International Journal of Engineering and Management Sciences (IJEMS) Vol. 4. (2019). No. 1
DOI: 10.21791/IJEMS.2019.1.6.

Accuracy Analysis of Two Parallel Manipulators

S. HAJDU[1], D. BODNÁR[2]

[1]University of Debrecen, Faculty of Engineering, Department of Mechanical Engineering
E-mail: hajdusandor@eng.unideb.hu
[2]University of Debrecen, Faculty of Engineering, Department of Mechanical Engineering
E-mail: bodnar.david2@gmail.com

Abstract. The aim of the study is to analyse and visualize the accuracy of two parallel manipulators. The kinematics are calculated using vectors and the Newton method. The accuracy is calculated based on the actuator errors, visualization is done with color shading. Calculations was done using MATLAB

Introduction

Parallel manipulators are getting used more and more in industry and medical applications [1], [2]. This study analyses the theoretical accuracy for two types of parallel manipulators. The calculations are done in MATLAB, based on previous work from the authors [3] about the kinematic calculations and workspaces of these types of Stewart platforms. The aim of the research is to develop a Stewart Platform for using it in a patient position device, or for using it as a payload stabilizing device in UAV and UGV [4], [5] applications. Stabilization in both cases could be done by kinematic calculations, or with fuzzy logic [6], [7]. If the platform is mounted on a vehicle it is important to know the dynamic parameters of the vehicle [8], [9].

1. Analysed types of Stewart platforms and paremeters used

The most common of parallel manipulators is the Stewart platform, which has six electronic actuators [10] connected parallel from a base to a moving platform. It has six degrees of freedom. There is also the rotary type of Stewart platform, where the connection lengths are fixed between the base and the platform, but the attachment points can be moved along the perimeter of the base.

Figure 1. Commercially available versions: General type (left) [11], and rotary type (right) [12].

Name	Type	Name	Type
XYZ cord. sys	Base coordinate system	P1-P6	Joint coordinates at the platform in X'Y'Z'
X'Y'Z' cord. sys.	Platform coordinate system	l1-l6	vectors of the actuators
O'	End effector position	|L1|	length of the actuator
B1-B6	Joint coordinates at the base	BM1-BM6	joint coordinates at the base after movement (only for the rotary type)

Table 1. Parameters used.

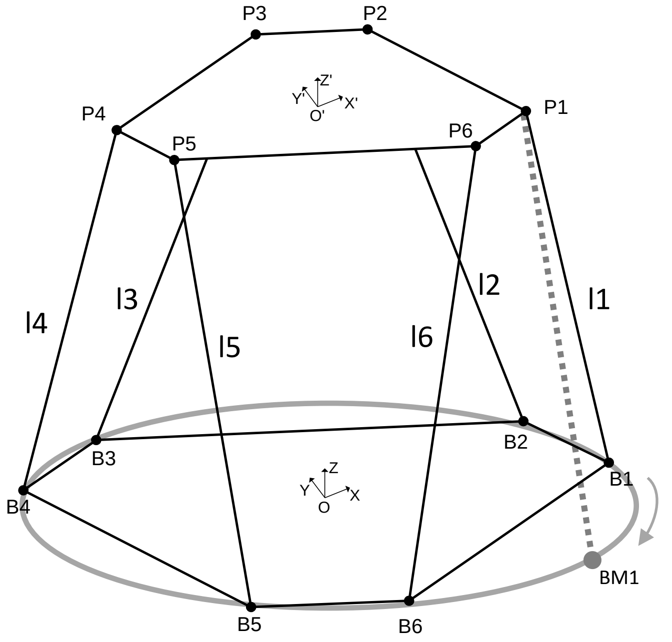

Figure 2. Parameters in schematic view, rotary parameters are shown in grey.

2. Kinematic calculations

There are two types of kinematic problems. The first one is when the end effector position is unknown, but the actuator variables are known, that is the forward kinematics problem. In this case there are multiple possible variations for the end effector position, because of the parallel kinematics of the robot. Analytical solution is not possible, but with the Newton method the problem is solvable. The downside is that this is an iterative method which requires more resources for the computation. It uses the Jacobian matrix of the robot. If the iterative method fails to find a root there is a possibility that the desired position is a singular position. It also fails if the desired position is outside of the workspace determined by the range of the linear actuators.

