MODELLING AND CONTROL OF A HIGHLY MODULAR MICROASSEMBLY SYSTEM

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Abstract

In this paper, we present the modelling and the control of a two hands robot used to handle tensile and delicate micro-object. The main goal of the system is to pick the micro-object and transport it to another location of the space for treatment or for assembly controlling the handling force. A unified model in the state space is used in order to introduce the mechanical caracteristics of the object notably in order to know the evolution of the force. The pole placement is optimized with a LQ (Quadratic Linear) control. The whole system, ie the pick-and-place system, is the basic principle of a modular microfactory used to produce, assemble or treat micro-objects.

Introduction

To assemble these very small products, called micro products (about some hundreds of μm^3), the use of traditional size assembly systems leads to important difficulties which can be hardly overcome because of the scale effect and the complexity of the physics of the microworld. The solution for the future is to have production systems where the dimensions and the cost are well related with the microproducts : the solution is the microfactory. Because of its double experiences (*microrobotic* and *design and control of assembly systems*), the LAB takes into account these thematics to develop a research area on microfactory and to produce a new approach breaking off of miniaturization. We wish to approach the problem of the design and the control of the microfactory through a highly modular concept [1]. Unlike the existing prototypes, we apply the modularity concept very deeply inside a station : each microactuator is an elementary module. A microfactory will consist in an important number of "elementary blocks" which enables great flexibility and re-use of the resources at the same time.

In this paper, we will study and automatize completly the basic task of a station which is in fact an assembly principle, the pick-transport-place principle : take the micro-object and transport it to another location with the control of the handling force. In the following section, we will present the system. Then, we will speak about modelling after what the study of the control is shown. Afterwards we will see the different simulations and some discussion before concluding.

Presentation of the system

The station is made up of two arms having each one two degrees of freedom. They can be controlled independantly whichever in translation or in rotation. Their dynamic in the two dimensions are supposed in the class of ordinary differential equations of second order because many type of actuators belongs to it. We can then replace an actuator by another type without studying again completely the modelling and the control, that is the notion of modularity that we introduce. In this paper, we specially use 4 direct current motors to operate the arms (Figure 1) : two linear and two angular motors.

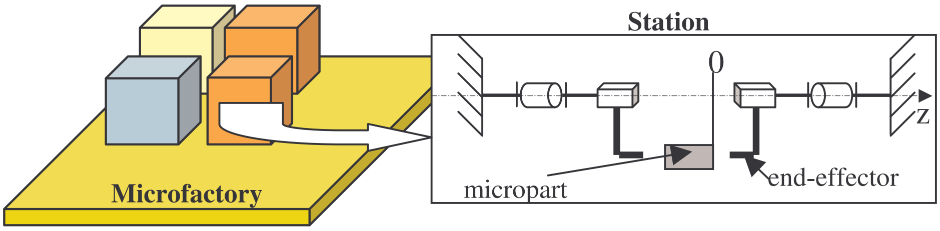

Figure 1 : Two independant arms.

Hypothesis, simplifications and principle

- As the rotation system and the translation system are equivalent, we only study the second one in this paper. Then, instead of use of a (0, θ , z) reference system, we only use a (0, z) (Figure 1).

- We assume that the micro-object to handle is very deformable comparing to the end-effectors, we model it by a spring with an initially length *l* and a stiffness *k*. Some studies about coupling effectors-object in macroworld have been already done in considering their strain, as examples [2] studies the stability and [3] the modelling of a microgripper-object in order to control the whole on effort. In this paper, we will model two independant micromanipulators which become coupled when they are in contact with the micro-object and then we will control them on position and on effort.

- We choose the co-ordinate of the right extremity of the micropart as its co-ordinate. Initially, its value is z_{oi} . When the cycle begins, the two subsystems come in contact with the micro-object, pick it and transport it to another location named z_{of} for treatment or assembly. Then, we propose that the right subsystem is controlled on position and the left one must be therefore controlled on force. As the initial location z_{oi} is known, we choose it as the origin of the axis (Figure 1). It is introduced automatically by a vision system. The goal is to allow the user introduce the final location of the micro-object and the handling force (references = (z_{of} ,F_h)) and make the system automatically do the task (Figure 2).

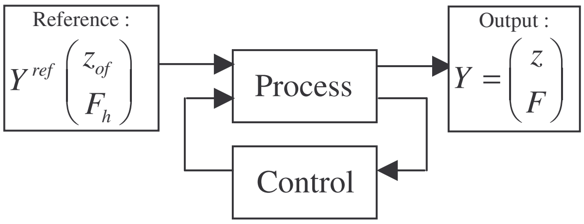

Figure 2 : Systemic scheme of the automatized process.

- Initially, the function of the station is microassembly where the task plan is *pick-transport-place*. If we want to re-organize it, for example change the *microassembly function* into *microdrilling function*, the new task plan must be *pick-transport-treatment-transport-place*. Our thinking is that the *treatment* task is the same as the transport task but where the location order (z_{of}) is unchanged in relation with the last coordinate. It is the way that *pick-transport-place* is for us the basic principle.

