PRECISION ASSEMBLY OF ACTIVE MICROSYSTEMS WITH A SIZE-ADAPTED ASSEMBLY SYSTEM

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Abstract The paper presents a size-adapted assembly system for the automated precision assembly of active microsystems. The part sizes of the microsystems can reach centimeter range, but they must be assembled with an assembly accuracy of about a few micrometers. The results of a sensor guided assembly process using a 3D vision sensor are shown. This process reaches a positioning uncertainty of 1.2 µm and an assembly uncertainty of 36 µm.

Keywords precision assembly, assembly system, sensor guidance

1 Introduction

Microsystem technology (MST) is a key technology for emerging markets. The third “NEXUS Market Analysis” estimates a projected market growth for 1st level packaged Microsystems and MEMS from US$ 12 billion in 2004 to 25 billion in 2009. Read/write heads, Inkjet heads and micro-displays will account for 70% of the market volume in 2009 [1].

For hybrid microsystems, a high assembly accuracy in the range of a few micrometers is required. In order to reach this accuracy, a size-adapted assembly system for sensor guided precision assembly was developed and will be presented in this paper. A precision assembly process of active microsystems will be described by means of a micro linear stepping motor.

2 Size-adapted assembly system

The size-adapted assembly system (Fig. 1, left) consists of a parallel robot *micabo*^{f2}, which provides a high accuracy due to its structure, and an integrated 3D vision sensor with only one camera. Additional components are an assembly fixture and part trays for the adjustment of parts inside the robot’s workspace. High flexibility is reached through product specific part trays and grippers, e.g. vacuum grippers with different nozzles and mechanical grippers [2].

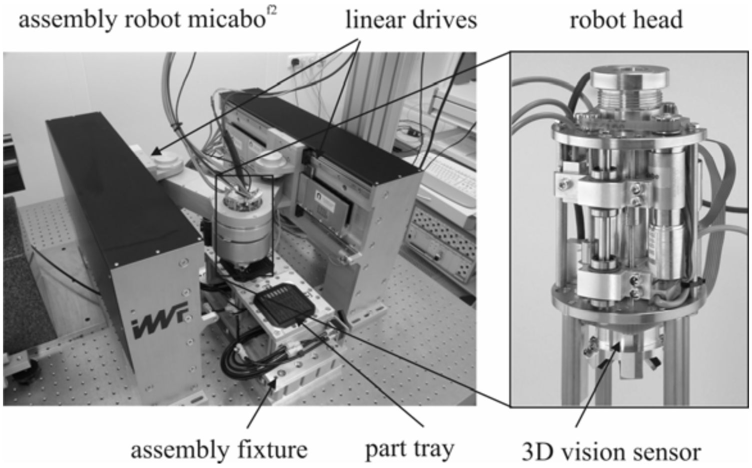

Fig. 1. Size-adapted assembly system

2.1 Parallel robot *micabo*^{f2}

At the IWF various size-adapted parallel and hybrid robots were developed for precision assembly. First, a functional model of a planar robot *micabo*^{e} [3] with 3 degrees of freedom (DOF) with a parallel structure and 1 DOF as serial lifting table for movement in z-direction was implemented. Second, a spatial robot *micabo*^{h} [3] with 6 DOF was designed. Afterwards, a spatial robot *Triglide* [4] based on a parallel structure with 3DOF and one serial rotational axis was realized.

Based on the experiences gained during the development of the above mentioned robot structures, the robot *micabo*^{f} [5] with 4 DOF for part handling and, as an advanced structure, the *micabo*^{f2} [6] with 4 DOF for part handling and 1 DOF for focusing a vision sensor was developed as a hybrid robot structure. Two parallel linear drives impart motion in the xy-plane. Each of them is connected to a slide, which is coupled to the arms of the structure with rotational bearings. A hollow shaft between the arms takes up the robot head, which is designed like a cartridge and forms the tool center point (TCP). Inside the robot head, two drives are installed. One of them moves a platform with a gripper and the other one moves the 3D vision sensor. The rotation around the z-axis is imparted by a rotational drive that is placed at one robot arm and transmits the movement to the robot head with a gear belt.

