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# Vision and Force Sensing to Decrease Assembly Uncertainty

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**Abstract.** This paper presents two ways of decreasing the assembly uncertainty of micro assembly tasks through further or optimized integration of sensors within a size adapted assembly system. To accomplish this, the orientation of the part to be placed with respect to the vision sensor is changed. This was possible through a new gripper which was able to overcome the restrictions placed on the system by the vision sensor. Another increase in precision was obtained through the integration of a force sensor into the wrist of the robot. This force sensor provides additional information about the placing process which allows the maximal force in the vertical axis to be limited. These improvements are then demonstrated on a task which requires the placement of linear guides which are 8.4 millimeters by 1 millimeter.

**Keywords:** precision assembly, sensor guidance, size adapted robot

## 1 Introduction

Micro assembly deals with the joining of parts which have at least one dimension less than 1 millimeter which need to be placed with accuracy on the order of a couple of micrometers or less. To accomplish such tasks, the hybrid parallel robot micabo<sup>f2</sup> was designed and constructed at the Institute for Machine Tools and Production Technology at the TU- Braunschweig [1]. The main task of this robot has been the assembly of a linear micro actuator. Although capable of precision assembly, the goal of improving the abilities of the micabo<sup>f2</sup> is an active area of research.

Within this paper the precision assembly robot micabo<sup>f2</sup> is presented. Machine vision is accomplished through a 3D vision sensor which has been integrated into the head unit of the micabo<sup>f2</sup>. This is followed by a brief overview of the precision assembly task which is used as a demonstration assembly task within the scope of this paper. With an understanding of the current system, two short coming are addressed, than overcome through the integration of additional sensors. It is ultimately shown that the precision as well as robustness of the micabo<sup>f2</sup> for assembly tasks is improved through these sensors.

The first method strives to take advantage of a better orientation of the rectangular part being assembled within the rectangular field of vision of the 3D vision sensor. It was shown in [2] that the limited view of the part during relative positioning increases the assembly uncertainty.

The second method looks at limiting the forces that occur at the end of the gripper when a part is being placed. These irregular forces can arise from things such as differences associated with part tolerances or different aspects of the glue being used. Under these loads, small parts can easily slide or deform. To overcome these effects, a force sensor is integrated into the wrist of the micabo<sup>f2</sup>. Its integration into the robot, along with the controller which is realized is presented.

### 1.1 Robot

The micabo<sup>f2</sup> is a size adapted parallel robot which uses two linear actuators to move two arms which meet to form the robot head figure 1. This planar configuration allows the robot 2 degrees of freedom (dof), and is the basis for its high precision and accuracy. Located within the head unit of the robot are 3 more dof which allow the end effector to rotate, the vertical actuation of the gripper, as well as an actuator to focus the vision sensor. The workspace of the robot is 160mm x 400mm x 15mm. Accuracy measurements which were performed according to EN ISO 9283 [3], show that the micabo<sup>f2</sup> achieved a repeatability of 0.6 micrometer.

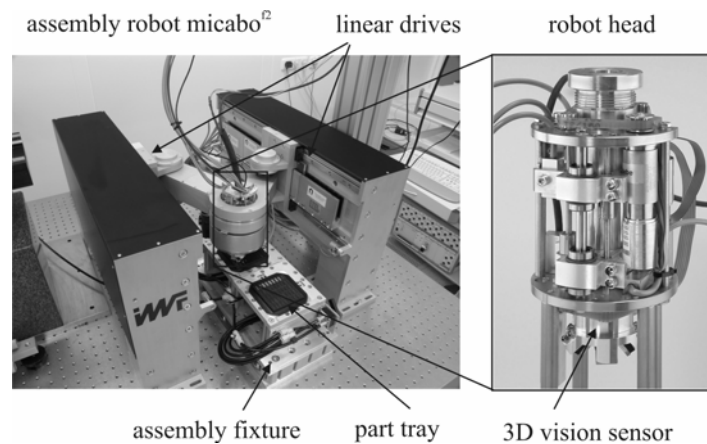
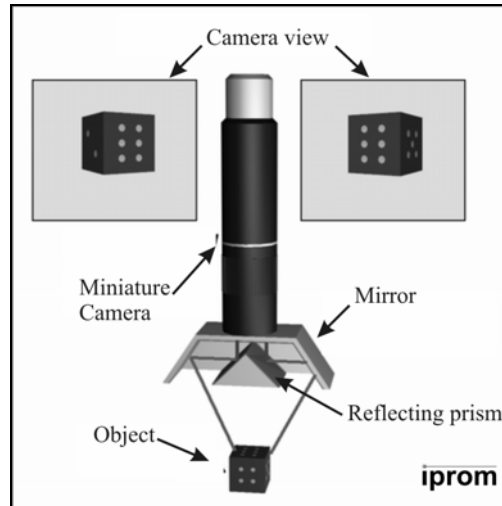