- When the contact is got, the transportation begins in the same time that the picking.

Modelling

For a sequence of *pick-transport-place*, we can have three states of the whole system : approach of the subsystems from their initial places up to the contact with the micro-object, picking of the micro-object and transportation. Hybrid Petri Net have been used to manage the planning task and the continuous states. We only show in this paper the transportation phase because of the limited number of pages. We then consider that the contact has been got at time *t=0,* ie $(z_r - z_l) \leq l$, where z_e and z_l represent respectively the locations of the right and the left subsystems. In that case, their states are coupled through the strain of the micro-object. The force which acts on this last depends on the locations z_r and z_l : $F = -k.((z_r - z_l) - l)$. We use a modelling in the state space because it let us unify the whole system during the couplage. If *-F* and F are the loads respectively applyed to the left and the right motors, the state equation is as follow :

$$\dot{X} = \frac{d}{dt}\begin{pmatrix} X_l \\ X_r \end{pmatrix} = A.X + B.U + B_0.l = \begin{pmatrix} A_l & A_{lr} \\ A_{lr} & A_r \end{pmatrix} \cdot \begin{pmatrix} X_l \\ X_r \end{pmatrix} + \begin{pmatrix} B_l & 0 \\ 0 & B_r \end{pmatrix} \cdot \begin{pmatrix} U_l \\ U_r \end{pmatrix} + B_0.l \quad (1)$$

Where A is symmetric matrix and $A_{ij} \quad (i \neq j)$ the coupling terms between the left and the right subsystems, $X_i = (z_i \quad V_i \quad I_i)^T$ the state vector of a subsystem. On the other hand, if $Y = (z_r \quad F)^T$, the output equation is $Y_1 = C.X + D_0.l$. To reduce this form, we use a variables change so that $Y_1 = Y - D_0.l$. Therefore, the new output equation is : $Y_1 = C.X$. At end, the state system with a constant input l considered as a constant noise (16) is as follow :

$$\begin{cases} \dot{X} = A.X + B.U + B_0.l \\ Y_1 = C.X \end{cases} \quad (2)$$

Control

Control of the static regime :

In the figure 3, if *K* represents the back matrix to correct the dynamic performances, L is the prefilter matrix for the static one. A third corrector named K_l was introduced in order to minimize the effect of *l* in the system as it behaves like a noise.

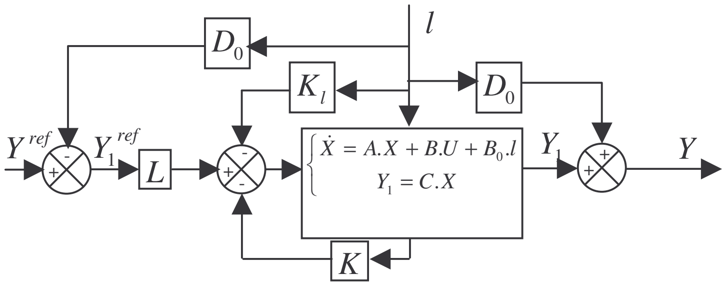

Figure 3 : Closed loop scheme.

When the static phase is reached, we can deduce the following equation :

$$Y_1 = C.\left(B.K - A\right)^{-1}.B.L.Y_1^{ref} + C.\left(B.K - A\right)^{-1}.\left(B_0 - B.K_l\right).l \quad (3)$$

As the term $C.\left(B.K - A\right)^{-1}.\left(B_0 - B.K_l\right)$ must be null, we deduce the disturbance rejector :

$$K_l = \left[C.\left(B.K - A\right)^{-1}.B\right]^{-1}.C.\left(B.K - A\right)^{-1}.B_0 \quad (4)$$

So, the prefilter matrix is got :

$$L = \left[C.\left(B.K - A\right)^{-1}.B\right]^{-1} \quad (5)$$

Control of the dynamic

We have chosen the LQ control to place the poles in order to take advantage of the performances both in input and in output that it offers. This optimisation also gives a good robustness for minimal linear systems, ie with the next form :

$$\begin{cases} \dot{X} = A.X + B.U \\ Y_1 = C.X \end{cases} \quad (6)$$

The exogen signal $B_0.l$ is constant, thrown out thanks to K_l and doesn't affect the output, we can then use an optimum quadratic criteria weighting the importance of *U* and Y :

$$J_{LQ} = \int_0^{\infty} \left(\rho.(U^T.R.U) + Y^T.S.Y\right).dt \quad (7)$$

Numerical applications

A little motor was taken in order to work with micro-object. The nominal voltage for each one is *24V* and the nominal linear speed is $\dot{z}_l = \dot{z}_r \approx 25mm/s$. The speed is enough slow to make us have a good resolution, but not very low to transport the micro-object at a high distance. For the object, we can take as example a deformable material having a $1\text{x}1mm^2$ of surface, $2mm$ of length and $1{,}4MPa$ of Young modulus. It leads us to $k = 7000N/m \approx 7kg/cm$. We Neglect in this paper the effects of adhesion forces [4]. As an example, we want to take the micro-object with a handling force $F^{ref} = 1N$ (it corresponds to its strain at *7,14%*) and transport it to *10cm* on farther.

