Discussion: "Kinematics of a New High-Precision Three-Degree-of-Freedom Parallel Manipulator" (Tahmasebi, F., 2007, ASME J. Mech. Des., 129, pp. 320–325)

Juan A. Carretero
Department of Mechanical Engineering,
University of New Brunswick,
Fredericton, NB, E3B 5A3, Canada
e-mail: juan.carretero@unb.ca

Meyer A. Nahon
Department of Mechanical Engineering,
McGill University,
Montreal, QC, H3A 2T5, Canada

Ron P. Podhorodeski
Department of Mechanical Engineering,
University of Victoria,
Victoria, BC, V8W 3P6, Canada

The author of Ref. [1] proposes a "new" high-precision three-degree-of-freedom parallel manipulator. The paper discusses the inverse and forward displacement solutions for the 3-$\underline{P}$RS manipulator, which is formed by three identical limbs, each containing an actuated prismatic joint (P) followed by a passive perpendicular revolute joint (R), a fixed-length leg, and a passive spherical joint (S), which attaches to the moving platform. In Ref. [1], the three active prismatic joints intersect at the center of the base platform and are contained within the base plane while being separated by 120 deg from one another.

We would like to bring to the readers' attention that although Tahmasebi [1] presents some interesting implementation issues, the same 3-$\underline{P}$RS manipulator was first presented in 1997 by Carretero et al. [2]. In March 2000, an improved version of that paper was published in ASME Journal of Mechanical Design [3]. Both papers present the inverse displacement solution of the manipulator where the lengths of the active prismatic joints are obtained as a function of the pose of the end effector. The pose is defined by three variables: two angles around mutually perpendicular inertial axes parallel to the base plane (tip and tilt) and a displacement normal to the base platform—just as they are in Ref. [1].

Also worth noting is the fact that the forward displacement problem (FDP) for this manipulator was solved by Tsai et al. in Ref. [4] for a variation of the 3-$\underline{P}$RS whose prismatic joints are all perpendicular to the base platform. The formulation in Ref. [4] is easily modified to obtain the forward displacement solution of the version where all prismatic joints are parallel to the base. This equivalent formulation of the FDP is presented in Ref. [1] but the work in Ref. [4] is only mentioned in passing in the Introduction.

With respect to the inverse displacement problem, Tahmasebi [1] considered a less general version of the 3-$\underline{P}$RS manipulator. That is, in Ref. [3], the angles between the three branches were left as design variables whereas in Tahmasebi's work, these angles are fixed at 120 deg and −120 deg, respectively. Note that the applications considered in Refs. [2,3,5] are also high-precision tasks, just as those claimed in Ref. [1]. More specifically, in Refs. [2,3], the authors suggested that the 3-$\underline{P}$RS manipulator could be used near its singular configuration for high-precision applications such as telescope image correction. This configuration, reached when all three fixed-length legs are close to being parallel, gives the manipulator higher resolution in that region of the workspace.

As pointed out in Refs. [3,6], motions in the tip and tilt directions come with unavoidable motions in the other three directions. That is, when the platform is tipped and/or tilted, small translations occur along two noncollinear axes coplanar to the base plane as well as a rotation around an axis perpendicular to this plane. These extraneous motions, independent of the platform's elevation, were deemed *parasitic* and minimized in Refs. [3,6]. Although these motions are noted in Ref. [1] as Eqs. (4) and (5), they are not recognized as having an adverse effect on the payload's location, particularly for the high-precision applications claimed by the author.

In addition to the aforementioned seminal work by Carretero et al., a number of documents have been published since 1997 discussing different aspects and variations of the 3-$\underline{P}$RS manipulator as well as analyzing the manipulators for a number of different applications. Following is a list of some of the works presented to date on the 3-$\underline{P}$RS manipulator, grouped by the general topic. These important works on the 3-$\underline{P}$RS manipulator were also overlooked in Ref. [1].

