Overview of Microgrippers and Micromanipulation Station Based on a MMOC Microgripper

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Abstract—This paper deals with an overview of recent microgrippers. As the end-effectors of micromanipulation systems, microgrippers are crucial point of such systems for their efficiency and their reliability. The performances of current microgrippers are presented and offer a stroke extending from 50 μm to approximately 2 mm and a maximum forces varying from 0.1 mN to 600 mN. Then, micromanipulation system based on a piezoelectric microgripper and a SCARA robot is presented.

Index Terms—micromanipulation, microgripper, micro-robot, piezoelectric, MOC.

I. INTRODUCTION

Pick-and-place tasks are largely widespread operations in the industrial world. These tasks, well controlled for parts of a few millimeters cubes and more, become very delicate when one wishes to handle objects of a few tens to several hundreds of micrometers. Effectively, surface forces become dominating at these scales in comparison with the volumic forces [1], [2]. If certain categories of objects can be handled by processes which proved a good reliability, in particular vacuum grippers for the positioning of electronic components for instance, manipulators with tightened fingers remain universal, intuitive tools for the user and can address a significant part in the resolution of microhandling problems.

Nowadays, various manufacturers propose micropositionning systems having good characteristics, in particular a submicrometric resolution. On the other hand, relatively few microgrippers are available on the market. We listed a great number of prototypes resulting from laboratories and we still note a strong interest of the scientific community for microgrippers. A justified passion because the field of the micromanipulation is far from being dried up and the needs are growing. Indeed, the micromanipulation, i.e. the handling of objects with dimensions from 1 μm to 1 mm, and micro-assembly concern many domains. Among these fields, we can quote:

- the assembly of rigid micromechanical parts such as microgears, optical lenses, microcomponents for the realization of hybrid circuits;
- the handling of samples for testing or characterizing them. Indeed, the characteristics of microparts carried out by microtechnology processes could be different as their counterparts obtained by more traditional processes in a bulk form. When microtechnic parts are produced, it is then necessary to carry out test samples from the same substrate in order to characterize the material thus elaborated;
- the handling of biological cells for medicine or biotechnologies, which is often carried out in liquid medium;
- the surgery for which certain operations require a precision that the human arm can not reach. It is for example the case of the ophthalmic surgery and the neurosurgery.

Section II gives an overview of microgrippers from research institutes and also from the market. Then, section III presents micromanipulations carried out with a station based on a MMOC Microgripper (Microprehensile Micro-robot On Chip) and a SCARA robot.

II. TWO-FINGERED MICROGRIPPER OVERVIEW

We list several tens of microgrippers, mainly prototypes resulting from laboratories (see Table I). We also mention some commercial microgrippers whose offer is growing up (see Table II). Nevertheless, all of these achievements are rather different the ones from the others which we classify in the following lines according to the principle of actuation used. Among these principles, we can quote microgrippers actuated by: electrostatic force, thermal effect, magnetic principle, shape memory alloys, fluidic principle, piezoelectric ceramics.

A. Microgrippers from research institutes

1) Electrostatic microgrippers: all these devices use the Coulomb forces present between two charged plates, subject to a difference of potential. In all cases, the system tends to maximize the capacity. However, there are several manners to generate and to use the electrostatic forces. We listed three types of actuation structures made up of:

- two plane surfaces: [3] proposes a structure made up of two tungsten beams (200μm long) offering a stroke of 6μm within bistable operation; [4] uses a structure obtained by deployment of two polysilicon plates designed to integrate the electrostatic actuator, the spring
beams and the finger tips of the gripper. The initial gap between the fingers is 100 μm and a controller, which introduces a limit voltage of “pull-in” dependent on the current position, allows a residual spacing between the tips of the gripper of 10 μm for hundred Volts. The author gives a delay time of 500 μs to close the gripper and a gripping force of 50 μN; 

- **interdigitated comb-drives**: [5] proposes a device in polysilicon. The performances of this microgripper addresses the handling of very small objects since the amplitude of opening-and-close of the fingers reaches 10 μm and generates a force of 104 nN at 50 V;

- **scratch drive actuators (SDA)**: for instance, sixteen SDA elementary actuators equip the polysilicon microgripper in [6]. They are able to move fifty micrometers and to generate 800 μm at the gripper’s tip.