The weighting diagonal matrix *R* and *S* are initially chosen with the Bryson method [5] :

$$r_i = \frac{1}{(\sup(u_i))^2} \;\; ; \;\; s_i = \frac{1}{(\sup(y_i))^2} \;\; ; \;\; \rho = 1 \qquad (9)$$

From these, we can refine their values according to our wishes about performances.

Simulation and discussions

We notice that the force applied must be very dynamic during transitory period in relation with the dynamic of the position because the micro-object must not be lost during the motion. The end effectors pick the object in the same time that they begin to move to the reference position (Figure 5b), in that case the force must reach the reference very quickly. However, the voltages U_l and U_r must not pass *24V* in order to avoid motors destruction. To refine weighting matrix in order to limit these voltages but in the same time to keep the output performances, we have used as references the maximal values of z_r and F. The maximum of z_r is : $z_r^{ref} = z_{r\max} = 100mm$ which corresponds to the length of the wanted workspace and we think that the handling force doesn't exceed *1N* ($F^{ref} = F_{\max} = 1N$). In fact, with these values, the micromanipulators cover the longest distances in the space states minimizing the output energy and maximizing input energy. Therefore, the refining (after trying values obtained with Bryson's method) consists to search values of R , S and ρ which make U_l and U_r less than *24V* but which let us have the output performances required.

The simulation shows the satisfaction of these : the time response of the force is *1,15s* while the one of the position is *25s* and the two voltages doesn't exceed *24V*. We notice that the current (not shown in the figures) through the motors didn't exceed *1A*.

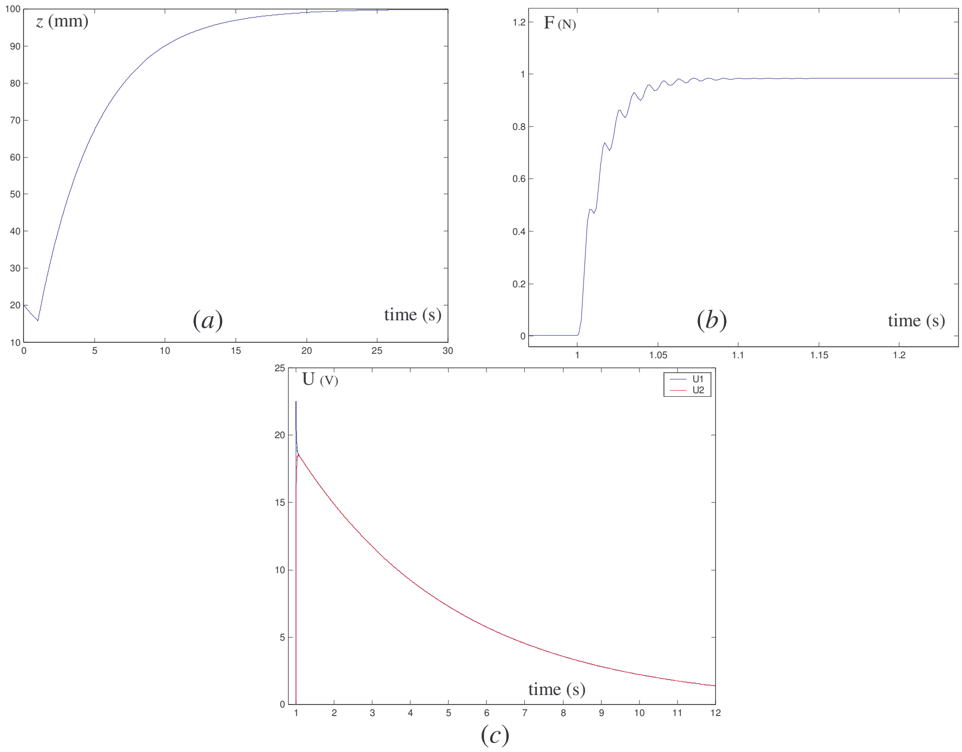

Figure 4 : Simulation : (*a*) evolution of the position of the micropart, (*b*) handling force, (*c*) voltage of a motor.

Conclusion

This paper has shown the modelling and control of a the basic principle of a modular microassembly system : the pick-transport-place principle by using motors as actuators. Our next step is to apply these methods to microactuators which are more suitable with microworld about performances and dimensions (piezoelectric, Shape Memory Alloy ...). We will also generalize them so that more complex and more number of subsystems may be input in the station in order to execute a task.

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