Fig. 1. The size adapted robot, micabo<sup>f2</sup>

### 1.2 Three Dimensional Vision Sensor

The 3D vision sensor implemented within the micabo<sup>f2</sup> was developed at a partner institute at the Technical University Braunschweig, the Institute of Production Measurement Engineering (IPROM) [4]. As can be seen in figure 2, the sensor takes advantage of stereo photogrammetry to gather 3D data. Here the stereo view of the environment requires only one camera, which allows the entire sensor to be fitted into the head of the robot. The sensor has a field of vision 11mm by 5.5 millimeters and offers a resolution of 19 micrometers/pixel. Repeatability measurements have shown

that this sensor has a standard deviation of  $\sigma_x = 0.220$  micrometer and  $\sigma_y = 0.290$  micrometer.

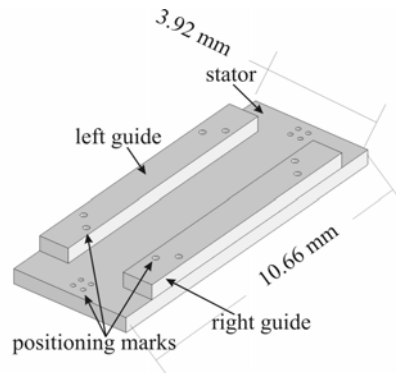


**Fig. 2.** Functional principle of the 3D vision sensor

### 1.3 Precision Assembly of Active Microsystems

The goal of the Collaborative Research Center 516 is the design and construction of a micro linear stepping motor [5]. The challenges in developing and manufacturing this reluctance based motor are equaled by the task of assembling it with the required tolerances. To overcome these, the mentioned size adapted robots along with its 3d vision sensor are being optimized to best fulfill this task. The task of improving the placement of these guides on the surface of the stator element is one of the main motivations for the presented work and is thus used as a demonstration task. The simplified motor model for this assembly task can be seen in figure 3, along with dimensions.

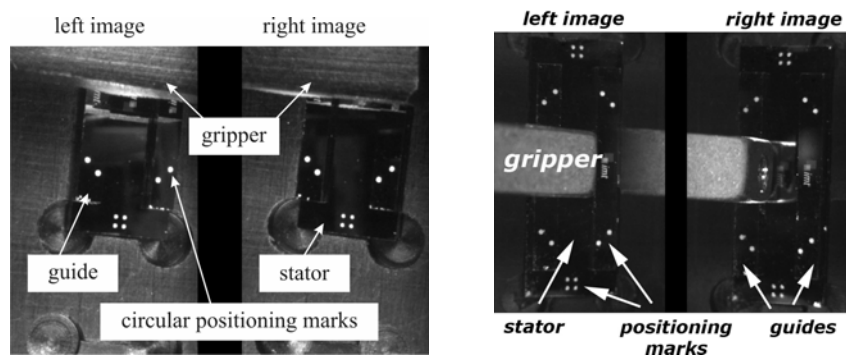
Circular positioning marks [6], which are created using a photolithographic manufacturing process, have been integrated into both the guides to be placed as well as the stator. The positioning marks (8 on the stator and 4 on each guide) in both images are measured and a resulting relative position vector is calculated. This can then be used within the robot control, which corrects the rotational and translational error within the plane parallel to the surface of the part. Once these are less than 0.8 micrometer, the vertical information is used to place the part.