- Kinematics: Inverse displacement problem [2,3,7] and later generalized in Ref. [8] for any orientation of the prismatic joints relative to the base. FDP [4]. Reduction of parasitic motions [3,6]. Kinematic calibration [9].
- Workspace size and quality: Dexterity [10,11]. Stiffness [12].
- Design and applications: Medical assistants [13]. Also, Tsai et al. [4] presented a slight variation of the version by Merlet presented in Ref. [13]. Telescope image correction [2]. Machine tool applications [14]. Micromanipulation [5].

References

[1] Tahmasebi, F., 2007, "Kinematics of a New High-Precision Three-Degree-of-Freedom Parallel Manipulator," ASME J. Mech. Des., **129**(3), pp. 320–325.
[2] Carretero, J. A., Nahon, M., Gosselin, C. M., and Buckham, B., 1997, "Kinematic Analysis of A Three-DOF Parallel Mechanism for Telescope Applications," *Proceedings of the 1997 ASME Design Engineering Technical Conferences*, Sacramento, CA, Sept.
[3] Carretero, J. A., Podhorodeski, R. P., Nahon, M. A., and Gosselin, C. M., 2000, "Kinematic Analysis and Optimization of a New Three Degree-of-Freedom Spatial Parallel Manipulator," ASME J. Mech. Des., **122**(1), pp. 17–24.
[4] Tsai, M.-S., Shiau, T.-N., Tsai, Y.-J., and Chang, T.-H., 2003, "Direct Kinematic Analysis of a 3-PRS Parallel Manipulator," Mech. Mach. Theory, **38**(1), pp. 71–83.
[5] Liu, D., Xu, Y., and Fei, R., 2003, "Study of an Intelligent Micro-Manipulator," J. Mater. Process. Technol., **139**(3), pp. 77–80.
[6] Carretero, J. A., Podhorodeski, R. P., and Nahon, M., 1998, "Architecture Optimization of a Three DOF Parallel Manipulator," *Proceedings of the 1998 ASME Design Engineering Technical Conferences*, Atlanta, GA, Sept.
[7] Ebrahimi Moghaddam, I., and Bahrami, M., 2005, "A Numerical Algorithm for Solving Displacement Kinematics of Parallel Manipulators," *IECON 2005: 31st Annual Conference of the IEEE Industrial Electronics Society*, Rakigh, NC, Nov. pp. 1864–1869.
[8] Pond, G. T., and Carretero, J. A., 2004, "Kinematic Analysis and Workspace Determination of the Inclined PRS Parallel Manipulator," *Proceedings of the 15th CISM-IFToMM Symposium on Robot Design, Dynamics and Control (RoManSy 2004)*, Saint-Hubert (Montreal), Quebec, Canada, Jun. 14–18.
[9] van Driel, C. G., and Carretero, J. A., 2005, "Calibration of the 3-PRS Parallel Manipulator Using a Motion Capture System," CSME Transactions, **29**(4), pp. 645–654.
[10] Carretero, J. A., Nahon, M. A., and Podhorodeski, R. P., 2000, "Workspace Analysis and Optimization of a Novel 3-DOF Parallel Manipulator," Int. J. Rob. Autom., **15**(4), pp. 178–188.
[11] Pond, G. T., and Carretero, J. A., 2006, "Formulating Jacobian Matrices for the Dexterity Analysis of Parallel Manipulators," Mech. Mach. Theory, **41**(12), pp. 1505–1519.
[12] Li, Y., and Xu, Q., 2004, "Kinematic and Stiffness Analysis for a General 3-PRS Spatial Parallel Manipulator," *Proceedings of the 15th CISM-IFToMM Symposium on Robot Design, Dynamics and Control (RoManSy 2004)*, Saint-Hubert (Montreal), Quebec, Canada, Jun. 14–18.
[13] Merlet, J.-P., 2001, "Micro Parallel Robot MIPS for Medical Applications," *Proceedings of the Eighth International Conference on Emerging Technologies and Factory Automation (ETFA 2001)*, Antibes-Juan les pins, France, Oct. 15–18.
[14] Fan, K.-C., Wang, H., Zhao, J.-W., and Chang, T.-H., 2003, "Sensitivity Analysis of the 3-PRS Parallel Kinematic Spindle Platform of a Serial-Parallel Machine Tool," Int. J. Mach. Tools Manuf., **43**(15), pp. 1561–1569.

