Characterization of Micro Manipulation Tasks Operated with Various Controlled Conditions by MicroTweezers

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***Abstract* – Micro manipulation tasks with micro tweezers were operated in different configurations. This paper discusses the main issues of pick and place operations with micro tweezers as geometric consideration, grasping force and quality of the contact surfaces. This study is based on positioning repeatability measurements and success rate of the tasks operated automatically on our micro manipulation setup. Results for a MEMS micro gripper show a high reliability of more than 90% of success rate and positioning repeatability under the micrometer.**

Index Terms – micro gripper, micro manipulation, positioning repeatability measurement, adhesive effect.

I. Introduction

The process of picking an object is based on reproducing our hand capability of grasping. Handling micro parts can follow the same principle after a miniaturization procedure thus by using micro tweezers. Scaling is not so evident since in the micro scale these operations have to deal with the adhesive effects. Dependence to environmental characteristics (temperature, humidity …) as well as material and quality at the interface has to be taken into consideration during the design and automation processes [1, 2]. Many researches have been pursued to develop micro tweezers in which actuator principles, fabrication process and so material choice have been extensively proposed [3].

We are presenting in this paper two types of micro grippers that were tested with different conditions of operations and then evaluated on the basis of pick and place operations in term of efficiency and positioning performances.

II. Handling parameters

Micro manipulation tasks are widely influenced by adhesive effects (capillarity, Van der Waals forces, electrostatic force) which are predominant at this scale compared to the gravity. Pick and place operations can be described based on the equilibrium of these adhesive effects at the interfaces part/tip and part/substrate (where parts are laid) during the different steps with the implemented gripping and releasing principles. In our case the grasping by tweezers is based on friction effect induced by the tightening force but the release is very dependant on adhesive effect.

The performances are so tightly dependant on parameters acting on the adhesion effect as the material, roughness, quality of the contact area and grasping force. Concerning specifically the tweezers misalignment of the fingers tips can provoke until the impossibility to catch the part or induce a disturbing torque on the part. Finally the control of the position needs mechanical references with sufficient stiffness.

III. Setup of micro manipulation

The micro manipulation setup was designed with the goal of integrating different kinds of manipulation tools and in order to test them in variable conditions with the possibility to measure their positioning capabilities and their reliability.

The setup [4] is based on the three degrees of freedom Delta^3 robot with strokes of ±2mm and positioning repeatability of ±10nm thanks to its flexure hinges based structure and contact-less actuators and sensors. A standardized interface allows to mount different kinds of micro grippers on the Delta^3 and to place their end-effectors directly in the field of view of the microscope. In order to protect the workspace against air flows it is enclosed in a chamber where the relative humidity can also be lowered by injecting nitrogen (fig. 1).

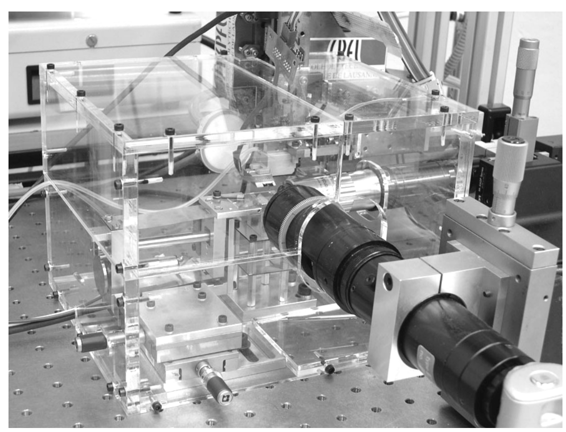

Fig. 1 Overview of the micromanipulation setup.

The operation of manipulation can be fully automated based on computer vision or operated in telemanipulation. A first microscope provides a bottom view of 470 x 350µm^2 and an image pixel size of 460nm based on a Mitutoyo 10x objective. This view serves to the object and tip detection and localization. Calibration of the microscope and measurement algorithm through a precise grid of 50µm marks gave a final accuracy of 200nm. The second microscope gives the lateral view through a camera mounted on a video zoom lens with magnification of 3x to 28x giving a field of view of 1.61x1.21 mm^2 to 0.17x0.13 mm^2 (Marcel Aubert system). This view serves as a fine supervision for alignment purpose and preparation procedure by the operator.

IV. Experimental procedure

Automated operations of detection, measurement and alignment were carried out in order to reduce the influence of the operator on the position repeatability measurement.

