Error Classification and Visualisation for Hexapod Positioning Units

A. v. Daake[1], C. Vetter[1], E. Böhm[2], O. Zirn[1]
[1] *Technische Universität Clausthal, Clausthal-Zellerfeld, Germany*
[2] *Böhm Feinmechanik und Elektrotechnik Betriebs GmbH, Seesen, Germany*

oliver.zirn@tu-clausthal.de

Abstract

This contribution focuses on geometrical error effects on the TCP (Tool Center Point) for a commercial positioning unit with a hexapod-architecture that is powered by stepper motors (see Figure 1). The effect of the geometrical errors can be predicted and thus be ranked, which facilitates setting up manufacturing priorities.

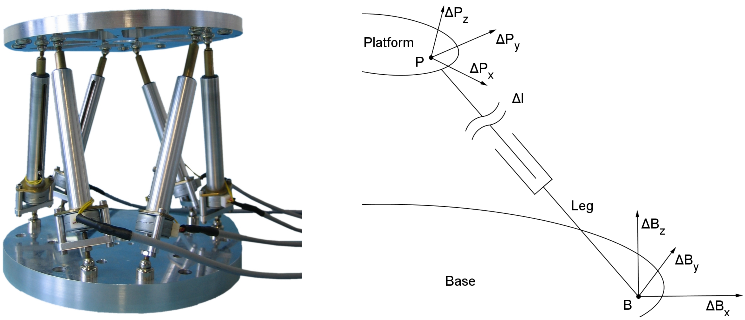

Figure 1: Hexapod Positioning Unit – error model for one leg

The error model shown in Figure 1 includes leg length as well as base and platform joint positioning errors. The bounds of the effects of geometrical errors on the TCP were investigated in 2000 by Kim and Choi [2]. For the analytical calculation of their effects on the TCP, direct kinematics are required. Caused by the complexity of the hexapod-architecture this cannot be solved in a closed form, as Raghavan proved in 1993 [3]. Husty showed in 1996 that different possible positioning unit postures lead to 40 solutions of the direct kinematics for hexapods [1]. Therefore an iterative approximation of the direct kinematics is introduced in Chapter 1 that results in the numerical calculation of errors in leg length and joint positioning error effects on the

TCP. The numerical results, which may be achieved using this method, offer information about the allocation of the error effects over the whole workspace. The 3D-Visualisation offers the opportunity to comprehend the allocation of single error's effects over the workspace quickly and intuitionally, and this way facilitates setting up priorities for manufacturing tolerances.

1 Iterative solving of the direct kinematics

1.1 Tangential movement

Starting from a known initial platform position, the motion relations v_i for all leg length displacements to move the TCP in one of its translational or rotational DOF (degrees of freedom) are given by the inverse kinematics using the Euklidic norm:

$$v_i = \{\Delta L_1, \Delta L_2, ..., \Delta L_6\}^T \text{ , } i = \{X, Y, Z, A, B, C\} \tag{1}$$

Each of these motion vectors is calculated based on a virtual infinitesimal displacement to represent the motion relations of all legs close to the TCP. The integration of these motion relations results in the matrix V, which represents the numerical form of the Jacobian matrix, which would be quite awkward or merely impossible here to be derived analytically for all kinematic parameters:

$$V = (v_X \quad v_Y \quad ... \quad v_C) \tag{2}$$

Multiplying this matrix by a direction vector $R = (X, Y, Z, A, B, C)^T$, the motion relations $A(A_1, A_2, ..., A_6)^T$ of the legs can be identified for any TCP-movement direction $V \cdot R = A$ close to the TCP.

$$\begin{pmatrix} \Delta L_{1X} & \Delta L_{1Y} & \cdots & \Delta L_{1C} \\ \Delta L_{2X} & \ddots & & \vdots \\ \vdots & & & \\ \Delta L_{6X} & \cdots & & \Delta L_{6C} \end{pmatrix} \cdot \begin{pmatrix} X \\ Y \\ \vdots \\ C \end{pmatrix} = \begin{pmatrix} A_1 \\ A_2 \\ \vdots \\ A_6 \end{pmatrix} \tag{3}$$

The tangent to the line movement, which results from the length modification of one leg a, is achieved by setting the motions of all other legs to zero and subsequently by solving the resulting 6th order linear equation system.