The workspace measures 160 mm x 400 mm x 15 mm. The control of the parallel linear drives can hold the desired position with an encoder resolution of 0.1 µm. In accuracy measurements according to EN ISO 9283 [7], the robot *micabo*^{f2} achieved a repeatability of 0.6 µm. This high repeatability is a good precondition for a precision assembly process.

2.2 3D vision sensor

The 3D vision sensor was developed at the Institute of Production Measurement Engineering (IPROM), Technical University Braunschweig [8]. It needs only one camera and a single image for a 3D imaging process as it applies the principle of stereo photogrammetry (see Fig. 2). It is based on a 3-dimensional reconstruction of the objects from a pair of images. The field of vision has a dimension of 11 mm in length and 5.5 mm in width with a resolution of 19 µm/pixel. Repeatability measurements showed standard deviations of $_x$ = 0.220 µm and $_y$ = 0.290 µm.

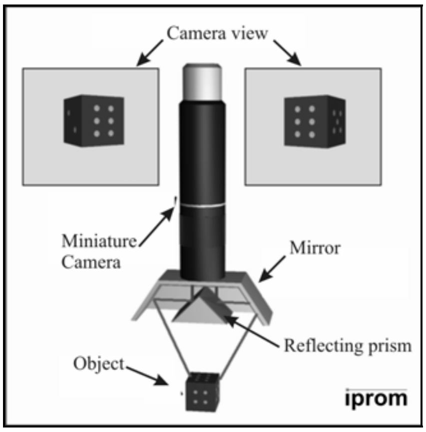

Fig. 2. Functional principle of the 3D vision sensor

2.3 Control system

A real-time system is used to control the assembly system. It features a PowerPC750 digital signal processor (DSP) running at 480 MHz. Two different control loops (Fig. 3) are used for the integration of the sensor information in the control system.

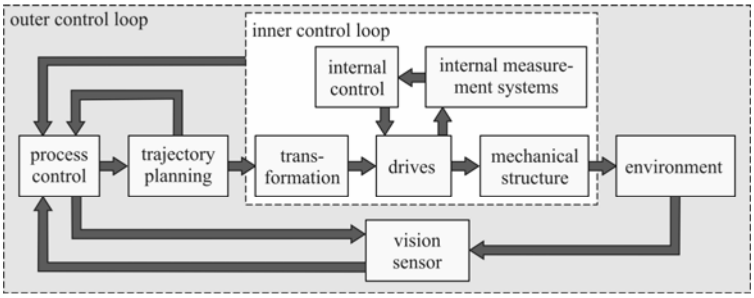

Fig. 3. Control of the assembly system

The process control gives commands to the robot control and demands information from the vision sensor system. The internal control loop works at a system execution time of 0.2 ms. The outer control loop works with 1 ms and contains the 3D vision sensor, which sends information about relative positions of the assembly group to the process control. A resulting vector of the current position from the robot control and the relative position vector from the vision system is calculated inside the process control and is transmitted to the trajectory planning.

At present, the sensor guidance works according to a so called “look-and-move” procedure. This means that the robot’s movement stops before a new imaging process starts and a new position correction is executed.

3 Precision assembly of active microsystems

A micro linear stepping motor [9], which works according to the reluctance principle, is assembled with the presented size-adapted assembly system. The motor parts were mainly manufactured with micro technologies developed at the Collaborative Research Center 516. One assembly task is the assembly of guides on the surface of the motor’s stator element. In Figure 4 (left) the assembly group of two guides on a stator is shown. The right image shows the view of the 3D vision sensor on the assembly scene.

Circular positioning marks [10, 11], which were manufactured in a photolithographic manufacturing process onto the group of components, are used by the 3D vision sensor for the imaging process. The positioning marks (4 on the stator and 2 on each guide) in both images are measured and a resulting relative position vector is calculated and given to the robot control. Inside the robot control, the relative position vector is separated into a rotation correction, a correction in xy-direction and, finally, the correction in z-direction, which places the guide.