- Input: Actuator variables
- Output: [X,Y,Z,Pitch, Yaw, Roll] – End effector coordinates

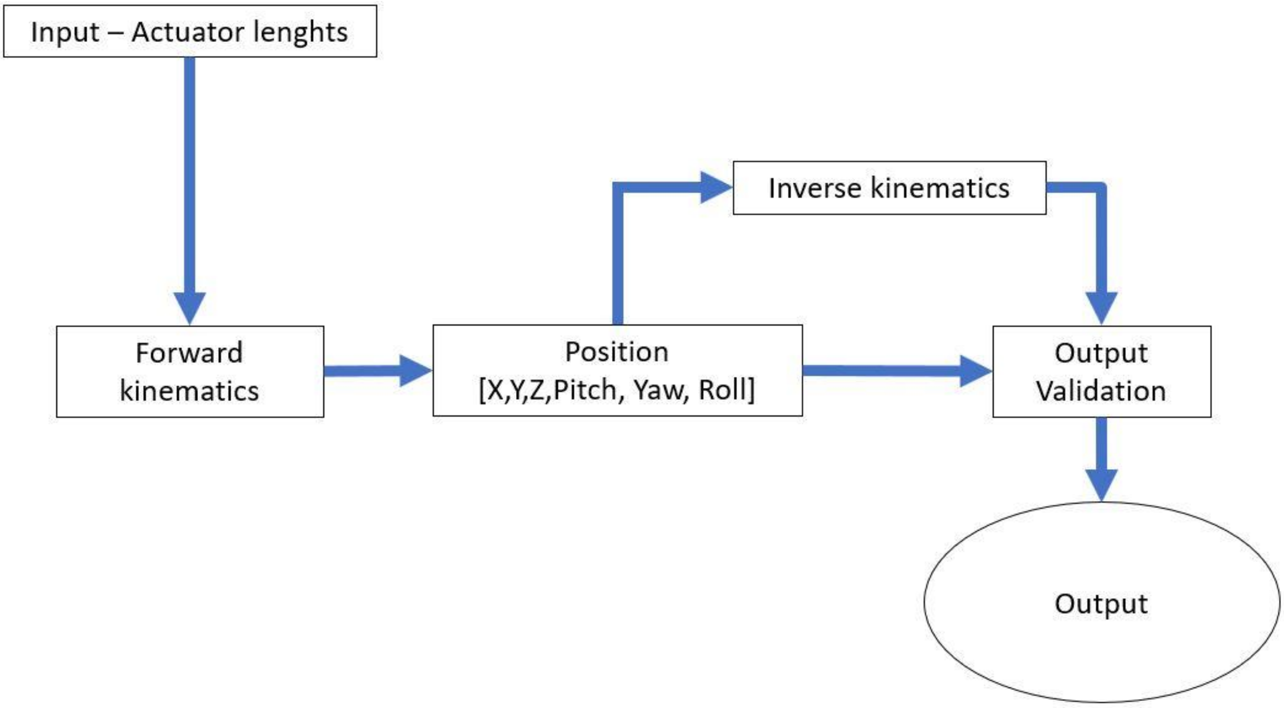

Figure 3. Flowchart of the forward kinematics calculation.

The second type of kinematic problem is when the desired position is known, but the required actuator length or position is unknown. Analytical solution is available, and it is very simple. The calculation is very fast and efficient because of this. The inverse and forward kinematics are always calculated in pairs to cross-validate the outputs, as shown in the flowcharts.

- Input: [X,Y,Z,Pitch, Yaw, Roll] – desired end effector coordinates
- Output: Actuator variables

