A Reconfigurable Planar Parallel Manipulator (RPPM)

Ryan Fisher, Ron P. Podhorodeski, and Scott B. Nokleby
Robotics and Mechanisms Laboratory, University of Victoria, Victoria, B. C., Canada

1. Introduction

The design of a Reconfigurable Planar Parallel Manipulator (RPPM) is discussed in this work. The RPPM was designed to allow formation of all major revolute-jointed planar parallel manipulator/mechanism designs. Three configurations are possible including a single-loop 2-DOF (degrees-of-freedom) 5-bar, a single-loop 3-DOF 6-bar and a three-loop 3-DOF 8-bar device (3-RRR). The 8-bar is illustrated in Figure 1 with the platform, the wrist, and the links of one branch labelled.

The RPPM will be used to test theories on redundant actuation/sensing of parallel manipulators. To be able to test effects of redundant actuation/sensing, the RPPM must facilitate redundancy in actuation and in joint displacement sensing. It must also be possible to sense the force being applied to the platform from each branch through their respective wrist centres.

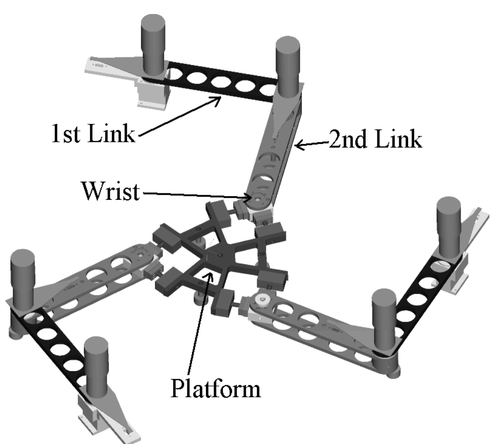

Figure 1: The RPPM in the 8-bar (3-RRR) configuration.

2. Design

2.1 Physical Design

The length of all the links of the RPPM were chosen to be the same based on symmetry and global workspace maximization [1]. The platform edge length (the distance from wrist centre to wrist centre) is equal to the link lengths. The location of the bases is variable by utilizing predrilled mounting points on a table surface.

The second link in each branch is located underneath the first link. This second link is a yoked link. The platform sits inside the yoke to ensure that a pure force is being transmitted through the passive revolute-jointed wrist. This configuration allows for approximately 330 degrees of rotation of the second link with respect to the first link and approximately 300 degrees of rotation of the platform with respect to the second link.

The RPPM rolls on the table surface with one ball transfer unit located at each branch elbow and three located at the platform. These ball transfer units take the weight of the mechanism orthogonal to the plane of motion. This reduces unwanted stresses and forces in the platform which would result in errors in the force sensing.

2.2 Reconfigurability

The ability to reconfigure the RPPM from a 8-bar to a 6-bar and to a 5-bar is of high importance. If the RPPM is initially assembled in the 8-bar configuration, a branch may be removed to create the 6-bar. To configure from the 6-bar into the 5-bar, the RPPM facilitates locking together of the second link in either branch with the platform to create one link of equal length to the other links.

2.3 Actuation

MicroMo (Series 3557) motors can be mounted at the joint between the base and link 1, and at the joint between link 1 and link 2 on any branch. This allows for up to 3-DOR (degrees-of-redundancy) in the 8-bar, 1-DOR in the 6-bar, and 2-DOR in the 5-bar. These motors, after speed reduction, are capable of speeds up to 0.6 revolutions per second. Motors can also be removed and a bearing mount installed. This creates a free revolute joint in place of the actuated joint. This design allows for non-redundant and different levels of redundant actuation.

2.4 Sensing

To sense the force being applied to the platform by each branch, two Transducer Techniques (MLP-25) linear force sensors are used. The sensors are located on the platform and are arranged orthogonally with their

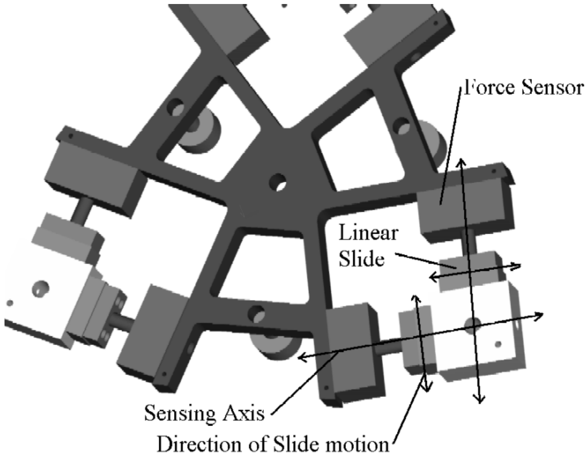

Figure 2: Layout of platform sensing.

