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Modular and re-organizable micromanipulation station

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Abstract : A new concept of microfactory is explored : modular, re-configurable and re-organizable microfactory. The concept is extended inside a station. Each component is observed as a plug-and-actuate elementary module. The basic function of a station is the *pick-and-place* : that offers the possibility of re-organizability. Instead of a microgripper, two independent arms are used in order to work with microparts with a high range of dimension. In the first prototype, each arm moves thanks to a *stick-skid* piezoelectric based microactuator. Its principle is explained and results of simulations are presented.

1 Introduction

To fabricate a product in the macroworld, it is generally necessary to use various types of operations : assembly, drilling, milling, lathing etc. For that, there are different types of lines in a factory through which components must go. In the microworld, this draft has already been found since the first prototype of microfactory. In this world, instead of *line*, the proper term used is *station* or sometimes *microstation*. Nowadays, studies, design and realization concerning a microstation are large : from microassembly (serial or parallel) to microtreatment (microdrilling, laser treatment etc). Nevertheless, design and realization about complete microfactory is not as generalized as microstations. In fact, some stations studied independently may be placed on a plate-form to create a microfactory but that sometimes necessitates a long preparation (make suit the data between the stations, the reference used etc). Thus, modular microfactory is born : each station behaves like a plug-and-produce module. In [1], a modular microfactory is proposed. Each station is considered as a module so that it is possible to add, change or remove one of it in case of panne of station or in order to increase the productivity. The microfactory is then called re-configurable.

In our approach, the level of modularity applied to the microfactory is not sufficient to be at the level of the microproduction market. Thus, the approach proposed in "Microfactory Project" [4][5] at the LAB is to extend this concept inside a station so that the tools and microsystems behave themselves like modules working in cooperation to accomplish a task (Figure 1). In this project, the station must also be re-organizable.

This paper describes the principle of a station under design at the LAB. Modularity and re-organizability concepts are discussed in the first section. Thus, the system is presented and the first prototype, currently in realization, is explained. At end, results of simulation are discussed.

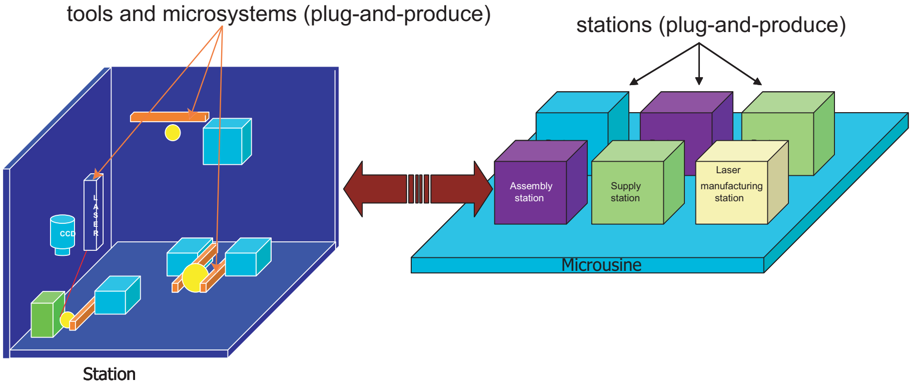

Fig. 1 – The concept of modularity is not only applied to the stations but also to the tools and microsystems inside a station.

2 Modularity and re-organisability of a station

Inside a station, each tool and sub-system is considered as a module. Whatever the type of module is (eg. direct current motor, piezoelectric actuator etc.), they must behave like a plug-and-actuate so that a stock of them may be to tendency (Figure 2-a). Every time an element is plugged, we have only to declare its model inside the controller system (intelligency) (Figure 2-b). Thus, an element in the stock is a pair of module/model.

The notion of re-organizability differs from the re-configurability one in the fact that the first one is on a higher level. A re-configurable station has the possibility to always run even if a module is failed. In fact, due to the modularity, we have only to change this last and the station is once more operational. Likewise, it is possible to increase the productivity in cloning the modules of a station but in that case, we will have created another station. In general, modularity implies re-configurability. On the other hand, the re-organizability is the occurrence to firmly change the function of a station : as example change *microassembly-function* into *microdrilling-function*. This is advantageous in the reason that all the stations in a stock are similar and have a basic function. When inputting them on the microfactory plate-form, a re-organization (function specification) is only sufficient. This is also profitable in the fact that for all the stations on the plate-form, a single type of stock of modules (tools and microsystems) is sufficient.