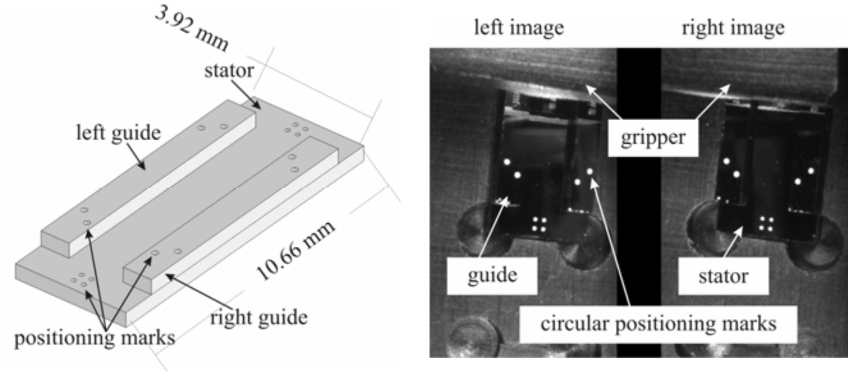

Fig. 4. Assembly group guides on stator (left); view of 3D vision sensor (right)

Figure 5 shows only the assembly steps for the left guide, because the assembly steps for the left and the right guide are equal. In a first step, the marks on the stator are checked. If the part can be recognized, the positioning of guides can be carried out. Otherwise, the stator that has already been checked will be excluded. The guides are checked, too, and are picked up if they are recognised. Gripping the guide and moving it to a pre-defined position above the stator is done without sensor guidance. Afterwards the sensor guidance is started automatically.

If the relative positioning vector reaches the pre-defined limit value of 0.8 µm in x- and y-direction, a final relative position correction is done by moving the robot in z-direction (height). This completes one positioning process. After both guides have been placed, the next assembly process begins until the part trays have to be changed.

At present, the guides are bonded onto the stator element by use of cyanoacrylate which has been pre-applied manually onto the stator element. The joining technology will be improved in future works at the Collaborative Research Centre 516.

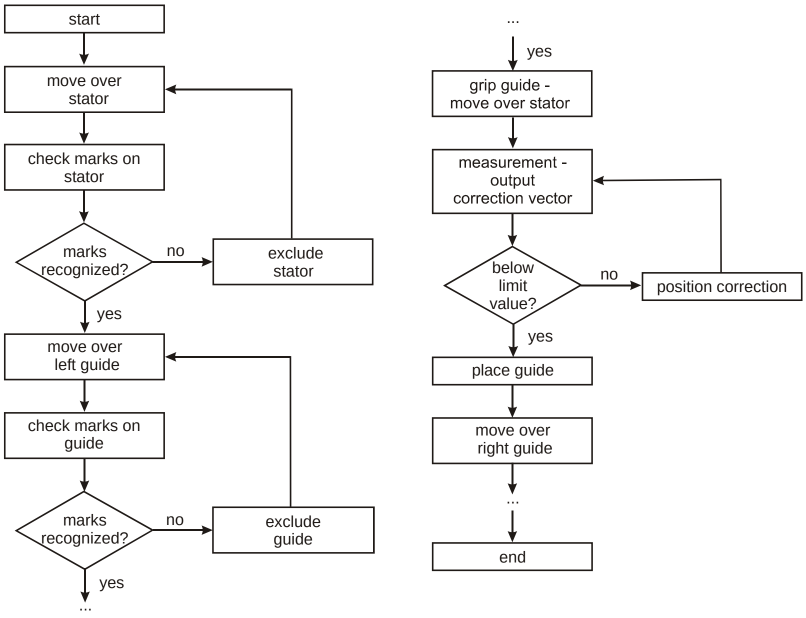

Fig. 5. Assembly of guides on a stator element

4 Results of the precision assembly process

To quantify the precision assembly process, two terms were defined - *positioning uncertainty* and *assembly uncertainty*. According to DIN ISO 230-2 [12], the *positioning uncertainty* is the combination of the mean positioning deviation and the double standard deviation. For precision assembly processes the term *positioning uncertainty* refers to the reached relative position between the assembly parts before the bonding process is carried out (in this case the guide is above the stator and has no contact).