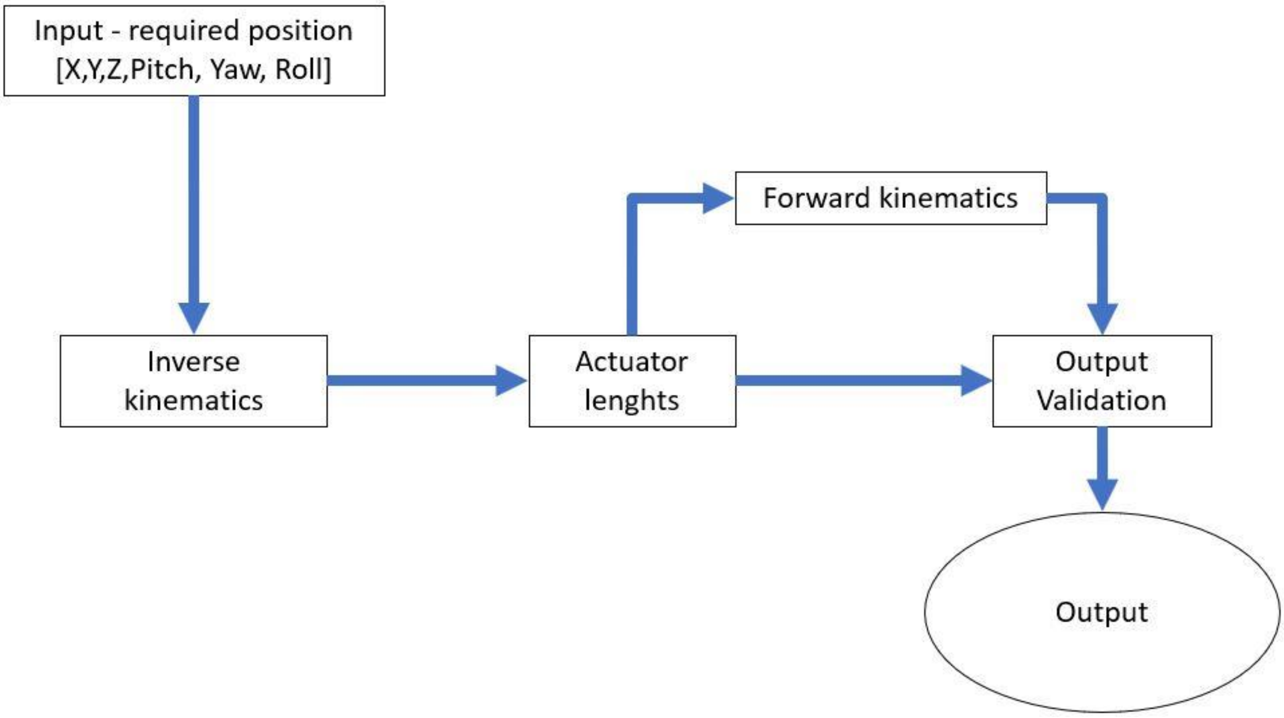

Figure 4. Flowchart of the Inverse kinematics calculation.

3. Accuracy analysis

The calculations started with obtaining scatters of points in a fixed height of the workspace, essentially it is a slice of the workspace. The points were evenly distributed with 1 [mm] distance between them. That distance was chosen because it already resulted in around ten thousand pairs of points, which was adequate for the task. These values were used to calculate the required actuator lengths and positions, which are required for the position accuracy analysis.

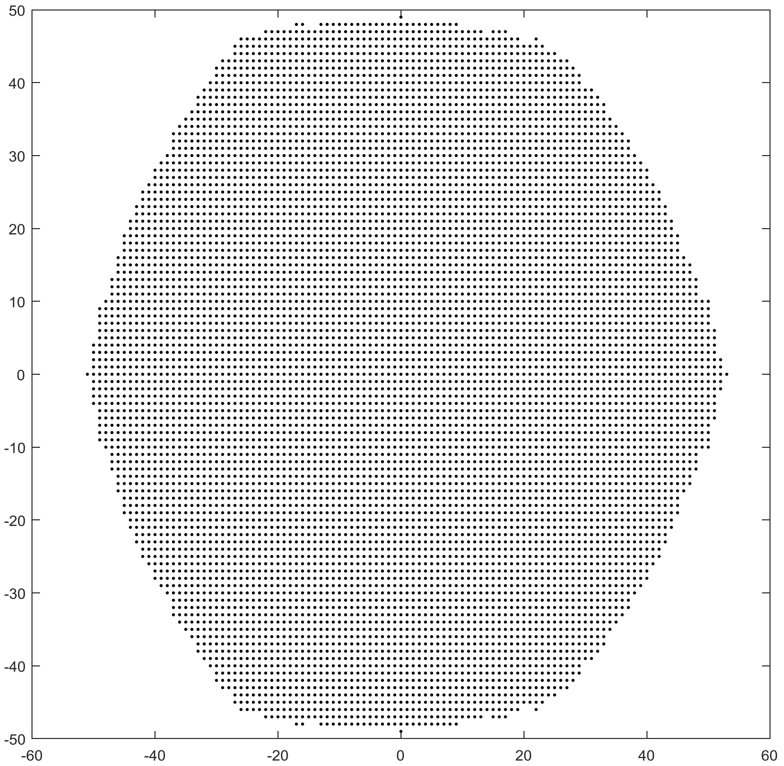

Figure 5. Points in a fixed height of the workspace.