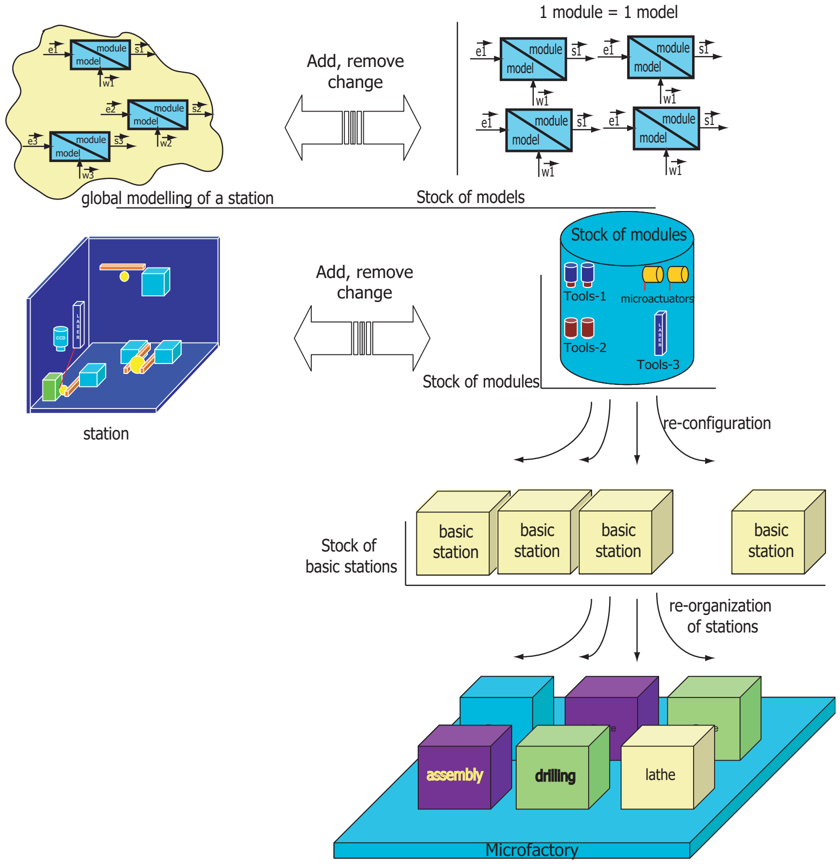

FIG. 2 – Each element inside a station is considered as a module. A model is associated to a module. Removal, placing or change of a module means removal, placing or change of elementary model. Thanks to the re-organizability, only one type of station is in the stock of microfactory stations.

3 Presentation of the studied station

Whatever the function is, beside the positions, the handling force in the microstation must be controlled. A *pick-and-place* principle is used because it offers the possibility of re-organisation. If it offers the possibility to do assembly (serial assembly) (Figure 3-a,b,c), it may be also profitable for treatment. In fact, treatment task is obtained when holding the micropart (position regulation) at a location of treatment and keeping the nominal handling force (force regulation) in considering the force and displacement due to the treatment as perturbations (Figure 3-f). A hybrid automata is used to manage the re-organization of the station.

On the other hand, instead of a microgripper, two independent microarms with end-effectors are used. That makes feasible the manipulation of microparts with high range of dimension (from $10\mu m$ or so up to some millimeters). Each arm has two degrees of freedom (DoF) : linear and angular (Figure 4-a).

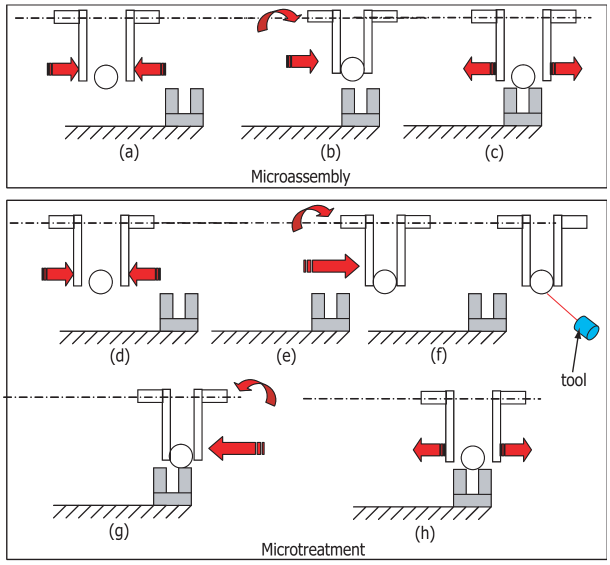

Fig. 3 – Pick-and-place principle with control of the position and the handling force. a-b-c : pick the micropart, transport and place it on another microcomponent to assemble them. d-e : pick the micropart and transport it to a treatment place. f : the system is regulated at the treatment position with a nominal handling force whatever the disturbances due to the task. g-h : return for microassembly or for putting the micropart on a microconveyor.

