IN SITU MICRO GRIPPER SHAPING BY ELECTRO DISCHARGE MACHINING

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Introduction

Bio technologies, electronic components, MEMS or watch industry require handling and positioning of ever smaller micro-parts (ten to hundred µm size). Several tools used for such tasks, called micro-grippers have been developed based on different catching and releasing principles. Vacuum grippers are mainly used in the macro world and have been successfully downsized to fulfill micro-world applications. Magnetic [1] and electrostatic [2] grippers have been also developed. Capillarity effects can also be used in order to manipulate macro- and micro-parts as presented in [3].
The oldest and simplest gripping tool is based on the grasping principle, reproducing the human hand gripping ability: two fingers are moving following a linear or curve translation in a plane, called here grasping plane, and when close enough of each other they allow tightening and holding a part. The downsizing of pliers like tweezers would lead us to use these friction-based gripping tools for micromanipulation. Furthermore they are already largely used for precise manipulation tasks in bio or medical applications for instance.

The manipulation conditions and environment are also critical for the caught micro-parts. Microsystems and micro-assemblies are generally fragile, sensitive to dusts and other contamination particles. Thus, the manufacturing and handling of micro-parts must be generally done in a clean room atmosphere. As micro-parts are getting ever smaller, manipulation tools must be downsized. Manufacturing means could also be downsized. In particular, clean room volumes can be decreased, in order to reduce costs. The impact of the operators in term of contamination can be cancelled if they can be brought out of the clean area. A microfactory concept and realization has been presented in [4].

Design issues and solutions in micro grippers

In order to manage a correct catch of a micron sized part to be manipulated a gripper must fulfill basic requirements such as tip geometry, stroke, catching force. Among the many gripping principles that could be investigated, only finger based grippers will be discussed in this paper.

Catching force, in finger based grippers called grasping force, creates due to friction a force which counterbalances the adhesions forces between the part to be manipulated and the medium were it is laid, called here the substrate. Forces values ranges are as low as 10 µN. Such low forces are difficult to reach and a larger gripping force can damage the part or make the part stick on the gripper: due to a local deformation of the part the contact area is enlarged and the adhesion forces are increased leading to the impossibility to release the part.
Stroke is determined by design. Depending on the manufacturing process of the gripper, a trade-off often appears between force and/or closing resolution and stroke. A large stroke has the advantage of providing a large flexibility, i.e. enabling to grip micro-parts with several sizes.
In term of *geometry*, the main issues are dimensions and misalignment. In most cases, grippers are designed to have the dimensions of their end-effectors in the same size order than the part to be manipulated. With this property fulfilled, it is easier to catch micro-parts and track them by vision (human or computer based) rather than with disproportionate end-effectors.

Misalignment can occur between the grasping plane and the substrate as shown in figure 1. This case could lead to a non ability to catch a part: the gripper is already touching the substrate whereas the part is still not situated in the gasping plane.

Misalignment can occur also between the fingers themselves. In this case, the fingers are not actuated in a same plane. This can introduce a torque on the caught part, which could be problematic, as the closing forces are shifted. A higher misalignment can lead to the non ability of catching parts, a finger touching the substrate whereas the second closes over the part or even the fingers are crossing over each other (figure 2).

These misalignments can come from manufacturing inaccuracies or deformations due to strain releases. In the case of discrete elements based grippers (assembled grippers) the assembly process can add misalignments errors.

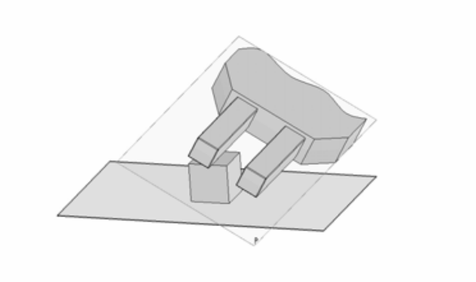

Figure 1: Gripping plane and substrate misaligned

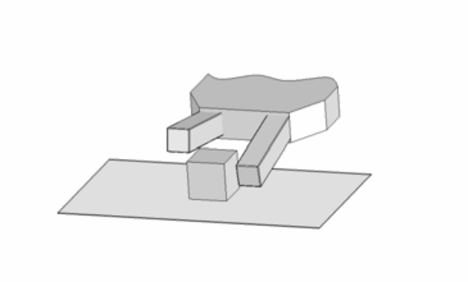

Figure 2: Gripper fingers misaligned

Three solutions to reduce misalignment problems are discussed further: monolithic design, addition of degree of freedom, post-manufacturing alignment.