The term *assembly uncertainty* describes the relative position between the assembled parts measured after the assembly process has been completed. This is the combination of the mean assembly deviation and the double standard deviation, too.

Positioning marks are used as an inspection criterion. They are used for quality control of the parts before the process and during the process for the sensor guidance and evaluation of the *positioning uncertainty*. After the process the positioning marks are used for evaluation of the *assembly uncertainty*.

During the process only one end of the assembled parts can be measured, because the gripper covers half of the guide and the stator (see Fig. 4, right). Therefore the relative positioning device observes only the visible sides of the assembled parts. This means, that the measured positioning error and the resulting *positioning uncertainty* is only determined by the visible part side. After the process both ends of the assembly group can be inspected and the overall assembly deviation can be measured. From the deviations the *assembly uncertainty* is calculated. This value is comprised of the overall errors during the assembly of the microsystem.

As expected, the *assembly uncertainty* of 36 µm is much higher than the *positioning uncertainty* of 1.2 µm. This is a result of the relatively long part sizes of 10 mm. A small angular deviation causes a positioning error (in xy-direction) on the side of the part which is invisible during the sensor guided positioning process and which is larger than the error on the visible side. With a greater part length this positioning error will be higher than with smaller parts. Actually the measured assembly deviations are smaller on the end of the assembly group that is visible during the assembly and used for the relative positioning process (average deviation of 7 µm and assembly uncertainty related only to the visible side 16 µm) as on the invisible side (average deviation of 20 µm and assembly uncertainty related only to the invisible side 44 µm).

Furthermore, deviations occurring during the joining process cause an increased positioning error. This leads to the before mentioned gap between *positioning uncertainty* and *assembly uncertainty*. Figure 6 shows the *positioning uncertainty* (left) and the *assembly uncertainty* (right) of 33 assembled groups. The circles in the diagrams show the radius of the uncertainties, which include 95% of the parts.

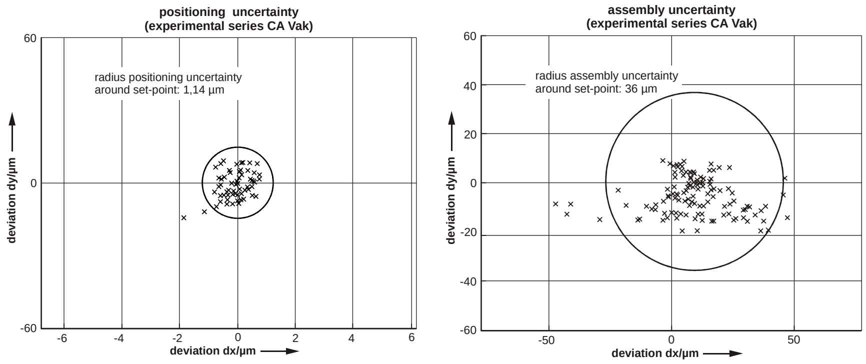

Fig. 6. Reached positioning uncertainty (left) and assembly uncertainty (right)

5 Conclusion

In this paper a size-adapted assembly system consisting of a parallel robot with high accuracy and an integrated 3D vision sensor was presented. Within a workspace of 160 mm x 400 mm x 15 mm a positioning uncertainty of 1.2 µm is reachable. Due to the relatively large part sizes and the joining process of the described assembly process, an assembly accuracy of 36 µm could be reached. However, an assembly accuracy in the range of a few micrometers is needed, as a result of which it should be improved in further research activities concerned with the development of joining and gripping technologies at the Collaborative Research Center 516. Furthermore, another arrangement of the positioning marks with a larger distance between the marks will be studied, which promises an improved positioning uncertainty, especially for angular deviations.

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