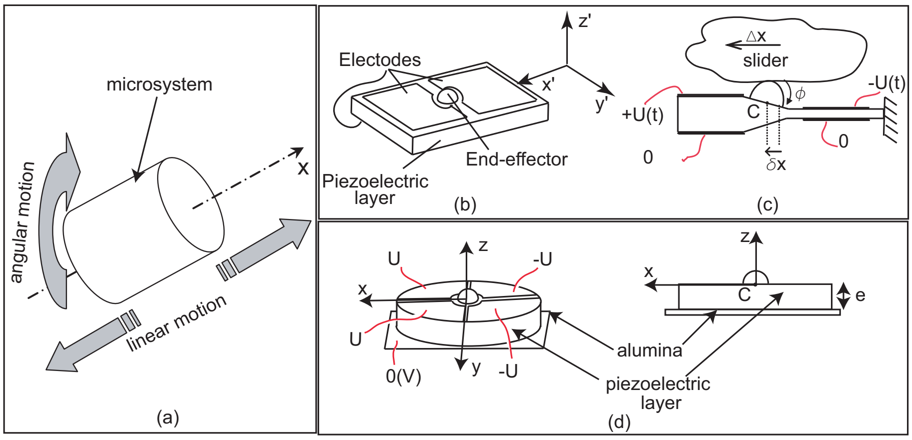

Fig. 4 – a : each arm has two DoF. b : the motions are obtained in using a microactuator proposed in [6]. c : when a voltage is symetrically applied, a displacement δx of C and a rotation ϕ of the hemisphere happen. The slider has then a small displacement. d : 2 DoF is obtained with this configuration of electrods [6].

4 Functioning of a sub-system

4.1 Principle of a microactuator

In our first prototype, under realization, the actuator used to move a sub-system is the one proposed in [6] because of the sub-nanometric precision and the compacity in multi-DoF offered (Figure 4-b). When supplying by two symetric electrical voltages the two electrods, a

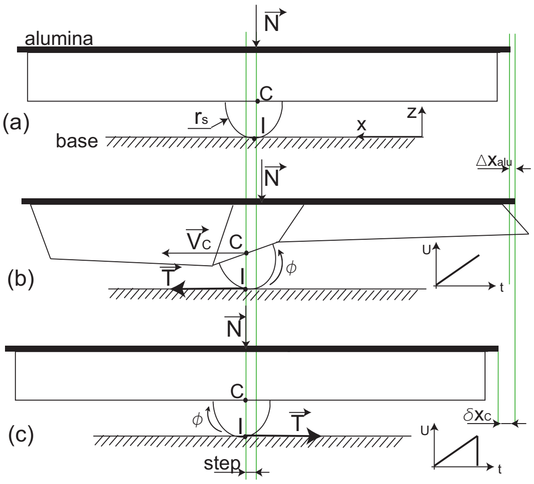

FIG. 5 – Scheme of a microactuator placed on the base (spindle). a : a normal load (radial relative to the spindle) is applyed in order to keep the contact. b : when two symetric voltages with a low slope are applyed to the two electrods, the hemisphere rolls without sliding. c : when the voltages are suddenly removed, the hemisphere skids.

transversal displacement δx of the point C is got and the end-effector (demi-sphere) does a small rotation ϕ around $y^{'}$ axis (Figure 4-c). The final displacement, a step, of the slider would be then : $\Delta x = \delta x + r_s.\phi$, where $\delta x.\phi < 0$. The configuration used in our application is shown in (Figure 4-d) which permits the microactuator have 2DoF (in local reference : along $x^{'}$ and along $y^{'}$). The principle of the motion is as follow :

- when applying slowly two symetric electrical potentials to the two electrods, the hemisphere does a rolling without sliding (stick-phase). The point C does a displacement δx relative to the alumina but this last does $\Delta x_{alu} = \delta x + r_s.\phi$ relative to the base (Figure 5-b),
- when the two voltages are suddenly removed, the hemisphere skids and there is no motion of C relative to the base(Figure 5-c). Instead of "stick-slip", we suggest to call this principle "stick-skid".