Monolithic design. Monolithic gripper, i.e. grippers made from a single manufacturing run can fulfill alignment requirements: They are of course exempt of assembly errors and their manufacturing process (stereolithography, DRIE, chemical etching…) can reach micrometer precision. A classical application is silicon MEMS micro-grippers. Commercial devices are already available [5].

As a counterpart they have to embed all functional features like actuating or force sensing. Their design and manufacturing process can be time consuming, complicated and expensive. Obviously, they can not offer a large flexibility in comparison to a gripper constituted of discrete elements in term of features as it is difficult or even impossible to change their sensors and actuators. Their design need to be fitted to a particular application and any change requires a complete new manufacturing run. Their fragility and yield rate can also be an issue.

Addition of degree of freedom. Micro grippers based on the tweezers principle have mainly one degree of freedom (d.o.f.) only acting in the grasping plane. A solution to reduce misalignment is to add a degree of freedom in a direction perpendicular to the grasping plane. In this case the misalignment can be actively controlled and corrected. Monolithic or Discrete Elements Based (DEB) designs can be used. This solution remains more complicated than a simple in-plane gripper, as a measurement of the alignment error needs to be done. Such a solution can be found in [6].

Post-manufacturing alignment. Another solution to reduce misalignment is to realign the device after its manufacturing process. This procedure can also be applied to monolithic grippers, but gets its main advantage with discrete elements based grippers. In this scenario, a micro gripper is roughly manufactured, assembled with commercially available parts (micro actuators, sensors) and finally micro-machined in order to realign its end effectors.

Micro manipulation stations and macro- and micro-machine tools are mainly equipped with a 3 d.o.f. (or more) robot. Then one can think to use the micro manipulation station to realize the post-assembly alignment machining: Movements needed for the machining (machining trajectories, wear compensation, EDM gap control) are provided by the manipulator itself, no additional machine tool is required. After the alignment process, the gripper can be used for the manipulation process directly: no dismantling has occurred between the fabrication of the gripper and its use, leading particularly to a perfect alignment of the gripper and the manipulation setup, excepting the intrinsic setup errors: manipulator, positioning of substrates. That is what we called "in-situ machining". Next chapter will present the implementation of this concept by means of electro-discharge machining. Table 1 summarizes advantages and drawbacks of discussed grippers.

	Alignment issues	Flexibility	Cost
Monolithic gripper	Good	Poor	High
Multiple d.o.f gripper	Good	Average	High
Disrete elements gripper	Poor	Good	Low

Table 1

DEB LSRO flexible and low cost gripper

A low-cost gripper has been developed in the Laboratoire de Systèmes Robotiques (LSRO) and is presented in figures 3 & 4. The gripper is made out of a base plate, 0.5 mm thick steel, laser cut. It contains the articulation to allow the opening/closing movement of the fingers. On this base plate are glued the end effectors. They are made of 20 or 50 µm thick stainless steel, laser or wire-EDM cut. The base plate is fixed on a gripper holder, which will be the interface between the manipulator and the tweezers. This interface includes pneumatic bellow as grasping actuator. It could also embed other features (force, torque sensors…), allowing a large flexibility.