**Fig. 3.** Simplified linear stepping motor assembly

## 2 Increasing Part Visibility

A limiting factor of the 3D vision sensor used for relative positioning is that the part being handled, as well as the functional marks on the substrate always needs to be visible. As the parts to be handled get smaller and smaller, the task of effectively gripping them, while not obstructing the view of the marks becomes more and more challenging. Further, the more that is seen of the part, the more accurately it can be placed using a vision based relative position system. This was shown in [2], in which a large assembly error is attributed to limited visibility of the part during the relative positioning phase. It is shown that the assembly error of the finished part was drastically larger on the side of the part which was covered by the gripper.



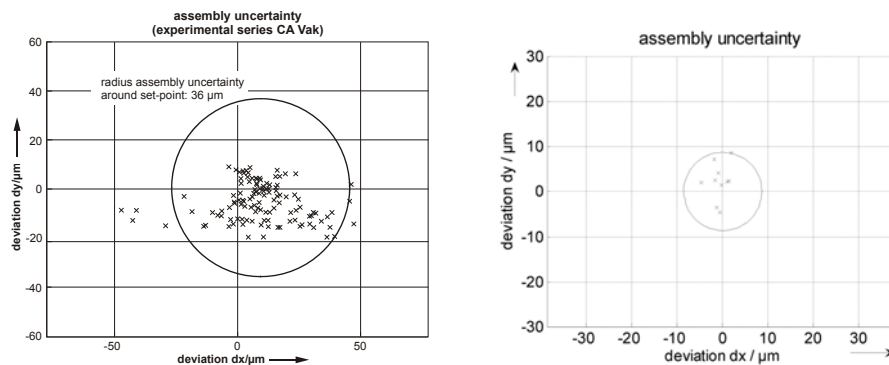
**Fig. 4.** Old gripping method (left) new gripping method (right), as viewed by vision sensor

Herein lays the problem in the above mentioned task, as there are limited ways of gripping such a long and narrow part. This is further complicated by the limitations of

the 3D vision sensor which require two nonadjacent sides of the part be visible, as well as limits the orientation of the part within its rectangular shaped sensing area. To overcome these obstacles a new gripper was designed, with the goal of improving the visibility of the stator when it is being placed on the substrate. This new gripper was designed so that the part is perpendicular to the gripper, where the old gripper had it parallel. Along with this, the orientation of the sensor to the gripper was rotated 90 degrees, so that the entire stator as well as guide can be seen during the placing process. As can be seen in figure 4, the combination of the new gripper and orientation of the part under the sensor allow the entire part to be seen during the place phase of the assembly task.

To facilitate a quantitative comparison between the old and new gripper, parts were assembled using the new gripper and compared against those with the old gripper. The resulting assembly data was then used to calculate the positioning uncertainty and assembly uncertainty. According to DIN ISO 230-2 [7], the positioning uncertainty represents the relative position error between the assembly parts before the bonding process, while the assembly uncertainty is measured after the bonding has been completed. Both terms are calculated as a combination of the mean positioning deviation and the double standard deviation.

To recall the assembly data which was obtained through the assembly of 33 guide/stator groups and the older vacuum gripper, a positioning uncertainty of 1.2 micrometers and an assembly uncertainty of 36 micrometers were thus obtained [2]. The resulting assembly uncertainty along with the data can be seen on the left hand side of figure 5.



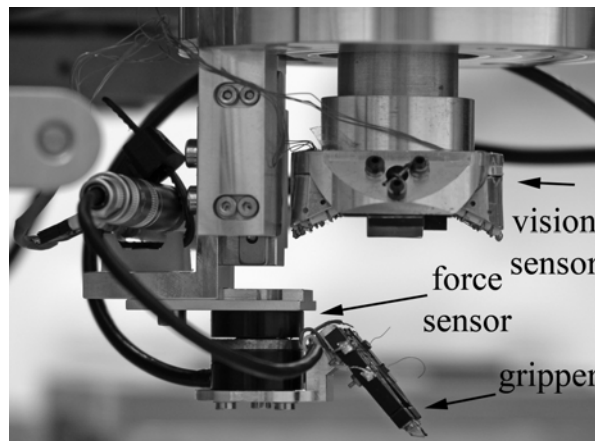
**Fig. 5.** Assembly uncertainty for the old gripper (left) along side the assembly uncertainty of the new gripper (right).