corresponding sensing axes intersecting at the wrist centre. To eliminate shear loading of the sensors, each sensor is mounted on a Del-Tron (RD-1) linear slide with the direction of travel of the slide perpendicular to the sensing axis as depicted in Figure 2. A typical set of applied and sensed forces, with and without the slides, is shown in Figure 3. It is clear that without the linear slides, the force sensed is not in the same direction as the force applied. With the slides, this direction error is greatly reduced and good agreement exists between the sensed and actual force magnitudes.

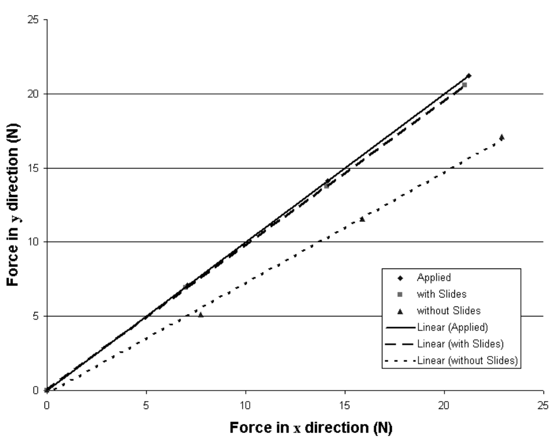

Figure 3: Graph of force applied and sensed (with and without linear slides).

To sense the displacement of the actuated joints, HP (HEDS-5540) optical encoders are located on the motors. The encoders give 512 counts per motor revolution. With a gear reduction of 134:1 and quadrature encoding, 274,432 counts per revolution of the output shaft can be resolved. When a bearing mount is being used instead of a motor, an optical encoder may also be used on the passive revolute-joint. This allows for redundant sensing configurations without redundant actuation. Honeywell (HOA-1881) infra-red sensors located on the base and on the second links are used to home the manipulator.

It should also be noted that torque sensing of the motor outputs may be desired in the future. Small adapter shafts will be required to install appropriate torque sensors between the motor reducer output shaft and the driven link. If required, the simple joint arrangement used will facilitate this.

3. Control of the RPPM

3.1 Displacement solutions

Inverse displacement solutions for all configurations of the RPPM have been resolved. Forward displacement solutions have been found for all redundant and non-redundant sensing layouts of the 5-bar and the 6-bar configurations. For the 8-bar configuration with non-redundant sensing (one sensor per branch for a total of three sensors) the forward displacement solution of Gosselin and Merlet [2] can be applied. For the 8-bar configurations with redundant sensing, the corresponding forward displacement solutions have been resolved.

3.2 Control

The RPPM will be controlled with Precision MicroDynamics (MFIO-3A) motion control cards installed on a PC running the QNX Realtime Operating System.

Initially the RPPM will be implemented as a non-redundantly actuated device. PID-based control algorithms will be used for these cases. Various forms of force control algorithms are being evaluated for implementation of redundant actuation.

4. Conclusions

The layout of the RPPM is reconfigurable allowing assembly of 5-bar, 6-bar, and 8-bar devices. The use of orthogonal sensing directions and linear slides at the wrists allows accurate sensing of the forces applied by the branches.

The RPPM will be a useful tool in testing theories on redundant actuation/sensing of parallel manipulators. Control of redundantly actuated parallel manipulators is a topic of current investigation.

References

[1] C.M. Gosselin and J. Angeles, "The Optimum Kinematic Design of a Planar Three-Degree-of-Freedom Parallel Manipulator," *Journal of Mechanisms, Transmision, and Automation in Design*, 110(1), 35-41, (1988).

[2] C.M. Gosselin and J-P. Merlet,"The Direct Kinematics of Planar Parallel Manipulators: Special Architectures and Number of Solutions," *Mechanism and Machine Theory*, 29(8), 1083-1097, (1994).