Modular Design Method applied to a Micromanipulation Station

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Abstract: A new method for the design of micromanufacturing systems is developed. This method, based on modularity, combines a top-down approach of production systems with a bottom-up approach to take into account the specific constraints of the technologies and know-how in the microworld. To execute an assembly task, we need operative devices and scenario adapted to the manipulation. These elements are encapsulated into a constituent module. For that, we have defined several types of basic modules that depend on to the technology support.

The proposed strategy allows many possibilities of operative architecture to assemble different types of product and to exchange the different modules when the results of the micromanipulation are not satisfactory. Thus, when the failure rate is too high, it is possible to change the actuator or to modify the control strategy or to include an additional element.

This paper reports the proposed concept, presents its application to a micromanipulation station developed in our research group. The station is composed of two microrobots which work in cooperation to execute pick-and-place sequences of parts measuring between 200 µm to 500 µm. The performance criterion is focused on the success of the operation in automatic mode.

Keywords: Micromanufacturing systems, Micromanipulation station, Automation, Modularity

1. Introduction

Micromanufacturing systems are used to operate in the microworld (such as micromanipulation and robotic micro-assembly) and also to perform batches fabrication of microproducts. As the sizes of the concerned objects and components are sub-millimetric, they need to be integrated in an environment fundamentally different from the human scale. For instance at this scale:

- adhesion forces are very paramount,
- the acceleration of the objects are high (as their mass is negligible) making them hardly manoeuvrable than classic objects,
- the direct sense is not anymore valuable and indirect elements such as camera-microscope systems and/or virtual-reality techniques are often used.

Meanwhile, the lack of convenient sensors – having the sizes, accuracy, bandwidth, and resolution adapted to the microworld's requirement – limits the control and performances improvement of micromanufacturing systems. In addition to these microworld specificities and technology limitation, micromanufacturing systems must ensure an acceptable level of productivity, flexibility and reactivity to be an efficient system for the realization of microproducts.

Recently, we have proposed a novel method for the design of micromanufacturing systems based on a modular approach [Gendreau 10]. This new method combines a top-down approach, common to any system of production, and a bottom-up approach to take into account the specific constraints of the technologies and know-how in the microworld. In this method, to execute an assembly task, we need a micromanufacturing system, which includes operative device, based on modules and scenario adapted to the manipulation. The proposed strategy allows many possibilities of operative architecture, in particular the exchange of different modules when the results of the micromanipulation are not satisfactory. The modular architecture allows to quickly and easily get an operational production device.

This paper reports the new method and presents its application to a micromanipulation station developed in our research group. The station is composed of two microrobots, which work in cooperation to execute pick-and-place sequences of parts. The performance criterion is focused on the success of the operation in automatic mode.

The paper is organized as follows. Section-2 reminds the proposed modular method of design of micromanufacturing systems. In section-3, we present the micromanipulation station used to test the new method. Finally, section-4 is dedicated to the presentation of micromanipulation tasks based on the new method.

2. Method of design of micromanufacturing systems

2.1 Context and need of a new method of design

Currently, the method of design of manufacturing systems is developed from a functional analysis. In this, a system is decomposed into several sub-systems, each of them assuming a function, with an organisation based on operating tasks. To produce a batch of components, the operator writes a scenario which uses the defined tasks.

This approach is not sufficient in the microworld because no success is guaranteed for each of the tasks. It is often necessary to reiterate the operation or to modify the strategy of manipulation (reconfiguration technique) or to change the components into the production system (reorganization technique).

In the industry, the microproducts are manually assembled with tele-operated devices including adapted interfaces for the operator (cameras, micro-grippers…). While a large variety (kind) of products can be produced, these micro-assembly systems are favourable for the production of unit parts. Indeed, the rate of success of the different operations is very low and one micro-assembly/micromanipulation task requires a very significant time. Therefore, these systems are not adapted for batch production. At the opposite, the production of microproducts in large series is ensured by specific production systems that are able to handle or to produce only a limited variety (kind) of micro-products. In both cases, the automation of the micromanufacturing systems is not profitable because the investments are very important because of the costs of the peripherals (camera, microscopy, etc.) and of the limited either number or variety of products. To surpass these limitations, we have developed a new approach for batch micromanufacturing systems to make them capable to adapt themselves for several types of products. In the approach, a modular architecture was applied and as a result, micromanufacturing systems become flexible and productive.