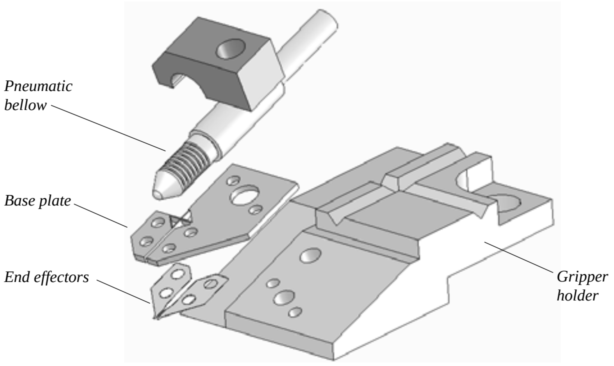

Figure 3: LSRO gripper 3D-CAD exploded view

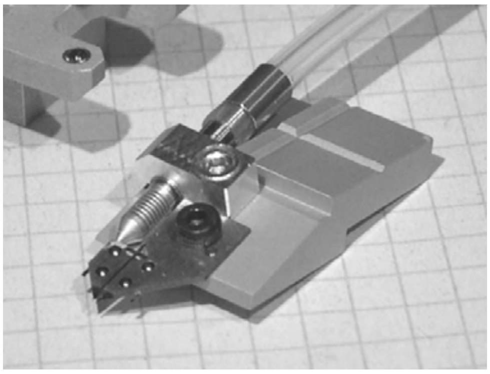

Figure 4: LSRO gripper

EDM and manipulation setup

In the experimental setup (figure 5) a 3 d.o.f. high precision robot developed in our laboratory [7], called Delta^3, is used as a micro-manipulation [8] station and a micro-electrodischarge machine [9]. Its articulations are made with flexible hinges allowing frictionless and linear motions. The robot is actuated with moving magnets actuators and controlled with 5nm resolution non contact linear encoders. These features allow the system to reach a repeatability of 10nm. Due to its Delta [10] parallel kinematic design and its actuators, its bandwidth reaches 400 Hz. This high dynamic feature will allow us to increase the EDM efficiency and quality as demonstrated in [11]. For example, controlled sine motions can be applied along the axes, with frequencies up to 100 Hz and amplitude from 1 to 10 µm increasing the washing and the evacuation of the eroded particles for a better efficiency. During the EDM process the robot is controlled by an AGIE SIT-B controller which includes the sparks generator. It can be programmed with a PC through a Labview Graphical User Interface. In the presented experiments, EDM voltage was set from 80 to 130 Volts.

During a micromanipulation process parts are laid on a manipulation substrate under a microscope. In order to align the gripper bottom in respect with this substrate, flat copper electrodes are disposed parallel to the manipulation substrate. Dielectric (distillated water) is brought by a syringe needle; contaminated water is evacuated through absorbing fabric.

Figure 5: Experimental setup

Gripper machining

DEB LSRO Gripper alignment.

LSRO grippers with 20 µm thick end effectors and a misalignment of about 5 µm have been realigned. After machining, the thickness of the thinner finger was reduced to about 12 µm. Grippers with 50 µm thick end effectors and a misalignment of about 15 µm (figure 6) have also been realigned. After machining, the thickness of the thinner finger was reduced to about 25 µm, as shown in figure 7. The process longs about 2 min for each gripper.

Figure 6: misaligned 50 µm end-effectors

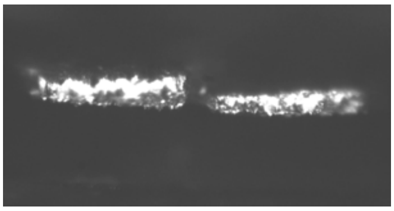

Figure 7: EDM-aligned 50 µm end-effectors

Monolithic LSRO gripper shaping

More than machine only the bottom of a DEB gripper, a complete shape could be produced in situ. As an evolution of the gripper presented earlier no end effectors are fixed but the tip of the base plate will be directly machined in order to provide end-effectors. In that case, the bottom of the gripper is aligned with the previously presented method (figure 8). Then, the top of the base plate is machined in order to reduce the gripper tip thickness to the same order of size of the dimension of the parts to manipulate. The top of the gripper is machined on an electrode overhanging the tip of the base plate, which is machined while the robot goes up (figure 9). Gripper thickness has been reduced to 40 µm from 0.5mm. The process longs about 10 mins. Previous/after machining pictures are presented in figure 10.