2) **Thermal microgrippers**: the microgrippers actuated by this principle exploit a dissymmetry which we can be dissociate in two categories:

- **a dissymmetry relating to the thermal properties of two materials**: in other words, this principle consists of a bimorph effect of a bi-material to obtain a deflection at the end of two beams which composed the microgripper. The heating process is generally obtained by Joule effect through the conductive alloy. The principle generally exploited to heat up the SMA is Joule effect caused by an electrical current directly through the conductive alloy.

The stroke of these microgrippers starts from 110 μm for the smallest one [17], and can reach 2.5 mm for the largest one [13]. The generated forces are of a few tens of milli-Newton: more precisely, 20 mN for [22] and 40 mN for [17]. These grippers, based on a thermal phase transformation, are rather slow: [14] gives a time of 1.75 s to pick an object and 4.5 s to place it; [15] points out an open-and-close time of 1 s.

- **monolithic grippers**: “monolithic” because they integrate the electrical structure, actuators, flexible joints and finger tips in the same SMA material.
A gripper based on a double memory effect is presented by [19]. The open-and-close amplitude of the gripper reaches 150 \( \mu \text{m} \). The same author also proposes a monolithic gripper made up of an actuator locally heated and a return spring. An originality of this device is its heating mode which is obtained by a laser beam pointed on the zone of actuation.

Concerning the manufacture techniques of these monolithic grippers, a technique usually used consists in cutting out the structure by EDM in fine Ni-Ti alloy plates.

- **Compliant structure actuated in an antagonistic way by SMA**: antagonistic structures are proposed by [18] and [20]. These structures are also called "differential" or "push-pull": an actuator is used for closing the fingers and a second for the opening. The actuators use the one-way memory effect material and the flexible joints of the structure exploit the super-elasticity of shape memory alloys, which has an elastic strain much more important than metals and have a better stability in time than polymers (in particular concerning the creep). This type of differential structure also has the advantage of accelerating the open-and-close time: it is of 0.5 s for [18] and 332 ms for [20] (i.e. 32 ms for the opening and 300 ms for closing, which corresponds to the cooling phase).

Ref. [21] presents a monolithic and antagonistic prototype of microgripper founded on a localised shape memory effect. The latter is obtained by an adequate heat treatment (by laser) of a zone which one wishes to make active. Thus, an electrical current undergoes a higher temperature in the whole structure but only the treated and pre-stressed zone tends to return to its memorized form and generates a force useful for the movement of the structure.

5) **Fluidic microgrippers**: these grippers exploit the pressure of a fluid to generate the deformation of flexible parts which allows the opening and the closing of the fingers. This actuation principle which gives a great density of energy, makes possible to consider large deformations and important forces. We classify the prototypes according to the nature of the fluid used, a gas or a liquid that conduct to:

- **Pneumatic grippers**: the pressurized gas is, in the presented example, the air. Ref. [23] uses a conventional piston to actuate a deformable four-links structure ensuring parallel open-and-close of the fingers. The mechanism, made out of aluminium, is machined by conventional techniques. This device allows a stroke of 1200 \( \mu \text{m} \) for a pressure of 1 Bar and a gripping force of 1400 mN for 2 Bar.

Ref. [15] presents a monolithic push-pull configuration microgripper made up of two pistons, one for the opening and the other for closing, and of a flexible four-links structure to amplify the parallel movements of the fingers. All these elements are made by microtechnologies either in silicon by Reactive Ion Etching (RIE) or in a resin (SU8) by a UV Deep Lithography process. This gripper offers stroke of 600 \( \mu \text{m} \) and a blocking force of 10 mN for a pressure of 120 mBar. The dynamic behavior is quite good since the authors point out an amplitude of the finger motions of 500 \( \mu \text{m} \) at a frequency of 150 Hz.

- **Hydraulic grippers**: [24] presents a prototype using an hydraulic principle with mercury as the fluid. The displacement of the piston is generated in this case by a rise in temperature of the fluid in a deformable chamber. The heating is obtained by the means of a laser source on an interface in contact with the mercury fluid. The actuator thus made up deforms a final acrylic resin body.