2.2 Method of design of micromanufacturing systems

As in classical manufacturing systems, the design begins with a structured functional analysis. A model SADT™ [Marca, 1987] is used to present the decomposition of the functions, until the low level of the model where are defined the elementary functions. At this level, each elementary function can be executed by a task which represents the sequences of actions. A state diagram, as a Grafcet model [IEC 2002], describes the behaviour of the system with different actions of the operative device. Then, it is necessary to define the best strategy to execute the operation with a great rate of success within an accepted time. The principle consists in the design of the constituent module which can execute this operation from the elementary modules library (figure 1). The relations and the links of the different modules, necessary to connect themselves, are specified with an UML model [Pilone, 2006].

In our concept, it is necessary to have multiple levels of modules: a constituent module is composed of basic modules, but also includes other constituent modules (figure 2). For example, a displacement can be obtained by a single actuator, with a control law based on a model of the actuator (nonlinearities compensation, etc.), in which case the constituent module is composed of a basic module “control law” and a basic module “actuator”. This constituent module may additionally need a sensor (displacement sensor, camera/microscope, etc.) to achieve higher performances if required. Thus, we also have a basic module called “sensor”.

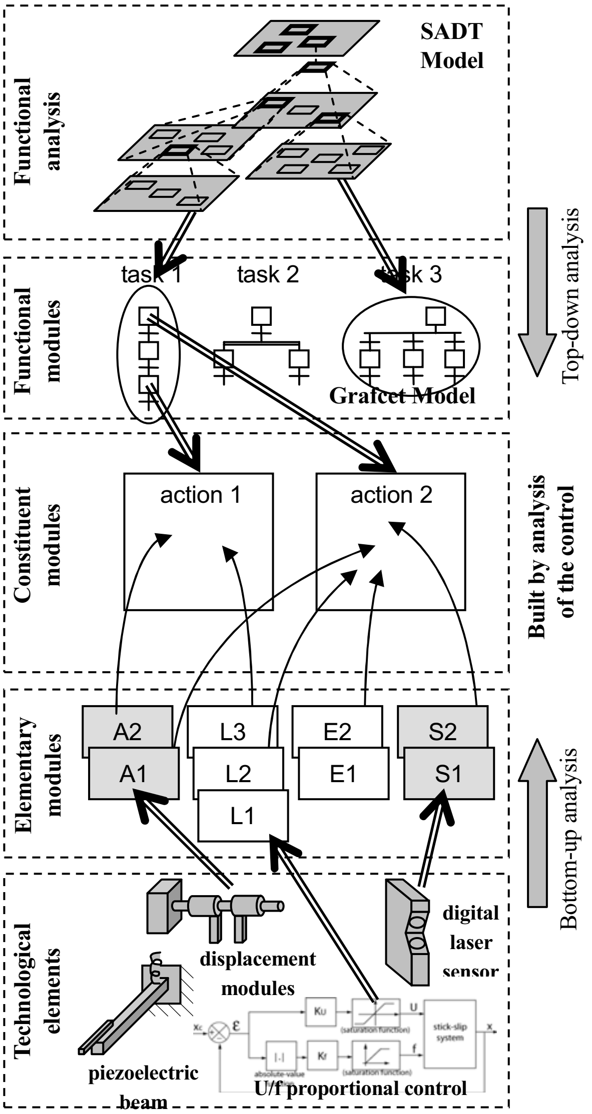


Figure 1: method developed in [Gendreau 10]