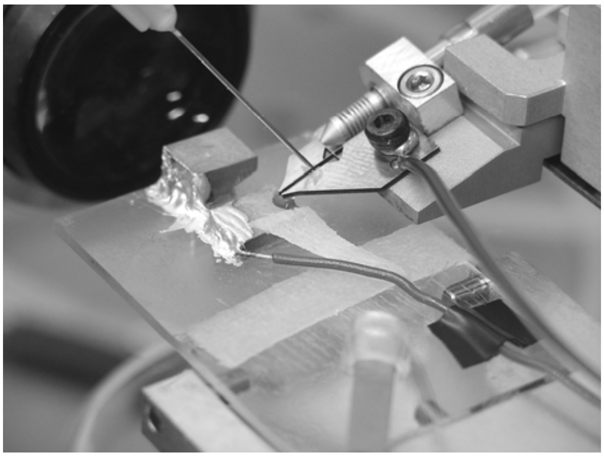

Figure 8: EDM of gripper bottom

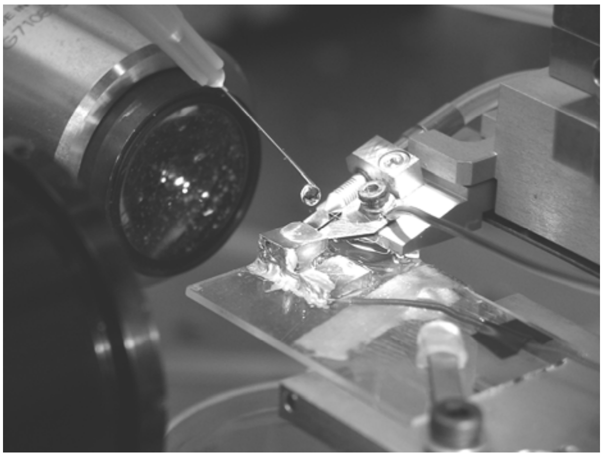

Figure 9: EDM of gripper top

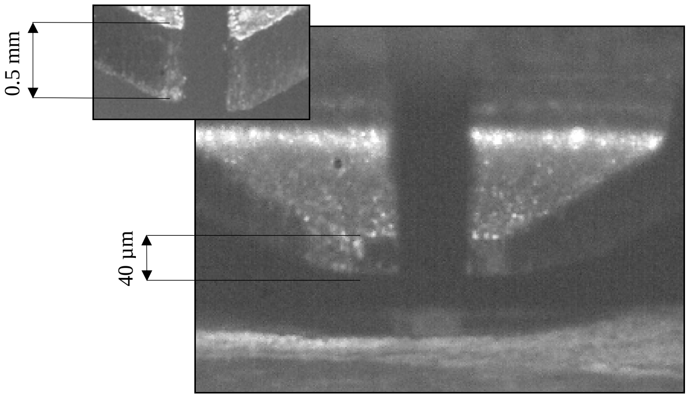

Figure 10: EDM shaped end-effectors

Shaped grippers for specific applications

In the case of an application requiring a gripper with a specific shape, different electrodes can be designed in order to realize complex profiles on grippers, on all sides. For example, a grove can be machined with a thin steel plate electrode. In the case of a one moving finger/one fixed finger gripper, this can be used to fully and accurately control the placement of the part inside the gripper.
Figure 11 presents bottom and side views of such a machining that has been realized on a 0.5 mm thick monolithic LSRO gripper. One can think also to create specific housings in grippers with electrodes of the shape of the part to manipulate. Moreover, any conductive material can be used, enlarging the flexibility of this method.

