



HAL
open science

Certified Kinematic Tools for the Design and Control of Parallel Robots (Extended abstract)

Alexandre Lê, Fabrice Rouillier, Guillaume Rance, Damien Chablat

► To cite this version:

Alexandre Lê, Fabrice Rouillier, Guillaume Rance, Damien Chablat. Certified Kinematic Tools for the Design and Control of Parallel Robots (Extended abstract). Mechanism and Machine Theory Symposium, Jun 2024, Guimarães, Portugal. hal-04646790

HAL Id: hal-04646790

<https://hal.science/hal-04646790>

Submitted on 12 Jul 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

CERTIFIED KINEMATIC TOOLS FOR THE DESIGN AND CONTROL OF PARALLEL ROBOTS

Alexandre Lê^{1,2,3}, Fabrice Rouillier^{2,3}, Guillaume Rance¹, Damien Chablat⁴

¹ Safran Electronics & Defense, 100 avenue de Paris, Massy CEDEX, 91344, Île-de-France, France, {alexandre-thanh.le@safrangroup.com, guillaume.rance@safrangroup.com}

² Sorbonne Université, Université de Paris Cité, Institut de Mathématiques de Jussieu Paris Rive Gauche, 4 place Jussieu, Paris CEDEX, 75252, Île-de-France, France

³ Inria Paris, 2 rue Simone Iff, Paris, 75012, Île-de-France, France, {alexandre.le@inria.fr, fabrice.rouillier@inria.fr}

⁴ Nantes Université, École Centrale Nantes, CNRS, LS2N, UMR 6004, F-44000, 2 rue de la Houssinière, Nantes CEDEX 03, 44322, Pays de la Loire, France, {damien.chablat@cns.fr}

1 MOTIVATIONS

Parallel robots [1, 2] are closed-loop kinematic manipulators usually with two platforms (a base and an upper platform as the end-effector) that are linked by multiple kinematic chains. Each kinematic chain has joints that are either actuated (active joints) or not (passive joints) and the consecutive joints are linked by a body. Such an architecture bestows numerous advantages: these mechanisms are best known for presenting interesting performances in terms of dynamics, stiffness and accuracy. Moreover, most of the parallel robots are actuated at their base (the other joints being usually passive). As a result, many parts of such robots are subject to traction or compression constraints [3] making it possible to use less powerful actuators and reduce the mass of the movable links, unlike their serial counterparts. Although parallel robots are less spread than the serial ones, they are gaining interest over the last decades in several domains: from the food industry for pick-and-place applications [4] (*e.g.* the Adept Quattro 4-DOF Delta robot) to the medical world (*e.g.* the SurgiScope 4-DOF Delta robot), through the simulated environments (*e.g.* the Rexroth 6-DOF hexapod dedicated to flight motion simulation). Moreover, other potential applications arise such as the inertial stabilization [5] of cameras [6] or sighting devices in the naval environment [7].

Despite all the before-mentioned advantages of parallel robots, the latter are also well-known for being complex systems: numerous historical challenges arose regarding these architectures, namely solving the Forward Kinematic Problem (finding the coordinates of the end-effector upper platform given the joint values) while determining the singularity loci to avoid and taking into account the effects of uncertainties on the design parameters of the closed-loop robots as well as on their control (measurement errors).

2 CONTENTS

This paper aims to present a methodology related to the design and the control of parallel robots. Its challenge is twofold. On the one hand, one focuses on the problematics of design. In particular, given a parallel mechanism defined by its design parameters and its kinematic modelling as well as its targeted application (prescribed workspace), the idea is to certify the absence of any numerical instabilities (computational and physical singularities) that may jeopardize the integrity of the robot. Such a work is called certification of the (Inverse and Forward) Kinematics of the robot and will be treated through two different but complementary approaches:

- the first one being global involving *symbolic* computation and formal calculus (elimination of variables, computation of the discriminant variety [8] w.r.t. the projection onto the parameter space) that can sometimes be difficult to compute due to the complexity of the robot of interest;
- the other one being rather local using *continuation* methods [9] coupled with *multiple-precision interval arithmetic* [10] (using the Kantorovich unicity operator [11]) that may be used for real-time applications.

The strength of this methodology relies on the appropriate combination of both techniques enabling the certification of a larger range of parallel robots. After exposing the theoretical concepts behind this methodology of certification, the latter will be applied to some examples of real-case parallel robots.

On the other hand, this paper also presents a strategy to control parallel robots, especially ensuring that the robot never leaves the certified workspace through a software joint velocity limitation algorithm. This strategy introduced in [12] will be detailed and applied to a special class of parallel robots: Spherical Parallel Manipulators (SPM) [13, 14] with coaxial input shafts (CoSPM) [15].