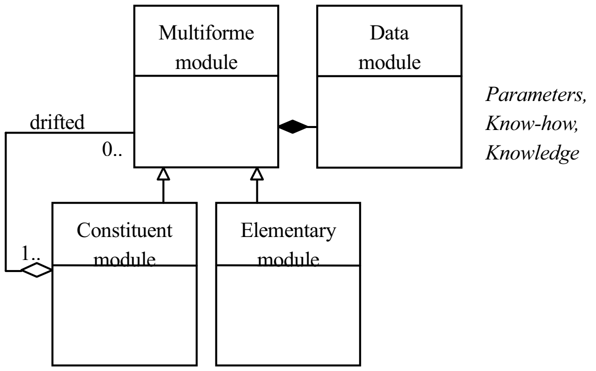


Figure 2: General model of the design of the modular structure

As a result, constituent modules consist in a combination of actuators, end-effectors, sensors and control laws. For that, we have defined several types of basic modules that depend on to the technology support.

The objective of the modularity is to be able to build a structure by successive assemblies of components; themselves can be the result of assembling most basic constituents. With this aggregation of the different (elementary) modules, it is possible to carry out any type of system.

The modularity approach is particularly interesting in microsystems and micromanufacturing systems because the (micro) components may be multifunctional. A single component based on piezoelectric material may be used as a sensor or actuator, or only an end-effector depending on how it is managed in the whole system.

3. Presentation of the experimental station

Figure 3 shows the (experimental) station that is used to experiment the proposed modularity approach. This station is composed with two microrobots developed in [Rakotondrabe, 2009]. Each of them, named Tring-module and referenced Ai, has two degrees of freedom: one translation referenced by Ti and one rotation referenced by Ri. The Tring-module can be moved along and around its support (a glass tube), thanks to 6 piezoelectric actuators. The behaviour of these actuators is strongly non-linear.

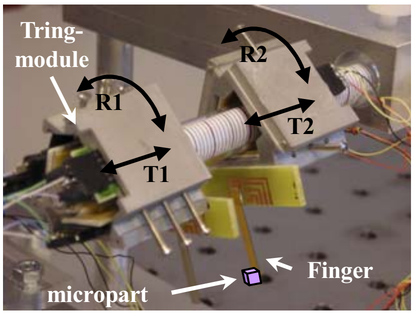


Figure 3: experimental station

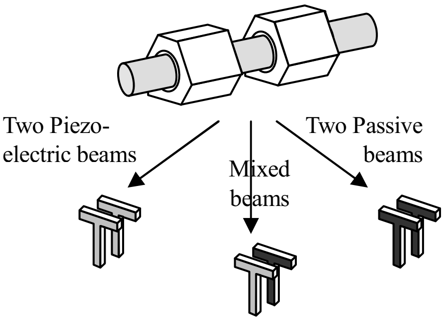


Figure 4: different material configurations

Each Tring-module Ai can accept a finger, according to many possibilities (figure 4). This element (finger) can be a passive beam (without controlled action), which is referenced Ei, or as piezoelectric beam. In the latter case, it can be used as an active end-effector element, referenced Ai with an adapted control law or considered as sensor element, referenced Si (figure 5). The same beam can therefore be used as sensor, actuator or passive end-effector. This is possible by using the concept of modularity.

The modular architecture permits to choose the best configuration to realize a micromanipulation task with a high probability of success.

A software associated to a camera/microscope can give information about the position, or the force (by deformation of a reference element). Both software and the camera/microscope are considered as two different sensor modules.

To sum up, the used technology and the possible roles of each element permit to define a complete elementary modules library (figure 6). The association of each element is regulated by the UML model.