Many preparation steps are required before making automated operations especially for the relative vertical position between the tips and substrate. The parameters of tests are modified only once automated process is launched. Tendencies according to these parameters can thus be observed as relative values.

The positioning error corresponds to the measure of the final position of the released part minus the target. An operation has been considered as failed if the release was not possible or if the positioning error was bigger than 20µm. The standard deviation in the x and y directions (σ_x, σ_y) of all the successful operations is then computed and the position repeatability corresponds to the biggest value of σ_x and σ_y. The success rate is the ratio between the number of successful release operations and the total number of release operations.

Manipulations that are discussed here were all operated with calibrated 50µm Polystyrene balls and at least fifty trials were executed for each specific case.

Efficiency of the release can be improved by different strategies concerning the escape way and acts also on the positioning performances. Preliminary experiments have confirmed that a small bottom vertical movement once tweezers are opened followed by escaping vertically gives the best results in positioning repeatability (fig 2). All the presented experiments will use this strategy at the release step.

Strategy	Position repeatability
Z-X	3.1µm
Z-Y	6.3µm
Z-Z	0.9µm

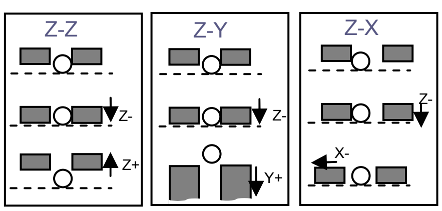

Fig. 2 Explored strategies to improve the positioning and the reliability of the release. After tweezers opening a movement of 10µm occurs in the bottom Z direction before going away of the part in the X, Y or Z direction. Tests were conducted with the MEMS gripper.

Experiments were based on two types of micro tweezers. A MEMS micro gripper was developed by IRIS within the framework of a TopNano21 project. One of the fingers is linked to an electrostatic actuator while the second is connected to a capacitive force sensor. The second micro gripper is modular in the sense that it allows the use of different types of end-effectors and is actuated by a pneumatic bellow.

V. MEMS micro gripper

The MEMS micro gripper is composed by an electrostatic actuator that allows a stroke of 100µm at 160V driving voltage and a capacitive force sensor with a sensitivity of 4.4mV/µN. Fabricated from a SOI wafer through deep reactive ion etching process (DRIE), its final overall dimensions are 7.7mm x 5.6mm x 0.45mm where the comb drive structures as well as finger tips and flexures are 50µm in thickness. To reduce capacitance effect through the connection, the capacitive readout chip is connected the closest to the gripper, thus directly on the flexible PCB (fig 3). Figure 4 presents operations of grasping measured by the force sensor. Integration problems did not allow us to use the force sensor feedback during the automated operations themselves. But it was estimated that the parts used during measurement process were grasped with a force repeatability of ±5µN.

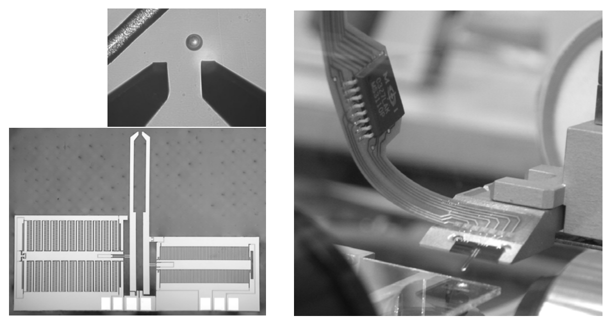

Fig. 3 MEMS micro gripper: (left top) microscope view of the tips compared to a piece of hair and a 50µm polystyrene ball; (left bottom) close view to the MEMS structure and (right) the gripper mounted on the Delta^3 robot.

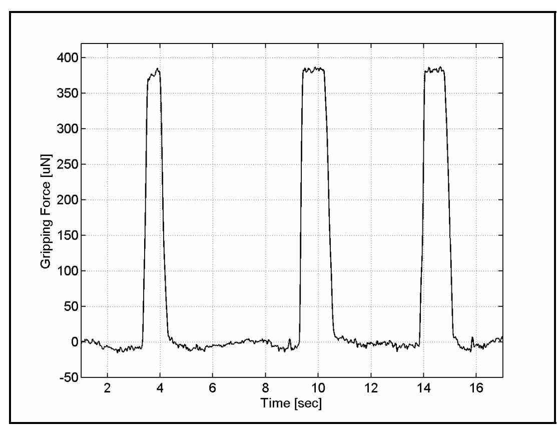

Fig. 4 Operations of grasping view from the force sensor.