6) **Piezoelectric microgrippers**: the abundant literature dealing with piezoelectric microgrippers attests that piezo-electricity is one of the most used actuation principle. Indeed, piezoelectricity offers considerable advantages: a great speed and overall a high resolution. Very early in comparison with the needs in micromanipulation, we can quote the patent described in [38] who proposes in 1986 a structure with two fingers made up of piezoelectric polymer bimorphs. The main existing prototypes were classified in three categories, according to their structure of actuation:

- **Grippers with compliant structure deformed by a piezoelectric actuator**: the majority of the authors use commercial piezoelectric stack [25], [26], [31], [29], [27], [30]. Ref. [32] and [11] exploit transverse strains of a piezoelectric blade. These strains are then amplified, typically by a coefficient of 20 up to 50, in order to obtain significant displacements at the end of the finger tips of a few tens of micrometers to several hundreds of micrometers. The microgripper described in [11] offers a stroke of 60 \( \mu \text{m} \) whereas the prototypes given in [26] and [30] reach the millimetre of excursion.

Whereas the deformations are amplified, the gripping forces are largely reduced compared to the force generated by the actuator. The range of the gripping force varies from 8 mN for [25] to 600 mN for [29], which remains sufficient to handle submillimeter objects.

The amplification systems are often carried out in metallic materials (Ti, Al, Cu, etc.) but can also be out of glass [31] or silicon [32]. An original compliant structure with variable stiffness by actuating a more rigid flexible joint is proposed in [32]. More traditional, the gripper described in [30] uses a compliant structure equipped with a four-link mechanism which allows a parallel open-and-close.

The fabrication techniques are as varied as materials used: the structures either are cut out in plates by conventional techniques, laser machining and EDM, or produced by electroforming [28]; glass is photo-
structured and silicon is machined by microtechnology techniques.

- **grippers made up of piezoelectric bimorphs**: their operating principle is based on the deformation of two beams, mechanically interdependent one of the other, fed by electric fields so that a first blade contracts whereas the other extends thus causing an deflection from the beam. For the fabrication of these grippers, [34] and [35] use commercial piezoelectric bimorphs on which they add steel-stainless finger tips. The gripper of [36] is equipped with two PZT/brass bimorphs whose end of the beams play the part of finger tips. With regard to the performances, the grippers of [34] and [35] respectively reach 400 $\mu$m for a voltage of only 30 V and 600 $\mu$m with 50 V. Lastly, these grippers have a low rigidity but can generate a force of 20 mN.

- **monolithic microgrippers with localized deformations**: in this category we can quote the original realization given in [37], the only one with being completely monolithic among the piezoelectric microgripper. Indeed, it integrates the functions of actuation, amplification and finger tips, the whole carried out in a massive piezoelectric ceramics plate (typically of 0.5 with 1 mm of thickness). Its principle of operation is as follows: distributed electrodes on each face of ceramics are supplied to extend and contract locally a flexible structure by the means of elastic hinges. The structure is studied to obtain a substantial amplification of the movement of the fingers. Concerning its characteristics, its rigid structure makes it possible to obtain forces of hundred milli-Newton and the maximum excursion of the fingers of 36 $\mu$m.

**B. Commercial microgrippers**

Whereas we listed many achievements of microgrippers resulting from research institutes, one can note that there is not a very abundant commercial offer. Probably non-exhaustive list, table II gathers the microgrippers we found on the market.

Among the physical principles used, piezoelectricity obtains a large score with four specimens out of eight:

- PiezoSystem Jena proposes a compliant structure actuated by a piezo stack;
- the gripper principle sold by Kleindiek Nanotechnik and Klocke Nanotechnik consists of contact interaction for coarse movements and of a linear deformation for fine movements. There is a difference between these two achievements: the first manufacturer uses in his applications actuators based on rotary motors and the second on linear motors;
- finally, the gripper “MG-1000” proposed by Preiser Scientific exploits the American patent n° US 4 610 475 [38] which describes a gripper made up of two piezoelectric polymer bimorphs.

