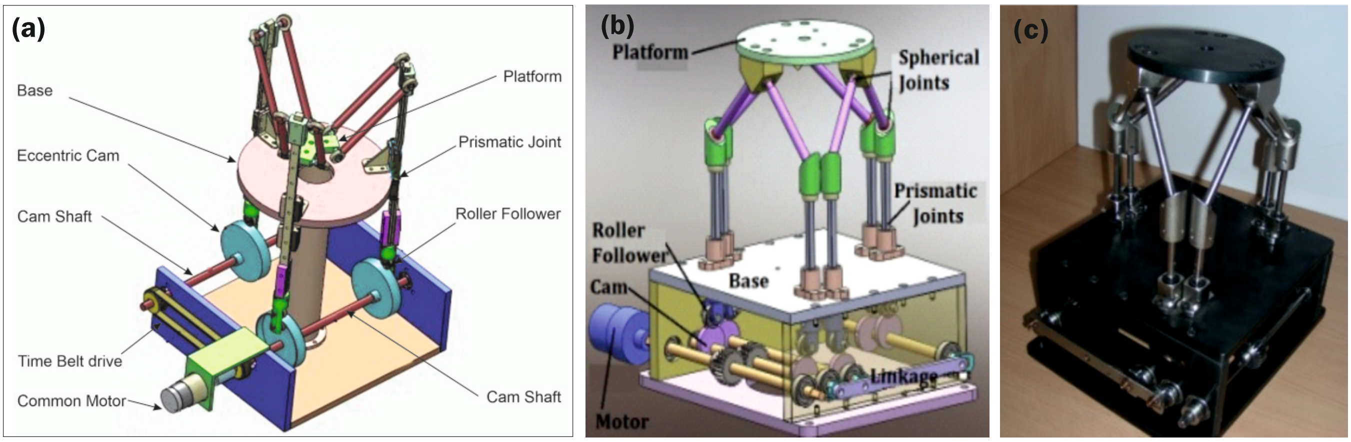
Single Actuator Parallel Mechanism to Generate "6D Trajectories"

The Prismatic-Spherical-Spherical (PSS) connector type of robot has fixed active axes. The model of 3-DOF Delta Parallel robot and 6-DOF PSS parallel robot along with the prototype is shown in Fig.6. The fixed active axes show specific advantages in building spatial trajectories using single actuator and constraining other active axes in a cooperative function rule. This is perceived not as a cooperation of robots but as a cooperation of joints within a robot to generate a unique spatial trajectory. The purpose is to generate repeating "6D motion trajectories" using a single actuator. The scheme is to functionally cooperate within the joint space of a robot to design a single actuator parallel mechanism-based robot to Generate "6D Trajectories". For a given spatial task space trajectory, the simple way to generate it is through the combination of the six cam-follower displacement at the joint space in a cooperative mode. The kinematic design, prototype development and algorithm to generate a 6D motion trajectory is elaborated in reference[3]. The concept shows feasibility of newer application domains for the mechanism.

The cam and the follower for a joint space prismatic displacement is proposed. The various combinations of cam and the follower methods for motion transmission are possible. The common shaft transmission for an array of PSS Parallel Manipulator based robots to follow a specific trajectory is discussed in reference[3]. Fig.6 shows model and prototypes of PSS based mechanism-based robots on a single actuator. Fig.7 shows the Mechanical Master-Slave, a passive manipulator, intuitively in cooperation at joint space.

Conclusion

High positional accuracy and the stiffness of the parallel mechanism-based robots are suitable for cooperation in position and force domain. The concept of mirroring manipulation through typical cooperative tasks using parallel robots are useful for large number of scientific applications.

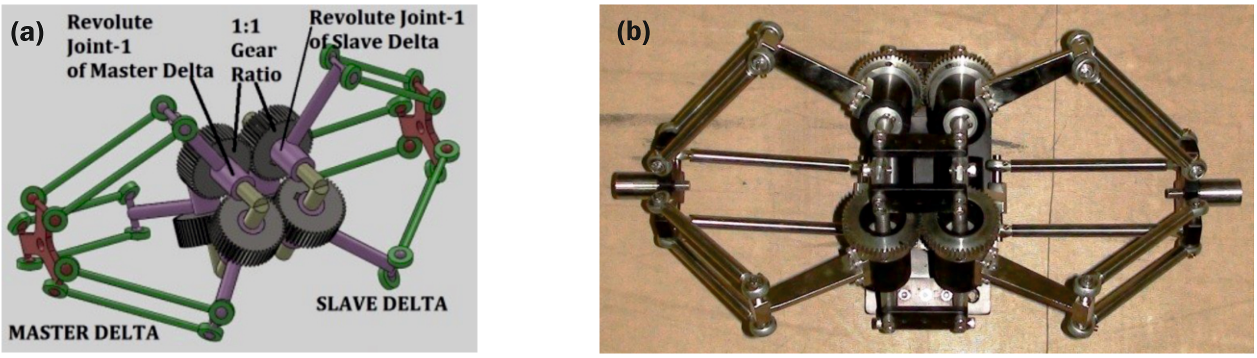


(a) Joint space Co. operation for 3-DoF Delta

(b) Joint space Co. operation for 6 DoF in PSS configuration

(c) Joint space Co. operation for 6 DoF PKM Prototype

Fig.6: Cooperation of joints in a parallel robot to generate a unique spatial trajectory.



(a) 3 DoF Delta in Mechanical Master-Slave, Configuration

(b) Prototype of 3 DoF Delta in Mechanical Master-Slave Configuration

Fig.7: Parallel mechanism based Mechanical Master-Slave Manipulator.

The mirror manipulations can provide a simple cooperative scheme for participating robots.

References

[1] A. Banerji, R. N. Banavar, D. Venkatesh, "A Non-Dexterous Dual Arm Robot's Feasible Orientations along Desired Trajectories: Analysis & Synthesis," 44th IEEE Conference on Decision and Control, Spain, 2005.

[2] T. A. Dwarakanath, Gaurav Bhutani and Puneet Srivastava, "Task space trajectory planning among cooperating robots through mirror motions", 15th NaCoMM 2011, IIT, Madras, Dec. 2011.

[3] K. D. Lagoo, T. A. Dwarakanath and D. N. Badodkar, "Single Actuator Shaker Design to generate Infinite Spatial Signatures", 2nd Int. & 17th iNaCoMM 2015, IIT Kanpur, Dec. 2015.