4.2 Integration of the microactuators and results of simulation

On a plate of alumina, two of it are placed in order to keep linear statism (Figure 6-a) and three plates are spread out 360° inside a sub-system in order to keep angular statism (Figure 6-b). Placed on a spindle, the whole system can move along 0x axis (x) and rotate around it (θ) (Figure 6-c) step by step. Of course, according to the considered reference, either the spindle (the system is a *linear-angular stepping micromotor*) or the microsystem (the system is a *linear-angular stepping microsystem*) moves.

Assuming that the piezoelectric behaves dynamically like an ordinary second order and using the LuGre model [7] to express the friction law, in [8], we have established a dynamic model of each phase (stick or skid) of each motion (linear angular). The piezoelectric party working equations were approached using Finite-Element-Method. If the input is the voltage U applied to an electrod, the friction T and the linear position x or the angular position θ represent the output variables. The system, strongly non-linear, has been simulated with frequency about

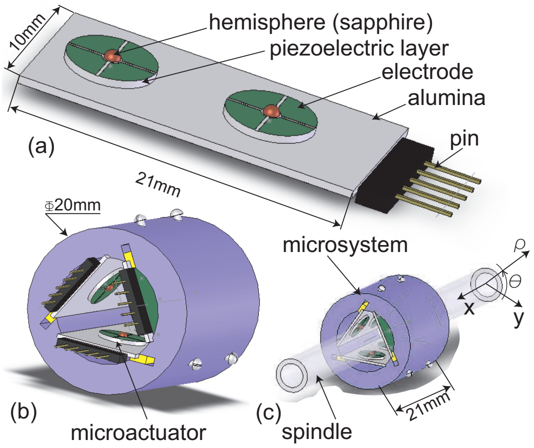

FIG. 6 – Integration of the microactuators inside a sub-system. a : two piezoelectric microactuators are glued on a plate of alumina in order to keep linear statism. b : three plates of microactuators are shared out 360° to have the angular statism. c : the sub-system (arm) can then move along or around the x axis. The spindle used is based on glass.

10kHz (Figure 7). The *skid* phase always generates vibrations which sometimes contain high amplitude overpass. We have therefore added a lull (duration $= t_2$) just after *skid* so that they will have approximately been damped before the *stick* reprise (Figure 7-a).

Theoretically, a step is near $(\frac{1}{1450})^o$ in rotation and near $30nm$ in translation (Figure 7-f and j). With the frequency used in the simulation, the speeds are near $1.15rpm$ and $1.8cm/min$.

5 Conclusion

The concept of microfactory was presented : each station behaves like a *plug-and-produce* module. The microfactory is re-configurable and the stock of stations comprises the same basic stations. Thus, the re-organizability is found inside the station : it is possible to change its function (eg. microassembly into microdrilling). The *pick-and-place* principle corresponds to the basic operation. Microgrippers was not used because of the limited dimension range of the micropart that they can handle. Two independent microarms were then necessary designed. The modularity concept was extended inside a station : each element (arm, tool etc.) behaves like a *plug-and-actuate* module. Any module is associated to a model. Due to the non-linearity of some of them (eg. the model of first prototype), all modelling is expressed in the state-space. Adding, changing or removing an element in the station means adding changing or removing a model in a global modelling.

This paper has described the mainlines of the concept and the method for the "modular and re-organizable micromanipulation station" of the "Microfactory Project" at the LAB.