Experiments were conducted on glass substrate with and without a 10nm chromium layer in order to have different adhesive effect on the substrate side. For the same purpose hydrophobic coating [1] were deposed on one of the MEMS gripper.

[1] The hydrophobic coating is a Perfluorosilane provided by the Nanostructuring Research Group (NRG) at the Advance Photonic Laboratory (APL) in EPFL

Table I give the results of the positioning repeatability measurement as well as the success rate. It looks like hydrophobic coating on the gripper tips improves mainly the success rate, as it could be expected since adhesion effects with the tips are lowered. Concerning the positioning performances significant difference appears only in the case of silicon tips on glass with chromium layer. In this situation difference of adhesion effect between tip side and substrate side becomes smaller than in the three other cases.

Gripper and substrate types	Position repeatability	Success rate
MEMS gripper, silicon fingers		
Glass	0.74µm	86.4 %
Glass + 10nm chromium	1.10µm	70.7 %
MEMS gripper, hydrophobic coated silicon fingers		
Glass	0.86µm	93%
Glass + 10nm chromium	0.84µm	85.7 %

TABLE I
POSITIONING RESULTS WITH MEMS MICRO GRIPPER

The force sensor linked to one of the finger allows a small movement of this one (a capacitive sensor measure basically a displacement). If very well known the error produced could be, in a certain range, compensated through the robot controller or actively compensated by the sensor itself. But to really optimize the positioning repeatability the best way would be to have a mechanical fixed reference on one finger and the actuator and sensor on the second one.

Achieving a positioning repeatability around the micrometer for the fourth situations shown was also possible because the advantages of MEMS gripper are mainly:

- To be monolithic so without any assembly error or misalignment (except for instance if internal stress deformed both fingers in a different way)
- To have well defined contact areas (DRIE process)
- To have an actuator with a sufficiently high resolution allowing minimizing the grasping force.

VI. MODULAR PNEUMATIC MICRO GRIPPER

Although this tool needs some assembly steps, it has as the advantage (at least from a prototyping point of view) to come from fast and low cost processes compare to silicon manufacture and to be easily adapted with specific shaped end-effectors.

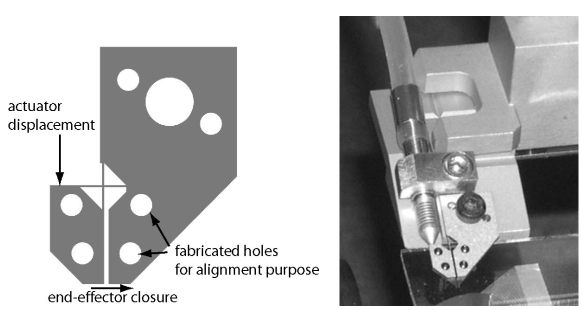

Fig. 5 (left) structure of the modular gripper basis;
(right) overview of a modular gripper mounted on the Delta^3 robot.

The movement of closure is induced through a pneumatic bellow acting on the flexible pivot of a laser cut gripper basis. The end-effectors are glued on this basis and aligned with the help of the fabricated holes (fig 5). Different designs as well as materials can thus be used as end-effectors given its modularity to this micro gripper.

The grasping force range given by the pneumatic actuator goes until 400mN with a resolution of 1mN. The experiments were pursued with two kinds of end-effectors that are presented below first with stainless steel fingers of 50µm in thickness, then with silicon fingers of 12µm.

A. *Stainless steel fingers*

These fingers were first cut by laser, but the sides were too rough so wire EDM (Electro Discharge Machining) was introduced (fig 6). Roughness should theoretically reduce the adhesive effect; in our case it decreases the level of detection of both micro object and gripper by our visual system. Indeed the part was like partially hidden by the asperities caused by the laser on the side wall. This produces an important loss of data that induces an error on the determination of the object position and then on the operation reliability. Thin metal end-effectors can be machined by EDM (20µm steel slides were adapted for this micro gripper), but it is complex to get thin structure at the tip that allows to grasp the object without crushing other objects lying around it.