Micro parts machining

Another application of specific shaped grippers is the electro discharge machining of the micro-parts themselves. During the EDM process, local pressures, dielectric flow, electrical tension and currents apply forces between the electrode and the part. For example a resistive force of 500 mN has been measured in [11] during the drill of a micro hole with an Ø149 µm electrode. Most of the time, these forces are neglected for a standard EDM machine in comparison to the weight of the objects. In the case of micro-parts of the size of tenths to hundreds µm tightened in a gripper, these forces can make the part sliding inside the fingers or even ejecting them. Then a grove in the gripper can retain the part vertically (figure 12) and allow a micro-part to be correctly µ-EDMed. With this technique we managed to machine a flat plane on a 200 µm diameter stainless steel ball (figure 13).

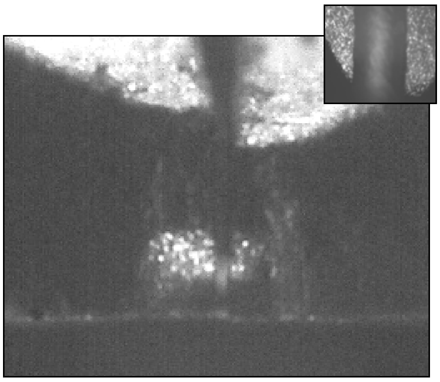

Figure 11: Front and bottom (top right) views of machined grove.

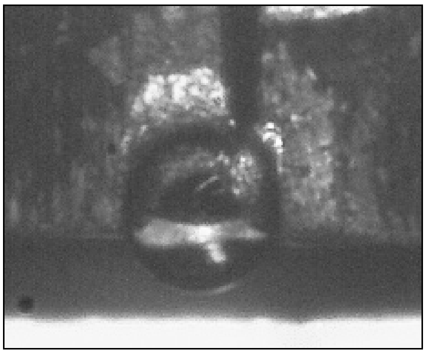

Figure 12: caught Ø200 µm steel ball in the micro-gripper

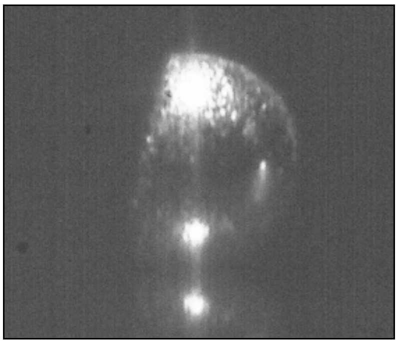

Figure 13: machined Ø200 µm steel ball

EDM micro-factory concept

The association of the in situ gripper shaping process and the ability to machine micron sized parts can introduce an EDM-microfactory concept. The synoptic in figure 14 illustrate this concept and a scenario is presented further:

1. Before a production process, a rough gripper is fixed to the manipulator (a). It is machined in-situ (b), in order to be perfectly aligned and can be shaped specifically for the application, as described in this paper.
2. Then the microfactory is ready for the electro discharge machining of small parts (d) and/or assembly tasks (f).
3. In the case of wear on the gripper, it can be corrected by electro-discharge machining means, or even replaced and quickly re-adapted to the application (a-b). Grippers can even be considered as consumables if they need to be machined with each machined micro-part.

Several issues need to be considered for this microfactory concept.

- In term of cleanliness, eroded particles and polluted dielectric liquid are a source of contamination for the micro parts or micro assemblies and could break cleanliness requirements or compromise microassembly operation. On an aesthetic point of view, evaporation of contaminated liquid will leave drop traces. Thus, a washing step would be needed (e).
- Most micro parts and micro assemblies are provided inside specific containers in cleaned air (c). Common request of a micro factory is to output value added product in such a conditioning (g). Meniscus breaks during air-to-liquid and liquid-to-air transitions create forces which could damage and/or make the part slipping from the gripper. Thus particular gripper shapes or hydrophilic coating, enabling easier water penetration must be considered.