<table>
<thead>
<tr>
<th>Actuation principle</th>
<th>Configuration</th>
<th>Firm (country)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>thermal</td>
<td>local expansion of Si compliant structure</td>
<td>MEMS PI (D)</td>
<td>“NMG-S Planar Gripper”</td>
</tr>
<tr>
<td>magnetic</td>
<td>DC micromotor</td>
<td>Preiser Scientific (USA)</td>
<td>“BG-2”</td>
</tr>
<tr>
<td>sync. micromotor</td>
<td></td>
<td>Bartels Microtechnik (D)</td>
<td></td>
</tr>
<tr>
<td>piezoelectric</td>
<td>unimorph</td>
<td>Preiser Scientific (USA)</td>
<td>“MG-1000”</td>
</tr>
<tr>
<td></td>
<td>stack</td>
<td>PiezoSystem Jena (D)</td>
<td>“S-805-00”</td>
</tr>
<tr>
<td></td>
<td>“stick-slip” and linear deformation</td>
<td>Kleindiek Nanotechnik (D)</td>
<td>“Omega Gripper”</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Klocke Nanotechnik (D)</td>
<td>“NMG-S Planar Gripper”</td>
</tr>
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</table>

The grippers of company MEMS Precision Instrument use the thermal expansion to actuate a compliant structure made in polysilicium or crystalline silicon. These microgrippers, very compact, offer a stroke of 35 $\mu$m and also have a quite large choice of finger tips.

Two more traditional microgrippers use electromagnetic motors. These two products are different by the use of DC motors (and encoders) for gripper “MG-2” from Preiser Scientific whereas Bartel integrates a synchronous micromotor. In both cases, the rotational movement is converted into a linear movement to deform the flexible structure of the gripper.

**C. Conclusion of the overview**

In conclusion, let us compare the performances of the microgrippers with two tightened fingers previously presented. The figure 1 locates all the grippers for which strokes and maximum gripping forces are known. With the exception of two electrostatic grippers, we note that essential offer is located for ranges of maximum stroke extending from 50 $\mu$m to approximately 2 mm and the maximum gripping forces varying from 0.1 mN to 600 mN.

It is not necessary to oppose a category of microgrippers to another. Each structure, each principle of actuation have advantages in a given configuration. However, we note that the majority of the presented microgrippers offer one degree of freedom, namely open/close motion of the fingers or, in the best case, two degrees of freedom when the two fingers are controlled independently. This type of grippers allow to grip, to hold and to release an object. The displacement of the gripper in the workspace is usually ensured by the degrees of freedom of the robot. It then seems interesting to extend the basic functionalities of a microgripper (grip, hold and release) towards new functionalities like the orientation of an object between the finger tips of the gripper.
III. A MICROMANIPULATION SYSTEM

A. The four DOF MMOC microgripper

The devised prototype MMOC is encapsulated in a compact case. On Fig. 2, the actuators - two piezoelectric bimorphs whose dimensions are 13 mm long, 1 mm wide and 0.4 mm thick - are integrated in a LEMO® connector - 43 mm long and 12 mm in diameter - from which emerges the useful parts, i.e. the finger tips - 12 mm long and 0.2 mm thick - that are in contact with the manipulated objects.

The performances of such a microgripper (MMOC) are the following:

- the measured strokes of open/close motions and up/down motions are respectively 320 µm and 400 µm for 100 V;
- the estimated blocking forces on each end-effectors tips are 55 mN in gripping (open/close) and 10 mN in insertion (up/down) for 100 V. These estimations were obtained using a finite element modelling;
- the measured resonance frequencies are 1070 Hz for gripping motion and 450 Hz for up-and-down motion.

The geometry of the finger tips can be adapted to the shape of the objects to manipulate, and their material to the required application. The left part of Fig. 2 presents several of those finger tips, made of Nickel, obtained with LIGA machining. A micro-tools exchanger has also been developed in order to automatically change the finger tips using the same actuator [39].

In summary, the important features of this new microgripper are the number of mobilities, the easy adaptation of the finger tips to the need, the easy plug-and-remove using a standard packaging, and then the easy integration in systems such as a manipulation station. Our microgripper is compared to the overview in Fig. 1.