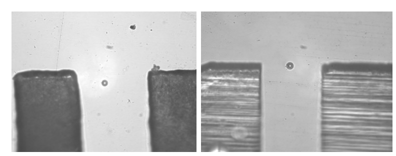

Fig. 6 Evolution of the quality of the fingers: from laser to wire EDM (scale: the balls are 15µm in diameter)

Pick and place operations were executed with the same conditions than the MEMS gripper. Positioning performances (see table II) are still affected by the quality of the contact surface as exposed before. High grasping force and geometric issues are as well main reasons for the low success rate. However those causes of poor positioning and reliability performances can become an advantage in assembly operations. For instance picking a silicon structure connected to the wafer by some bridge needs a consequent grasping force in order to detach it. Thanks to the high stiffness of the finger tips the part is strongly grasped and will not be lost during the breaking as it could be by using a vacuum gripper. Assembly operations of MEMS structures were carried out successfully with this micro gripper. More positioning performances are studied with silicon end-effectors.

Substrate type	Position repeatability	Success rate
Glass	6.18µm	71.4%
Glass + 10nm chromium	1.71µm	58.8%

TABLE II
POSITIONING RESULTS WITH MODULAR GRIPPER AND HYDROPHOBIC COATED STAINLESS STEEL END-EFFECTORS WITH 50µm POLYSTYRENE BALLS

Geometric issues:
Main issues in term of geometry for tweezers-like grippers are dimensions and misalignment. Grippers end-effectors are usually designed in the same size order than the part to be manipulated, mainly to facilitate accessibility and human/computer vision (avoiding shadows). Misalignment between the gripper tips and the substrate, or between the tips themselves can introduce gripping problems (torque is created in case of misaligned end-effectors) and can even lead to a non ability to catch a part.

These misalignments come from manufacturing and assembly inaccuracies or deformations due to strain releases. Three solutions to reduce misalignment problems are available:

Monolithic design: Monolithic gripper, thanks to their manufacturing process (stereolithography, DRIE, chemical etching…) can reach micrometer precision and are of course exempt of assembly errors. Their design and manufacturing process can be time consuming, complicated and expensive. A typical example is the MEMS gripper presented earlier in this paper.

Post-manufacturing alignment: After manufacturing and assembling, the end effectors of the gripper are realigned. Electro-Discharge Machining (EDM) can be used [5] (fig. 7). EDM can also be used to realize specific shapes. Figure 8 shows a 0.5mm thick end effectors reduced to ~40µm.

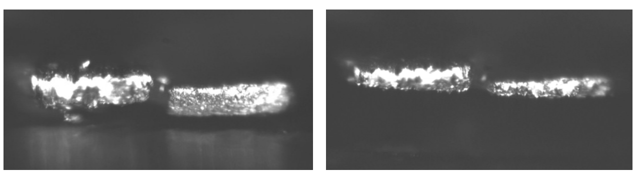

Fig. 7 (left) misaligned 50µm end-effectors, (right) after EDM alignment.

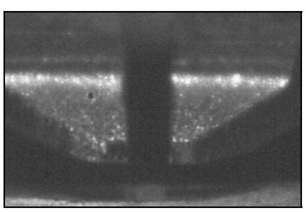

Fig. 8 Reduction of the end-effectors thickness from 0.5mm to ~40µm.

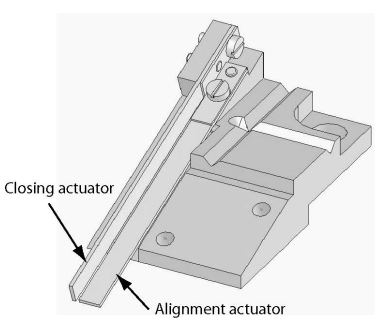

Fig. 9 Micro tweezers with two degrees of freedom: actuation and alignment correction based piezoelectric bimorphs.

Addition of degree of freedom: To reduce the misalignment some degrees of freedoms are added to the gripper. The misalignment can then be actively controlled and corrected. Such a solution can be found in [3]. At LSRO, a gripper prototype based on two piezo bimorph actuators (one actuator for closing, one for alignment) is actually under test (figure 9).

B. Silicon fingers

Thin silicon tips were mounted on the gripper basis (fig. 10). They are 12µm thickness and fabricated by DRIE [6]. Experiments were first conducted by modifying the glass substrate with a hydrophobic coating. The same procedure is again used for the repeatability measurement. Table III shows the results. As expected the presence of hydrophobic coating on the substrate induces a worst positioning due to the lack of adhesive effect on the substrate. As the stiffness of the fingers is quite low it appears a small deformation at the closure, limiting the grasping force to some point, but inducing also at the opening a lateral force on the part laying on the substrate. Depending on the adhesion to the substrate, this force perturbs the final position of the part.