The accuracy analysis assumes that only one actuator has an error between the required and actual position, but that error is the maximum specified value for the actuator. The control value was calculated without any added errors. The error was then added to one of the actuators, forward kinematic calculation was done, saved, and the next actuator got the error value added. When every calculation was done with positive error values the same calculation was done, but with the error value subtracted from the actuator position. This resulted in 144 positions in various distances from the control point. Every points distance was calculated from the control position, and the highest value was saved. That value is the worst-case scenario for that position. A more detailed analysis could be made assuming that more than one actuator has errors, which is more likely in practice, but the time required for the MATLAB code to run the analysis already reached more than 8 hours for these set of calculations.

The results of the calculations were instructive. The general type Stewart platform maximum positional error for 0.05 [mm] actuator error was 0.045 [mm]. The rotary type maximum positional error for 0.18 [mm] actuator error was 0.15 [mm].

4. Visualization

The visualisation for the results was also done in MATLAB. The accuracy analysis script's output was the same as the points scatter script output, but with one extra value added for each row of points – the highest error. To be able to get a visual reference for the points not included in the analysed points shading was needed. This was done by making a mesh from the obtained points using 2-D Delaunay triangulation, which ensures that the circumcircle associated with each triangle contains no other point in its interior. With that mesh the authors were able get an approximation for the accuracy of every point inside the examined slice of the workspace, which was at zero height. The dispersion of the error is as expected, very low in the centre of the workspace, and gradually increases towards the end of the workspace. The general type shows a large area with high error, which needs further investigation.

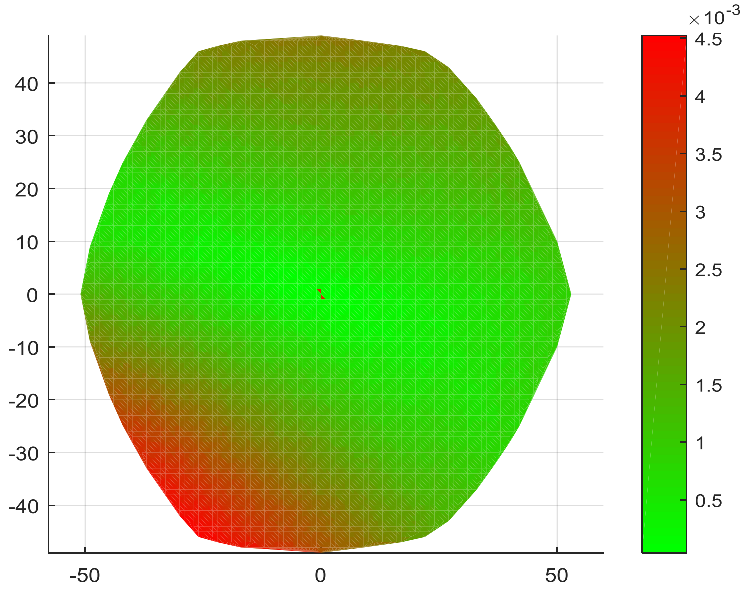

Figure 6. General type error visualization.