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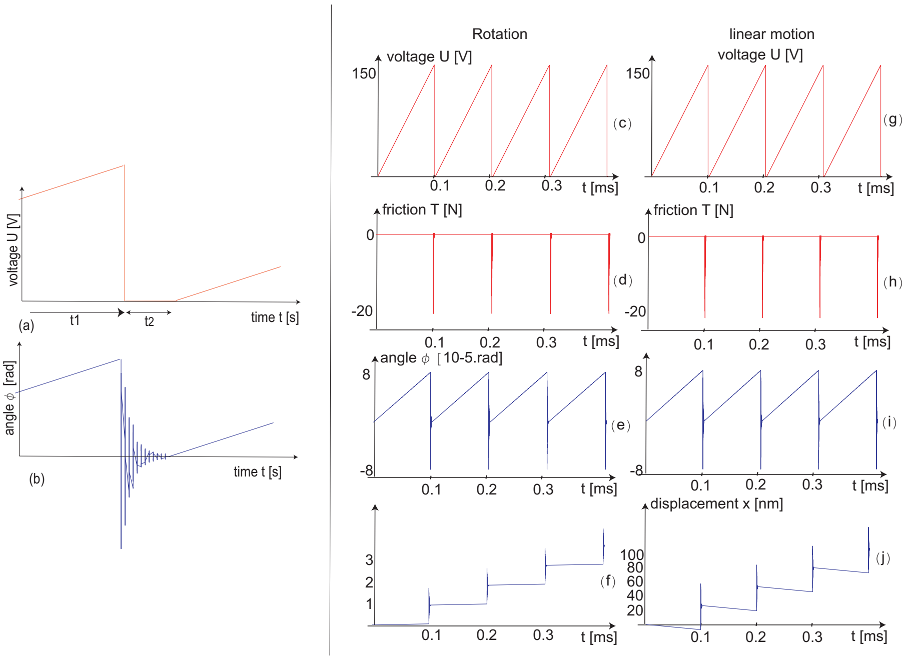

Fig. 7 – a : due to the vibrations just after *skid*, a delay was introduced so that they are pratically damped before the reprise of the *stick*-phase. c and g : evolution of the voltages applied in rotation and translation motion. d and h : evolution of the friction between the hemispheric end-effector and the spindle. When a high slope voltage is applied, the friction suddenly increases and the hemisphere skids. f and j : evolution of the angular and the linear motion.

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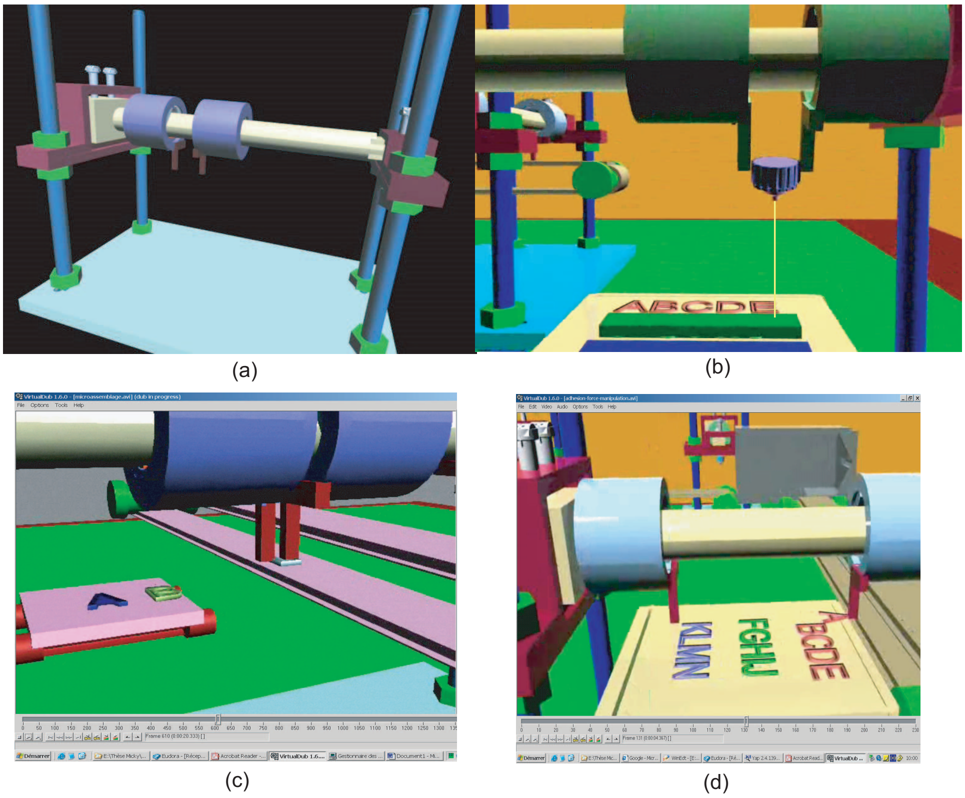

FIG. 8 – a : a station is made up of two independant arms (sub-systems) having each one linear and angular motion possibility. b : instead of carrying the micropart, the station may also transport the tool laser according a trajectory in order to accomplish an imprint on a plate of material. c : here, a microassembly is done, the two arms pick the letters, transport them one by one and place on a plate to realize a display. d : it is also possible to use only one arm to pick-and-place a micropart. The principle is based on the adhesion forces.