B. The RP-1AH industrial Robot

The RP-1AH is an ultra compact SCARA robot with a deforming parallelogram architecture (see Fig. 3). The main specifications are as follow:

- a repeatability of ±5 µm in X and Y direction, ±10 µm in Z direction and ±0.02 ° in θ axis;
- a high speed operation: a cycle time of 0.28 s (100 mm per 25 mm);
- a motion range of 150 mm in width (B), 105 mm in depth (A) and 30 mm in height (E). This area is equivalent to A5 size.

C. The micromanipulation station

The hardware of this station (Fig. 4) is composed of:

- an industrial RP-1AH robot;
- the MMOC gripper with its high voltage interface;
- a PC computer equipped with a National Instruments card (PCI-6733) to drive the microgripper, and with a serial RS-232C port to communicate with the robot;
- several compliant tables giving secure workspaces to avoid damages of the microgripper;
- vision systems based on two cameras (above and side view) with a video monitor which allows a visual feedback.

The software architecture is based on two master-slave applications. The slave program running on the robot controller waits for commands transmitted from the master application. The latter, developed using Labview® 7.1 NI, transmits informations required by the robot controller and the microgripper and offers to the operator the following functionalities:

- the calibration of the station, carried out only once, allows an easier programming of the robot trajectories.
and prevent collisions between the microgripper and its environment. To carry out that, two stages are necessary: to determine the tool transform related to the microgripper and to determine the compliant table reference frames.

- the teleoperated micromanipulation: this operating mode allows the operator, via the keyboard and a graphical interface, to control incremental displacements of the robot, in translation according to its xyz axes and rotation $\theta$ around $z$ axis, as well as the microgripper, in open-and-close and up-and-down of the fingers.
- the automatic positioning of objects: this mode allows, once an object is picked by the microgripper, to position it in an automatic way.

Fig. 4. The micromanipulation station.

D. micromanipulation experiments

We have used the micromanipulation station to achieve a complete calibration setup in order to perform teleoperated micromanipulations and automatic placements of submillimetric objects. All the experiments reported in these columns concern the micromanipulation of cubic microparts that measure 100 to 700 $\mu$m in side. Some pictures, extracted from a video sequence, illustrate the functionalities of the micromanipulation station (see Fig. 5 and 6).

First, the left picture of Fig. 5 shows the axis calibration of a compliant table. The procedure consists to determine the lower vertical limit $z_0$ reached when the operator detects, by the means of lateral vision, a soft contact on the table with the finger tips of the gripper. This value is thus stored in the robot interface which manage as a new limit to avoid collisions.

The right picture illustrates the acquisition procedure to determine the tool transform. For each acquisition, the reference point, materialized by the center of a sharp needle, must be located at the center of the finger tips of the gripper. Three different robot locations are needed to compute the tool transform. Once this calibration transferred to the robot interface, the displacement and the rotation are referred to the end of the tool, i.e. the middle end of the finger tips for our MMOC microgripper.

Fig. 5. Axis calibration of a compliant table and tool transform calibration.

The automatic mode is illustrated on Fig. 6. Starting from the top-left picture, i.e. a cube is already selected and hold between the finger tips of the gripper, the robot automatically goes to the second working table to place the object at the first programmed position. It comes back to allow the user the selection of an other cube and to place the object to the second programmed position. Then, the procedure can be repeated until filling up the sequence that consist to perform, here, a circular placement on the table as shown on the last picture.

Fig. 6. Teleoperated selection of cubes to perform an automated circular placement of these micro-objects.

IV. CONCLUSION

While the end-effectors are a crucial point of micromanipulation systems, the present overview allowed to show the great interest to solve micromanipulation problems using two-fingered microgrippers with various approaches and actuation principles in order to propose efficient and reliable tools. We presented also a four DOF microgripper installed on a SCARA robot to obtain a semi-automatic micromanipulation station. Teleoperated micromanipulations and automatic positioning tasks were successfully carried out. In the future, in order to have a fully automatic micromanipulation station we need to implement pattern recognition with standardized objects and force sensing to avoid damages of the handled micro-objects and of the finger tips. For that, the repeatability and the accuracy of the global system have to be measured. The integration of a micro-tool exchanger would make the station flexible.