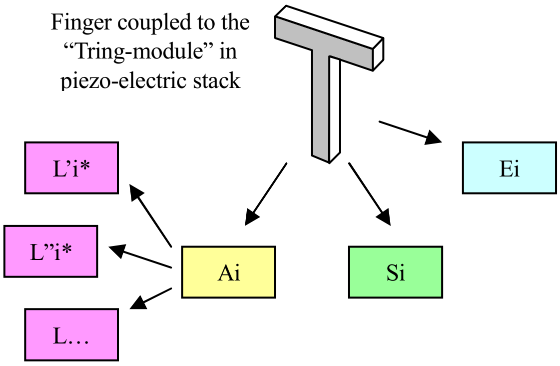
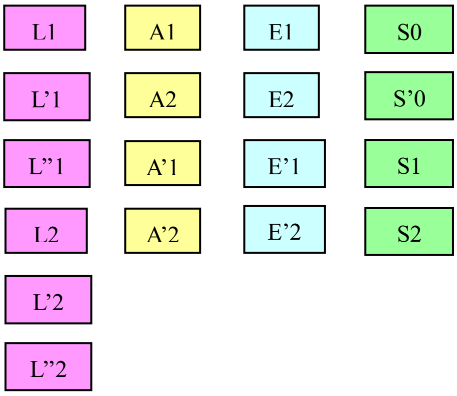


Figure 5: Model of the finger



L1	A1	E1	S0
L’1	A2	E2	S’0
L”1	A’1	E’1	S1
L2	A’2	E’2	S2
L’2			
L”2			

Figure 6: elementary modules library

4. Different strategies of micromanipulation

The example of task in studied in this paper is a pick-and-place task usually used for robotic micro-assembly. To pick and place a small part with two fingers, the task is described by the sequence in figure 7. In this figure, the sequence was transcribed by a hybrid grafcet where the sub-tasks (actions) are defined by the discrete states and the continuous dynamic behaviours (force and displacement modelling, control and measurement) are given in each of them.

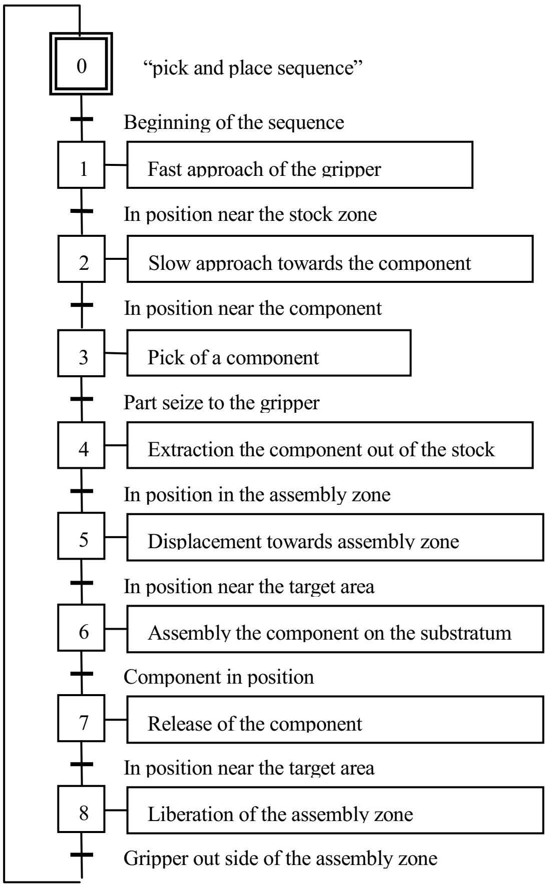


Figure 7: sequence diagram transcribed into hybrid grafcet

In the first action (coarse approach), the two Tring-modules come near the object (component) to be picked. A displacement control law Li is used for that (figure 8). The specification is that the settling time of the closed-loop is short, the accuracy being less important.

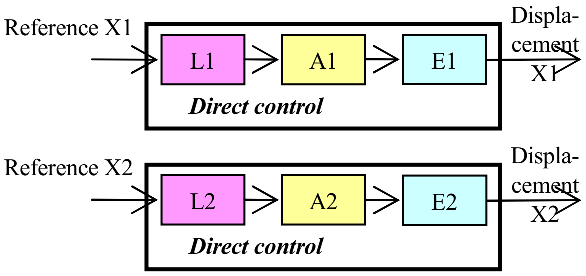


Figure 8: displacement control of the Tring-modules

In the second action (fine approach), the accuracy of the position is very important to approach the component without spilling. The speed of each Tring-module must be slower and a control of the fine positioning is necessary to arrive just in contact with the component. A vision device permits to control the trajectories of the two Tring-modules and stop it at the right time (figure 9).