$$\sum_j \Delta L_{ij} \cdot R_i = 0 \text{ , } i = \{1, 2, ..., 6 \setminus a\} \tag{4}$$

1.2 Robustness by error detection and correction

Using small iteration steps, this algorithm leads to marginal errors. Considering the positioning unit prototype in Figure 1 and an iteration step size of 0.01 mm the movement of the passive legs related to the active leg a can be specified to $\Delta L_i < 0.1‰ \cdot \Delta L_a$, $i = \{1,2,...,6 \setminus a\}$. Nevertheless a finite number of steps unavoidably leads to a deviation of the TCP-position and -orientation from the intended line with a given tolerance, i.e. the length modification of the passive legs exceeds a certain tolerance ε. The fact that all legs lengths are calculated for each iteration step allows a permanent supervision during the iteration without any additional effort. If a leg i violates the condition $\Delta L_i > \varepsilon$ it may be adjusted using the same, already implemented algorithm.

2 Results

As a result of this numerical computation the effect of single errors in leg length on the position and orientation of the TCP may be calculated and visualized over the whole 3D workspace. Figure 2 shows several shells of the positioning unit's workspace at constant TCP-orientation, where the coloration depicts the translational effect of one error in leg length on the TCP.

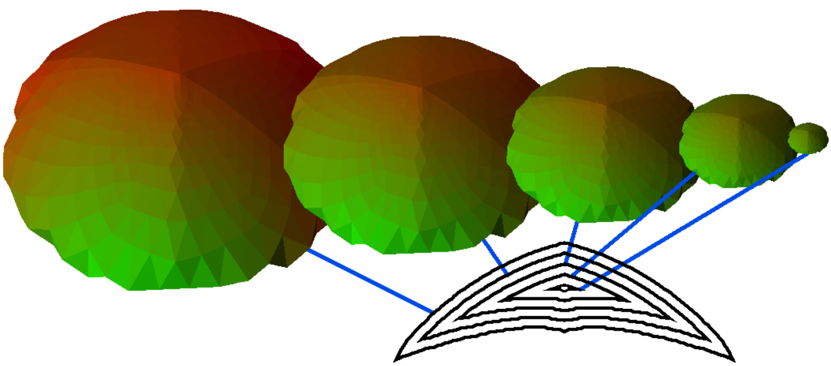

Figure 2: 3D-workspace showing the effect on the TCP for a single leg length error

For an animated workspace-video visit http://www.ipp.tu-clausthal.de/forschung/projekte/parallelkinematische-positioniereinheiten/

The achievable positioning accuracy of the hexapod unit will now be investigated by using the numerical algorithm described above. The stepper motor drive results in a leg length quantification error in the range of 7 µm. The pitch error of the used screws is specified at ± 20 µm. The manufacturing tolerances for base- and platform-joint locations are ± 10 µm. The effects of all these errors on the TCP is displayed and ranked in Table 1 in order to classify the urgency of reducing different error sources by suitable calibration methods. The listed translational errors on the TCP are calculated as the Euklidic distance between nominal and actual position, while the listed rotational errors describe the absolute maximum of all three rotations.

Table1: Error effects on the TCP

error type	transl. max	transl. min	rot. max	rot. min
screw pitch	34.4 µm	22.4 µm	15.41 m°	10.71 m°
base-/platfrom joint (x/y)	13.68 µm	≈ 0 µm	6.16 m°	≈ 0 m°
base-/platfrom joint (z)	11.2 µm	11.18 µm	5.36 m°	3.84 m°
quantization	10.85 µm	7.84 µm	4.39 m°	3.81 m°

The influence of different error types is calculated and visualized in this work, which will help to design future kinematic concepts considering their workspace, reproducibility of poses and complexity of calibration.

Acknowledgement:

The presented results have been worked out in the applied research project AiF-ZIM KF2081602WO9 founded by the German Federal Ministry of Economics.

References:

[1] M.L. Husty, An Algorythm for Solving the Direct Kinematic of Stewart-Gough Type Platforms, Journal of Mechanism and Machine Theory, 1996

[2] Han S. Kim and Young J. Choi, The Kinematic Error Bound Analysis of the Stewart Platform, Journal of Mechanical Design, Vol. 128, 2000

[3] M. Raghavan, The Stewart Platform of General Geometry Has 40 Configurations, Journal of Mechanical Design, Vol. 115, 1993