- Presence of distilled water used as dielectric liquid will increase the humidity rate of the micro factory atmosphere. Capillarity sticking effects are increased and can lead to the non-ability to release the part from the gripper. In this case, hydrophobic coatings could be used to reduce the capillarity force. A trade-off appears here and a compromise has to be found as a hydrophilic coating would be used to facilitate liquid penetration.
- In the case of visual controlled micromanipulation or even computer vision based assembling meniscus of liquid will create distortion of images leading to the impossibility to control the robot end-effectors. Optics would have to see trough a transparent container with plane sides, in order to provide a correct vision of the underwater scene. What’s more, different medium (air and water) in the optical way induce a change of the focal length in comparison to the full in-air optical way. Separated underwater-dedicated and in-air-dedicated optics or focal length adaptive systems must be used.

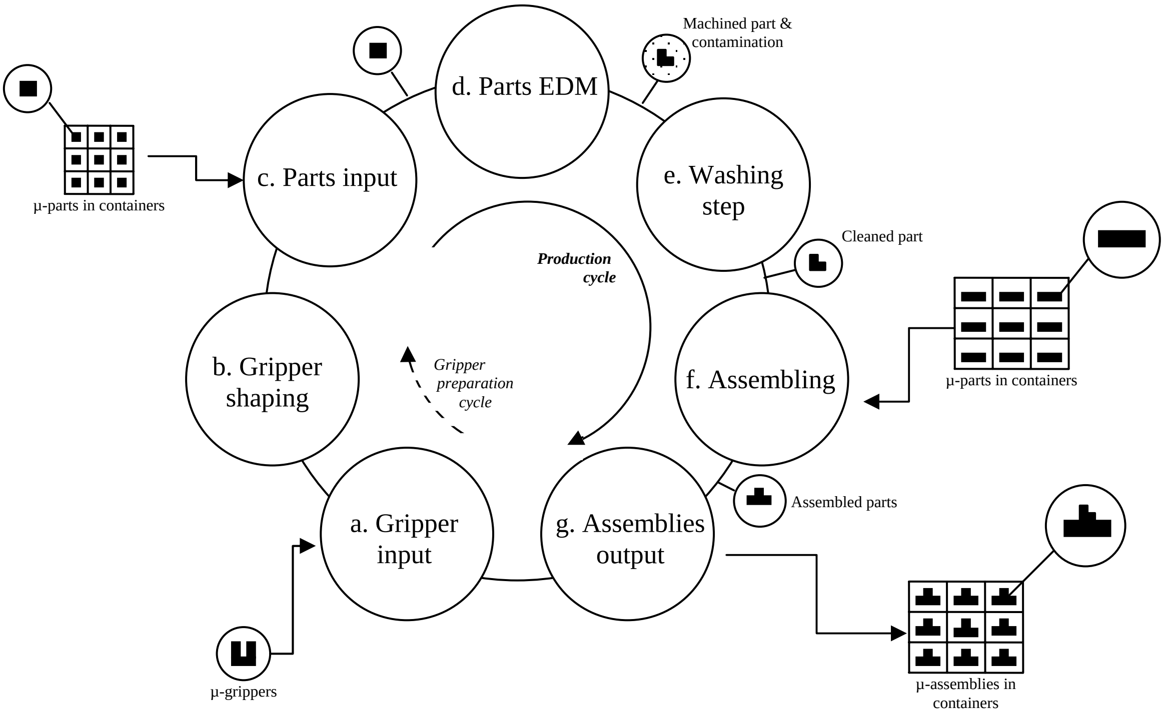

Figure 14: microfactory concept synoptic

Conclusion

We have presented an affordable machining process which could be easily included in a micromanipulation setup in order to create tweezers-like grippers or grippers shaped for a specific application. No additional machining hardware is required, excepting the sparks generator. The micro-grippers will be flexible, low-cost and exempt of misalignment errors in regard to the manipulation setup. We have shown that precise micromachining of micron sized parts or microstructures can be realized with a compact equipment. Thus, a microfactory concept has been introduced, in order to apply the "in-situ machining" technique to an automated and low cost clean-room manufacturing process. Issues for this application have been discussed.

A future work can be the design and construction of an EDM-microfactory demonstrator combining gripper shaping, micro-parts electro-discharge-machining and microassembly.

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