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FUZZY POSITION/FORCE CONTROL OF A MINIATURE GRIPPER DRIVEN BY PIEZOELECTRIC BIMORPH ACTUATOR

^{O}Young-Chul Kim*, Seiji Chonan*, Zhongwei Jiang*

Department of Mechatronics and Precision Engineering, Tohoku University, Sendai, Miyagi 980 - 77, JAPAN
Tel: +81-22-217-5879; Fax: +81-22-217-5879; E-mail: kim@rose.mech.tohoku.ac.jp

Abstracts This paper is a study on the fuzzy force control of a miniature gripper driven by piezoelectric bimorph actuator. The system is composed of two flexible cantilevers, a stepping motor, a laser displacement transducer and two semiconductor force sensors attached to the beams.

Obtained results show that the present artificial finger system works well as a miniature gripper, which produces approximately 0.06N force in the maximum. Further, the fuzzy position/force control algorithm is applied to the soft-handing gripper for stable grasping of a object. It revealed that the fuzzy rule-based controller be efficient controller for the stable drive of the flexible miniature gripper. It also showed that two semiconductor strain gauges located in the flexible beam play an important roles for force control, position control and vibration suppression control.

Key words Active Grasping Control, Flexible Miniature Gripper, Force Control, Position Control, Vibration Suppression Control Fuzzy Rule-Based Controller, Piezoelectric Bimorph Actuator

1. INTRODUCTION

Artificial hands and fingers which are capable of grasping a variety of objects have been studied by several researchers, including Salisbury and Craig[1], Dario and Buttazzo Paker[2], Mills and Goldenberg[3] and Chonan and Jiang[4].

The forces of contact during manipulation convey substantial information about the state of the manipulation such as textures, slip, impacts and grasping, and other contact conditions produce force and position signatures that can be used for identifying the state of contact. In these cases, it is very difficult to build mathematical models of correlation of the physical contact point with the flexible gripper.

To solve these problems, we have considered two method; one is that the semiconductor strain gauge is attached within a flexible beam, and another is that the methodology of fuzzy control is directly applied to the system. The strain gauges in the beam have measured two information, i.e., force and position which are from vibration of a flexible beam. By the acquired signals, it is possible to have both force control and vibration suppression control through only a strain gauge. Fuzzy control also seems to be most adequate in cases where the parameters of contact point are strictly not relevant.

In this paper, we present an experimental study on the fuzzy force control of a miniature gripper driven by piezoelectric bimorph cells. It is composed of both flexible fingers and stepping motors in order to catch a soft and a rigid object. Fuzzy control algorithm which is to avoid instability of system during grasping objects is applied. The important factors of system performance are two; impact force between a object and fingers and the tuning of fuzzy scaling factors. This paper also showed the improvement of system performance according to the regulation of these parameters.

2. DESCRIPTION OF THE MINIATURE GRIPPER

2.1 Description of mechanism

Fig. 1 shows a parallel two fingered miniature gripper with two semiconductor strain gauges(KSP-2-120-E4, KYOWA) attached to the beams. Each finger is made up of a piezoelectric bimorph strip at the base and a flexible copper cantilever. The laser displacement transducer(LC-2100,KEYENCE) which is for measuring the tip vibration is placed at the tip of finger. The cantilever is driven laterally by the bending deformation of the piezoelectric bimorph actuator. However, the resulted fingertip displacement is not sufficient for grasping a moderately large object. To compensate for this small displacement of the finger, the two fingers are supported separately by linear ball bushings which ride on a fine screwthread(SKS FKB-D401A, THK). The busing is driven by a stepping motor(PX245-03A,ORIENTAL MOTOR). The maximum speed is 5 mm/sec and a moving distance of one pulse is about 5μm. The linear slide mechanism takes charge of the coarse and slow motion and the real actuator, piezoelectric bimorph actuators, plays role in fast and fine motion control. The measurement signals extracted from laser displacement transducer and semiconductor strain gauge are entered into computer(PC-9801,NEC) through A/D converter(AB98-05,ADTEK) for controlling the signals and a GPIB board for recording the result signals. The control output signals which are ranged from +5 Volt DC to -5Volt DC are calculated by computer, and then are delivered to D/A converter(AZI-211,INTERFACE) and power amplifiers ranged from +100 Volt DC to -100 Volt DC according to output voltage of D/A converter.