Using the newly developed gripper in conjunction with the new orientation, 10 guides were assembled on stators. This data showed a similar positioning uncertainty of 1.3 micrometers, while the assembly uncertainty was reduced to 8.6 micrometers. This data along with a circle representing the uncertainty can be seen on the right hand side of figure 5. Although this limited data does not allow for a conclusive

statement, it does allow one to draw the inference that the new orientation decreases the assembly uncertainty.

### 3 Force Sensor Integration

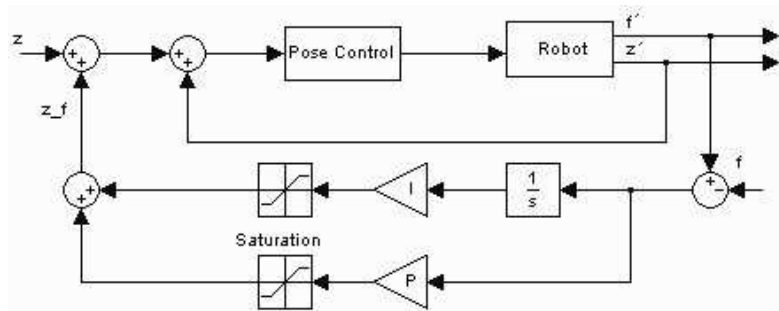
Although information about the relative difference in height between the object being placed and the substrate on which it is being placed can be gained from the 3D vision sensor, it is unable to overcome differences which arise from inconsistent glue drops as well as part tolerances. In order to gain more information in the vertical axis, a force sensor was added into the wrist of the micabo<sup>f2</sup> robot.



**Fig. 6.** Force sensor integrated into the wrist of the micabo<sup>f2</sup>

An integral part of this was finding the correct sensor, as it required a balance between size, force range, and sensitivity. These characteristics were found best satisfied with the Schunk FT Nano-1712/0.12. With a maximal force of  $\pm 17\text{N}$  and resolution of  $\pm 1/160\text{ N}$  in the Z axis, it was viewed as adequate for this application. It was then integrated between the gripper and the vertical axis of the robot as can be seen in figure 6. Though this sensor has a coarse resolution for precision assembly, it is fine enough to allow the robot to gain information about the contact taking place between the part being placed and substrate.

After the sensor's integration into the physical system, a software calibration routine was developed which takes the offset of the sensor to the gripper into consideration. This was achieved through a force and moment balance, ultimately allowing force on the gripper to be solved for. The last step was the integration into the control loop. Here a cascade control loop is chosen with the inner loop controlling position, and the outer adjusting the position as a function of the force [8,9]. The resulting control loop can be seen in figure 7. A saturation function was introduced which prevents the robot from moving down to "increase" the force if it is less than the desired force.



**Fig. 7.** The implemented cascade force/position controller

After the functionality of the force controller was confirmed, it was used to set square parts on the above mentioned stator in conjunction with a hot melt adhesive. With its implementation, it is shown that the robot system is better able to accommodate irregularities which can arise when hot melt adhesives are used. Here the properties of the hot melt adhesive during the placing portion, such as whether or not the drops are fully melted or not can be determined. In the case that a larger droplet of the hot melt is not thoroughly heated and thus still hard, the force controller can limit the maximal force seen at the gripper. Reducing the maximum seen force at the gripper not only prevents damage to the robot or part but also improves the precision, as parts are less likely to move while being placed.

## 4 Conclusions

Two ways of improving the precision of a micro assembly using a size adapted parallel robot were introduced. First the shortcomings of the 3D vision sensor were overcome through the integration of a new gripper in conjunction with rotating the sensor to take advantage of its rectangular image sensor. It was shown that this resulted in an assembly uncertainty of 8.6 micrometers, in comparison with the old uncertainty of 36 micrometers. Next a brief review of how a force sensor was integrated into the Micabof2 was presented. This sensor was used to provide redundant information about the vertical axis, ultimately improving the robustness of the robot to accurately indifferences in the z axis.

## 5 Acknowledgements

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