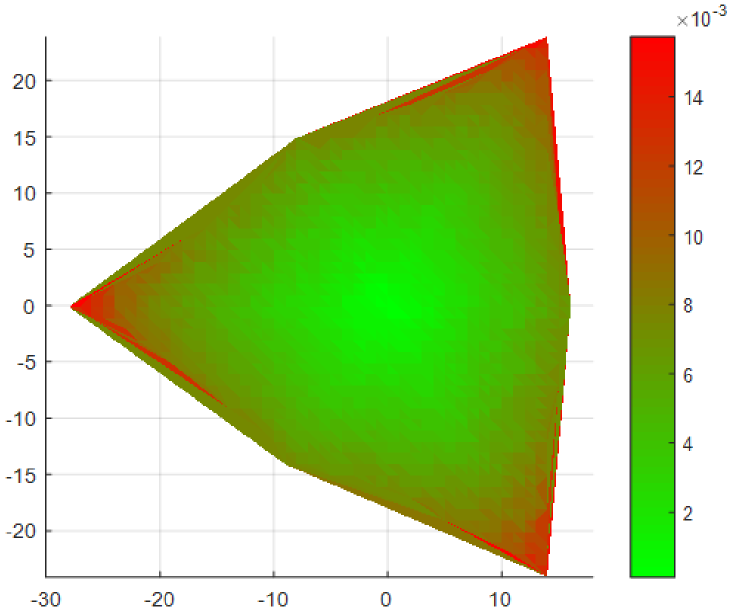

Figure 7. Rotary type error visualization.

5. Conlusion

Conclusion of this paper is that these two types of parallel manipulators respond well to actuator errors. Actual position errors are expected to be always less than that of the actuators, very small in the middle, with the big errors only present near the edge of the workspace. The unexpected error zone on the general type is planned to be investigated with singularity analysis.

6. Acknowledgements

The work/publication is supported by the EFOP-3.6.1-16-2016-00022 project. The project is co-financed by the European Union and the European Social.

References

[1] Advanced Robotics and Mechanism Applications: *Analysis and Synthesis of Parallel Robots for Medical Applications*, A.R.M.A. Research Laboratory, Columbia University, Department of Mechanical Engineering

http://www.columbia.edu/cu/mece/arma/people/nabil_simaan/ms_research.shtml

[2] MICROMO: Hexapod Surgery Assistant: *Servo Motor Applications, Miniature Hexapods Used In Spinal Surgery*

https://www.micromo.com/applications/medical-lab-automation-equipment/application-case-study-micro-precise-surgery-assistant

[3] D. Bodnár – S. Hajdu (2018) *Kinematics and Workspace analysis of parallel manipulators*. International Journal of Engineering and Management Sciences (IJEMS). 3 (2) DOI: 10.21791/IJEMS.2018.2.1.

[4] R. Szabolcsi (2016) *A New Emergency Landing Concept For Unmanned Aerial Vehicles.* Review of the Air Force Academy. 32 (2) pp. 5-12.

[5] R. Szabolcsi – J. Menyhárt (2015) *Loads Affecting UGVs' Technical Status.* Review of the Air Force Academy. 30 (3) pp. 15-20.

[6] J. Menyhárt – R. Szabolcsi (2016) *Support Vector Machine and Fuzzy Logic*. Acta Polytechnica Hungarica. 13 (5) pp. 205-220.

[7] L. Pokorádi – J. Menyhárt (2016) *Electric Vehicles' Battery Parameter Tolerances Analysis by Fuzzy Logic.* A. Szakál (szerk.) Proceedings of the11th IEEE International Symposium on Applied Computational Intelligence and Informatics SACI 2016. 412 p., Konferencia helye, ideje: Timisoara, Románia, 2016.05.12-2016.05.14. Budapest: IEEE, 2016. pp. 361-364. (ISBN:978-1-5090-2379-0)

[8] G. Szíki (2011) *Computer program for the calculation of the performance parameters of electromobiles*. Int. Rev. Appl. Sci. Eng 2 1-6.

[9] G. Szíki – G. Juhász – R. Nagyné Kondor – B. Juhász (2017) *Determination and Solution of the Motion of Equation of a Pneumatic Drive Vehicle*. Proceedings of the 1st Agria Conference on Innovative Pneumatic Vehicles - ACIPV 2017 / ed. L. Pokorádi, Óbuda University, Institute of Mechatronics and Vehicle Engineering, Budapest, pp. 55-58.

DOI: 10.21791/IJEMS.2019.1.6.

[10] G. Szíki – K. Sarvajcz – A. Szántó (2017) *Dynamic Simulation of a Series Wound DC Motor Applying the Control Design and Simulation Module of Labview* . Bodzás, Sándor; Mankovits, Tamás (szerk.) Proceedings of the 5th International Scientific Conference on Advances in Mechanical Engineering (ISCAME 2017) Debrecen, Magyarország; University of Debrecen Faculty of Engineering, (2017) pp. 540-543.

[11] [Symétrie Breva http://www.symetrie.fr/en/products/positioning-hexapods/breva/

[12] Mikrolar R3000 Rotopod: http://mikrolar.com/r3000.html