Then, during the picking action, the clamp force must be controlled and the component should not be dropped and neither crushed. Thereby, several possibilities must be executed:

1. One of the two Tring-module is motionless, and the displacement is realised with the other Tring-module. The picking is controlled using a camera and visual servoing feedback (figure 10);
2. One of the two Tring-module is motionless, and the displacement is realised with the other Tring-module. The picking force is controlled using the feedback from the piezoelectric beam attached on this second Tring-module (figure 10);

3. The two Tring-modules are motionless and the displacement is obtained with one or the two

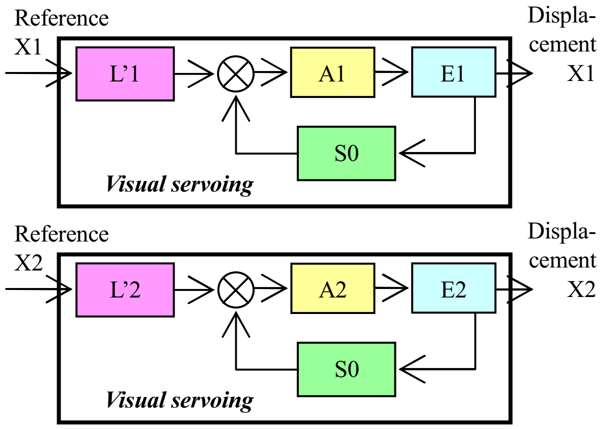


Figure 9: closed-loop control in vision
of the two Tring-modules

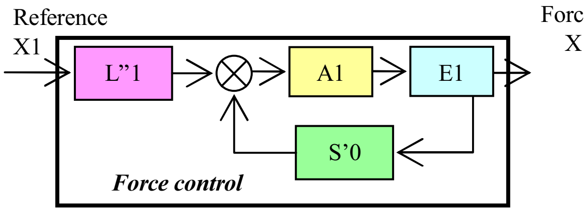


Figure 10: closed-loop control in force of a Tring-module N°1

piezoelectric beams attached on these modules. The feedback information can be obtained with the camera or the other piezoelectric beams.

In actions 4 and 5, the control strategy is more delicate. In fact, the actions consist in the transport and positioning of the component with the same previous constraints: the component should not be crashed in the gripper (composed of the two modules) neither striked down. To success these actions, both the displacement and the force are managed and controlled. A double close-loop must be considered with the two actuator devices. Figure 11 presents a possibility of control of the force and position. The first Tring-module (A1 module) moves in a direction X and it is controlled (L'1 law module) in position by the camera (S0 module). The associated piezoelectric beam is passive (E1 module). The second Tring-module (A2) moves in the same direction and is controlled in force (L"2 law module) by using the piezoelectric beam as sensor (S1 module).

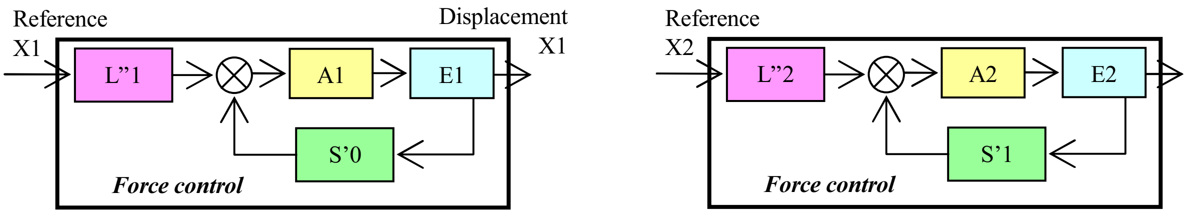


Figure 11: closed-loop control of the force and of the displacement for the two Tring-modules

4. Conclusion

This work presented the application of a method for the design of a flexible micromanufacturing system on a micro-assembly station. The method is supported by a modular architecture which takes into account the specificities of the microworld. The issue is very interesting for the industry which needs automated systems for the medium-volume assembly of the hybrid M(O)EMS.

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