The paper will be organized into two main parts and as follows:

- *Tools for the Design.* A first section recalls the basic notions required for the kinematic analysis of parallel robots as well as the existing methods and tools used by roboticists to investigate the latter. A second section exposes some certified kinematic tools and the mathematical background behind them. Some study cases on various parallel robots (*e.g.* 3-DOF tripod [16], 3-DOF SPMs [13, 15], hexapod [17]) will be given in a third section.
- *Tools for the Control.* A fourth section explaining a strategy to secure the control a special case of parallel robots, Spherical Parallel Manipulators with coaxial input shafts (CoSPM) so that the robot of interest never leaves the safe regions delimited by the tools previously introduced. Results can however be generalized to other parallel manipulators.

REFERENCES

- [1] T. Leinonen, “Terminology for the theory of machines and mechanisms,” *Mechanism and Machine Theory*, vol. 26, no. 5, p. 435–539, 1991.
- [2] J.-P. Merlet, *Parallel Robots (Second Edition)*. Springer, 2006.
- [3] W. Khalil and S. Briot, *Dynamics of Parallel Robots : From Rigid Bodies to Flexible Elements*. Springer, 2015.
- [4] R. Clavel, “Conception d’un robot parallèle rapide à 4 degrés de liberté,” Ph.D. dissertation, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, 1991. [Online]. Available: <http://infoscience.epfl.ch/record/31403>
- [5] T. Taunyazov, M. Rubagotti, and A. Shintemirov, “Constrained orientation control of a spherical parallel manipulator via online convex optimization,” *IEEE/ASME Transactions on Mechatronics*, vol. 23, no. 1, pp. 252–261, 2018.
- [6] S. Ansari-Rad, M. Zarei, M. G. Tamizi, S. Mohammadi Nejati, M. T. Masouleh, and A. Kalhor, “Stabilization of a Two-DOF Spherical Parallel Robot via a Novel Adaptive Approach,” in *2018 6th RSI International Conference on Robotics and Mechatronics (IcRoM)*, 2018, pp. 369–374.
- [7] A. Lê, F. Rouillier, G. Rance, and D. Chablat, “Inertial Line-Of-Sight Stabilization Using a 3-DOF Spherical Parallel Manipulator with Coaxial Input Shafts,” in *11th International Symposium on Optronics in Defense & Security*, Bordeaux, France, Jan 2024, p. 11. [Online]. Available: <https://inria.hal.science/hal-04483255>
- [8] D. Lazard and F. Rouillier, “Solving parametric polynomial systems,” *Journal of Symbolic Computation*, vol. 42, no. 6, pp. 636–667, 2007.
- [9] E. Allgower and K. Georg, *Numerical Continuation Methods: An Introduction*, ser. Springer Series in Computational Mathematics. Springer Berlin Heidelberg, 1990.
- [10] N. Revol and F. Rouillier, “Motivations for an arbitrary precision interval arithmetic and the MPFI library,” *Reliable Computing*, vol. 11, no. 4, pp. 275–290, Aug. 2005. [Online]. Available: <https://inria.hal.science/inria-00544998>
- [11] L. V. Kantorovich, “On Newton’s method for functional equations,” *Functional Analysis and Applied Mathematics*, vol. 59, no. 7, pp. 1237–1240, 1948.
- [12] A. Lê, G. Rance, F. Rouillier, A. Quadrat, and D. Chablat, “On a Software Joint Velocity Limitation of a Spherical Parallel Manipulator with Coaxial Input Shafts,” 2024.
- [13] C. Gosselin and J.-F. Hamel, “The agile eye: a high-performance three-degree-of-freedom camera-orienting device,” in *Proceedings of the 1994 IEEE International Conference on Robotics and Automation*, 1994, pp. 781–786 vol.1.
- [14] A. Lê, F. Rouillier, G. Rance, and D. Chablat, “On the Certification of the Kinematics of 3-DOF Spherical Parallel Manipulators,” *Maple Transactions*, vol. 3, 08 2023.
- [15] I. Tursynbek, A. Niyetkaliye, and A. Shintemirov, “Computation of unique kinematic solutions of a spherical parallel manipulator with coaxial input shafts,” in *2019 IEEE 15th International Conference on Automation Science and Engineering (CASE)*, 2019, pp. 1524–1531.
- [16] D. Chablat, R. Jha, F. Rouillier, and G. Moroz, “Non-singular Assembly Mode Changing Trajectories in the Workspace for the 3-RPS Parallel Robot,” in *Advances in Robot Kinematics*, J. Lenarčič and O. Khatib, Eds. Cham: Springer International Publishing, 2014, pp. 149–159.
- [17] J.-P. Merlet, “Solving the forward kinematics of gough-type parallel manipulator with interval analysis,” *The International Journal of Robotics Research*, vol. 23, pp. 221–236, 03 2004.