Miniature 3-DOF Planar Parallel Kinematics with Large Workspace for Precision Positioning of Endeffectors

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Abstract

Cost effective miniature fine positioning units with a workspace of several millimetres and sub-micrometer resolution are required to bridge the gap between fine-positioning units with sub-millimetre workspace and larger precision robots. A miniature triglide parallel mechanism actuated by piezo linear drives and a workspace of 6 x 7.5 mm² has been developed. Measurements proved a positional repeatability better than 3 µm and orientation repeatability better than ± 0.3 mrad on average.

1 Introduction

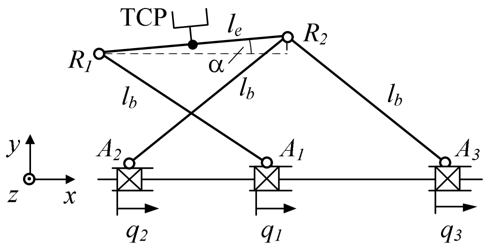
Many microassembly processes are characterized by huge contrasts between the size of the micro parts and the size of the used equipment what shall be overcome by the development of so called microfactories or size adapted robots [1]. For instance, microassembly of piezoceramic micro parts into locally micro structured sheet metal parts has been realized in a microfactory [2]. Like in most microassembly processes, there are particularly demands for miniature positioning units with a few millimetres of workspace in the xy-plane and resolution in the sub-micrometer range. Further, high allowable load larger than 10 N for mechanical joining operations, fast positioning speed, high accuracy and repeatability are required. Those specifications are particularly met by robots with planar parallel kinematic structures.

Recently, two concepts of parallel robots for microfactory applications using active rotational joints have been presented by Raatz et al. [3] and Tuokko et al. [4]. In contrast to those, an approach of using linear drives and passive rotational joints is presented in the following. This structure allows for less moved masses, particularly because the rotary drive at the end-effector can be omitted for many applications.

2 Design concept

2.1 Novel 3 DOF kinematic structure

The design of the miniature parallel robot is based on a planar triglide structure (cf. figure 1). Three similar linear drives are arranged in one xz-plane (cf. figure 2). The TCP is located in the midpoint between the passive rotational joints R_1 and R_2 which therefore define the xy-position and angular orientation of the TCP.



variable	description
A_1, A_2, A_3	rotational passive joints on the drives
q_1, q_2, q_3	travel of the drives
l_b	length of the beams
l_e	length of the end-effector plate
R_1,R_2	rotational passive joints
TCP	tool center point

Fig. 1: Kinematic structure of the miniature triglide mechanism and nomenclature

The structure of the mechanism was optimized in terms of size, workspace and resolution by performing numerical simulations. A beam length of $l_b = 25$ mm and travel range of the linear drives $q_{imax} = 18$ mm have been found to result in a maximum workspace. Though the length of the platform l_e should usually be shorter compared to the beams l_b by a ratio of 1:3 for optimum workspace [5], $l_e = 23$ mm was chosen to allow mounting of gripper changing systems according to DIN 37565-20 with vaccum supply, electric connections and a ∅ 7.5 mm hole for through-gripper vision as described in context with the use of transparent electrostatic grippers in [6].

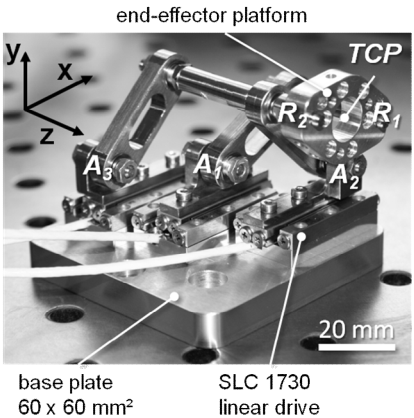
2.2 Miniature linear drives for actuation

Aiming at a compact design, linear drives with small footprint are required. Given that, a desired resolution of 0.1 µm, a travel range of 18 mm, maximum speeds of 8 mm/s and blocking forces of several Newtons are solely achieved by linear piezomotors what makes them an optimum choice for miniature parallel kinematics. NEXACT linear actuators (PI GmbH & Co. KG), Piezo LEGS Linear (PiezoMotor Uppsala AB) and SLC (SmarAct GmbH) all feature nanometre resolution and travel ranges of 18 mm. In fact, the SLC 1730 with dimensions of 17 x 30 x 8.5 mm³ was chosen for this application, because it provides a complete system including linear actuator and linear guideways for bearing transversal loads of several kilograms.

2.3 Set-up of a prototype mechanism and control

Figure 2a shows a prototype of the miniature parallel kinematics fitting on a base plate with a footprint of 60 x 60 mm². That plate can be mounted for example to a coarse positioning unit as described in [2] and therefore enable sensor guided micro part to macro part assembly. All rotational joints (A_i; P_j) are pretensioned ball bearings with minimum backlash.

The linear drives are equipped with optical sensors featuring 0.1 µm resolution enabling closed loop control of the drive position. For control of the parallel kinematics both the direct (DKP) and inverse (IKP) kinematic problems of the mechanism have been solved analytically giving the workspace plotted in figure 2b. An open loop control solving the IKP has been realized using LabView. Future work will focus on implementation of IKP and DKP in a closed loop control.



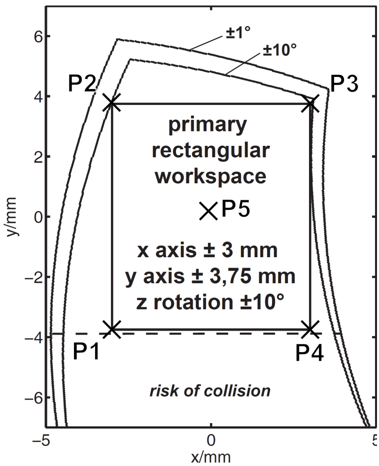


Fig. 2a: Picture of a prototype mechanism

Fig. 2b: Plot of the workspace

3 Measurements of positional repaeatability and minimum step width

The kinematics shall be used in a sensor-guided micro assembly process. Therefore, the constitutive properties are positional repeatability and minimum step width. Measurements according to DIN EN ISO 9283 were performed in five points of the workspace (cf. figure 2b) using three eddy current sensors (MicroEpsilon eddy NCDT ES08) which were arranged in an obtuse angled triangle to obtain values for x, y and α. An aluminium cube was mounted instead of a gripper for applying maximum load. The results in table 1 show that on average, the positional repeatabiltiy was better than 3 µm and and the orientation repeatability better than ± 0.3 mrad which is sufficient for the desired micro-assembly process. Minimum step widths could not be measured due to the measurmente uncertainity of the sensors, that is the step width is smaller than 0.5 µm per 0.1 µm step of the linear drives.

Table 1: Measured values of positional and orientation repeatability

	P1	**P2**	**P3**	**P4**	**P5**	**avg**
positional repeatability RP_I / µm	3.67	4.23	2.73	2.33	1.73	2.94
orientation repeatability RP_C / mrad	±0.19	±0.68	±0.15	±0.18	±0.16	±0.27

4 Conclusions

A miniature triglide mechanism with a rectangular workspace larger than 6 x 7.5 mm² and possible rotation angles of ± 10° has been developed. Positional repeatabilities better than 3 µm and minimum step widths smaller than 0.5 µm are achieved by the mechanism. Since those properties are sufficient for many micro assembly processes, the mechanism offers to close the size gap between parallel kinematic mechanisms based on flexures with workspace dimensions in the sub-millimeter range and larger mechanisms with larger size and weight with workspace of several millimeters.

Acknowledgement

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