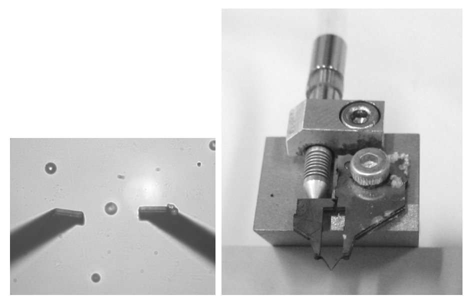

Fig. 10 (left) microscope view of the silicon tips; (right) modular micro gripper with silicon tips.

Substrate type	Position repeatability	Success rate
Glass	2.38µm	91%
Glass + hydrophobic coating	6.94µm	93%

TABLE III
POSITIONING RESULTS WITH SILICON TIPS FOR THE CASE OF GLASS SUBSTRATE WITH AND WITHOUT HYDROPHOBIC COATING

The same effect can be observed on a glass substrate when the relative humidity is lowered (table IV). However when manipulating on a hydrophobic coated glass substrate, position repeatability stays quite stable coming from 6.94µm at 44% to 5.95µm at 3% relative humidity.

Relative humidity	Position repeatability	Success rate
44 ± 3 %	2.38µm	91%
22 ± 2 %	4.09µm	89%
3 ± 1 %	4.47µm	76%

TABLE IV
POSITIONING RESULTS WITH SILICON TIPS WITH RELATIVE HUMIDITY OF 3%, 22% AND 44% ON A GLASS SUBSTRATE

Choices of the best assembled grippers have had to be done of course before experimentation and as 50µm balls were manipulated with tips of only 12µm, the misalignment starts to be a very problematic issue. Moreover smaller parts like thin slides of silicon of 8µm in thickness were also impossible to catch because the tips were crossing themselves due to the lack of stiffness and the error of alignment.

VII. MAIN ISSUES OF MANIPULATION TASKS WITH TWEEZERS

Based on the manipulation experiments several issues were observed concerning the reliability of a precise positioning:

- *Grasping force:* a force applied on a micro object creates a local deformation of the part, increasing the adhesion force [7]. The grasping force should then be limited to the minimum. A calibrated actuator or force sensor can be used. Other method can be the integration of a passive elastic element that limits the force exerted on the part. In every case the detection of the contact (through the visual system or a force sensor) between tip and object is an important issue that defines the minimum grasping force.
- *Quality of the contact surface:* the roughness plays an important role to decrease the adhesive effect [8], as well as the area of the contact and its shape. The quality of the contact surface is also matter of detection performance.
- *Accessibility:* the end-effectors have to be adapted to the shape and especially to the size of the micro components to not crush parts all around and also for visual detection performance (shadow effects). It has so to be in the same size order than the micro part to be manipulated.
- *Finger tips alignment and perpendicularity:* The positioning of the part is dependant of all forces and torques induced by the finger tips. Misalignment of the finger tips induces torque on the micro object or even impossibility to catch. Error in the perpendicularity between contact surface and substrate and between the two tips becomes also a sensitive parameter when looking for high positioning capability.
- *Stiffness:* a lack of stiffness at the finger tips provokes an uncertainty in the final position of the tip and can induce a reflexive force at the gripper opening. A stiff and fixed finger tip should be used as mechanical reference.

VIII. CONCLUSION

Experiments were performed with two kinds of gripper in different configurations. Issues as geometric consideration, grasping force and contact surface have been discussed. Results for the MEMS micro gripper show a high reliability achieving about 90% of success rate and positioning repeatability under the micrometer. Despite it is very fragile, fine resolution of actuator as well as high quality of the contact area showed to be of high interest to control the pick and release operations. Modular micro gripper has shown a great interest for assembly operation as finger tip can be easily adapted to the part specifications. Mainly because too high grasping force and worst quality of the interface positioning performances are lower than MEMS micro gripper but still usable for assembly process with positioning repeatability under 5µm. With silicon end-effectors however positioning repeatability of 2.4µm was achieved despite the low stiffness of the fingers.

Automated manipulation and assembly tasks that could occur in a microfactory for instance would need tools adapted to a range of micro components. The manipulation of cubic parts is thus necessary as this change of shape will add the problem of orientation. Future experiments will be executed with cubic 50µm parts with structured surfaces to study the influence of roughness and multi contact points.

ACKNOWLEDGMENT

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