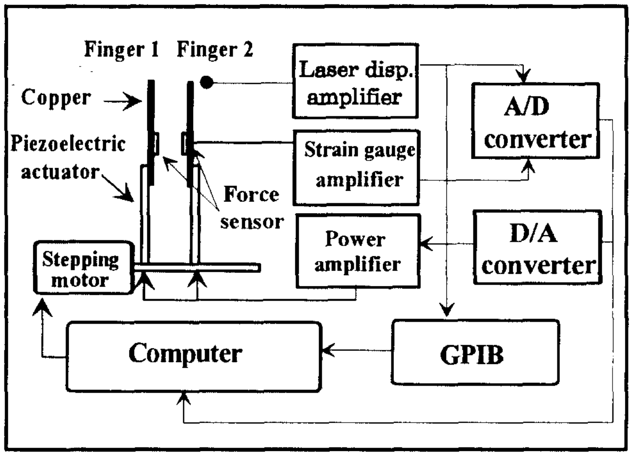

Fig. 1 A schematic diagram of a two fingered system with piezoelectric bimorph actuators

2.2 Physical parameters of two fingers

The physical parameters of fingers are shown in Table 1 and Table 2. The maximum forces of each finger are approximately 0.06N(6.1[gf]).

Equation (1) shows the relationship between acquired measured value of a force meter and output voltage of strain gauge amplifier according to the change of input voltage of power amplifier ranged from ±*5Volt* DC of D/A converter at piezoelectric bimorph actuators, respectively. The force meter is located at the tip place of a beam. The measurement is started from the contact instance between the finger and the force meter. In particular, the relationship derive from using least square method of curve fitting as follows each finger:

$$\begin{aligned}&\text{Finger 1}: Y_{fv1} = 1.136 \times X_v - 0.12\\&\text{Finger 2}: Y_{fv2} = 1.245 \times X_v - 0.076 \qquad (1)\end{aligned}$$

where X_v is the output voltage[V] of D/A converter and $Y_{fv1,fv2}$ are the force[gf] of the force meter at finger 1 and finger 2 respectively.

The above results measured three times once a input data, and then take an arithmetical average. Result signals acquired from the force sensors showed the linearity in spite of external force on the tip of beam. It means that the part of piezoelectric bimorph actuator is not deformed when a certain external force runs. Therefore the signals of strain gauge are caused from the only bending moment of a copper beam.

Table 1 Physical parameters of finger 1

Property	Actuator	Beam
Length [mm]	32.19	40.02
Width [mm]	11.98	6.00
Thickness[mm]	0.65	0.30

Table 2 Physical parameters of finger 2

Property	Actuator	Beam
Length [mm]	32.19	40.45
Width [mm]	11.98	6.24
Thickness[mm]	0.65	0.30

3. DESIGN OF FUZZY FORCE CONTROLLER WITH A MINUTE FORCE

In this section, we describe basic algorithm of a fuzzy force controller.

3.1 The design of fuzzy rule-based controller

It has designed through this procedure for active fuzzy grasping controller.

[step 1] the definition of controller input and output variables

[step 2] the design of the membership function and the fuzzy rule base

[step 3] the fuzzy inference mechanism

[step 4] the defuzzification strategies and making the lookup table

We present the block diagram of designing the fuzzy rule-based controller in Fig. 2.

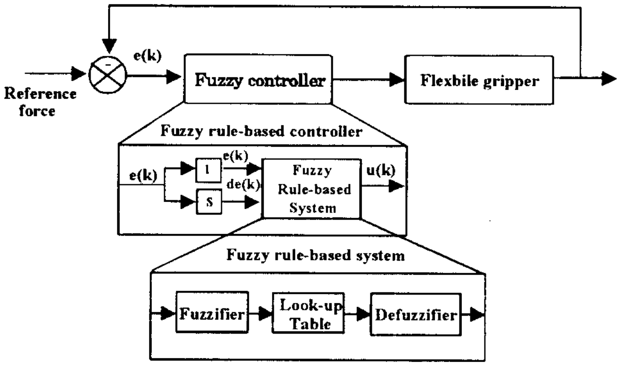

Fig. 2 Fuzzy force controller of a flexible miniature gripper

3.2 The definition of controller input and output variables

The proper choice of process state variables and control variables is essential to the characterization of the operation of fuzzy system. The fuzzy controller described here are designed two inputs and a output.

One of inputs is the error(e(k)), calculated in a normal manner by subtracting the process output(y(k)) from the desired force(sp(k)) where k represents the current discrete time.

$$e(k) = sp(k) - y(k) \qquad (2)$$

The other input, de(k), is change in error and is obtained by subtracting the error at last sampling instant from the present one.

$$de(k) = e(k) - e(k-1) \qquad (3)$$

The output, du(k) is determined from the lookup table which is depended on the e(k) and de(k). The control input, u(k) is obtained by adding the previous control input, u(k-1).

$$u(k) = u(k-1) + du(k) \qquad (4)$$

3.3 The definition of membership function and linguistic variables

There are three linguistic variables: error, change in error and change in controller output. For simplicity, membership function is used of the triangle-shape form. A universe of discourse is discretized into 13 levels with seven terms(Which is called by primary fuzzy set). It is expressed as :

$$U = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$$

Fuzzy partition of the term sets are showed in Fig. 3. Linguistic variables are defined with seven term sets which are abbreviated below:

PB : Positive Big PM : Positive Medium PS : Positive small
NB: Negative big NM: Negative medium NS:Negative small
ZO : Zero

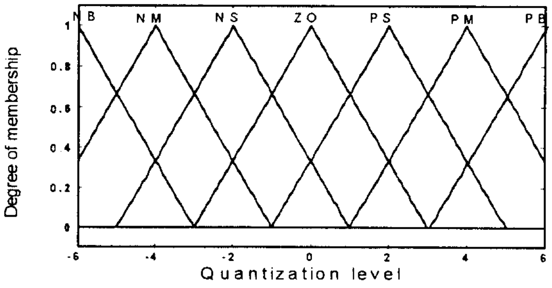

Fig. 3 Membership function for stable grasping

3.4 The design of fuzzy rule-base

A fuzzy system is characterized by a set of linguistic statements based on expert knowledge. In the fuzzy system, the fuzzy rule base is the heart of the fuzzy logic system in the sense.

It consists of a collection of fuzzy *IF - THEN* rules in the following form:

$$R^{(l)}: IF\ error\ is\ A_1^l\ and\ change\ in\ error\ is\ A_2^l,\ THEN\ du\ is\ B^l \qquad (5)$$

where A_1^l, A_2^l, and B^l are fuzzy sets in $U_i \subset R$ and $V \subset R$, respectively, and then, error, change in error, and du are linguistic variables. The number of fuzzy IF-THEN rules l, is 49. Basically, the rule base is derived from meta-rules, which is devised from Macvicar-Whelan[7].

3.5 The fuzzy inference mechanism and the defuzzification strategy

It infers fuzzy control actions employing fuzzy implication , rules of inference in fuzzy logic and the defuzzification. The compositional rule of inference is used Max-Min method. The defuzzifier methods are several method, however we use the center of gravity method. Table 4 has shown the result determined through these procedures.

Table 4. Decision table using the center of gravity method

								DE						
		-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
	-6	-6	-6	-6	-6	-6	-5	-5	-4	-3	-2	-1	0	0
	-5	-6	-6	-6	-6	-5	-5	-5	-4	-3	-2	-1	0	0
	-4	-6	-6	-5	-5	-4	-4	-3	-3	-2	-1	0	0	0
	-3	-6	-6	-5	-4	-3	-3	-3	-2	-1	0	1	2	2
	-2	-5	-5	-4	-3	-3	-2	-2	-1	0	1	2	3	4
	-1	-5	-5	-4	-3	-2	-2	-1	0	1	2	3	4	4
E	0	-4	-4	-3	-3	-2	-1	0	1	2	3	3	4	4
	1	-4	-3	-3	-2	-1	0	1	2	2	3	4	5	5
	2	-3	-3	-2	-1	0	1	2	2	3	3	4	5	5
	3	-2	-2	-1	0	1	2	3	3	3	4	5	6	6
	4	-1	-1	0	1	2	3	3	4	4	5	5	6	6
	5	0	0	1	2	3	4	5	5	5	6	6	6	6
	6	0	0	1	2	3	4	5	5	6	6	6	6	6

4. RESULTS AND DISCUSSIONS

In the previous section, we presented description of mechanism and the algorithm of fuzzy control and made a look-up table. Now, we can apply the rule-based controller into position/force control of a flexible manipulator with searching the effectual contact factors and with capturing a soft and a rigid object and show the efficiency of strain gauge for controls ,which is attached to the beam.

In the Fig. 4, it shows how to control a flexible finger used a lookup table. Q1 and Q2 mean the quantization and GE, GCE and GU are scaling factors. Basically the system performance is depend on the scaling factors, which are similar function with parameters of PID.

The fuzzy control strategies have divided two stage: one is moving fingers in roughly grasping range by using stepping motor, another is applying the fuzzy rule-based controller for stable grasp into a object with several contact conditions.

Position signals which displayed lower signal in the Fig. 6-8 approach to the motor speed of zero. The ratio between laser displacement and output voltage is 1mm/V.

From Fig. 5, it shows the results of fuzzy position/force control with catching a object of different stiffness. The desired force is approximately 3.0 [gf]. All of scaling factors are GE = 0.01, GCE = 0.03, GU = 5. The speed of stepping motor is about 5 mm/sec. The selected objects are as follows: plastic material is a diameter 6 mm and length 15 mm, sponge rubber is 9×15×4 mm, and rubber is 10×15×5 mm. These results have small steady state error, however, the large force spike is not appeared. Also the tuning of scaling factors is easier than that of PID parameters. It is possible for fuzzy controller to catch a small object having variation of stiffness.

Fig. 6 depict experimental results of capturing a rigid object ,which handled with same parameters of results of Fig. 5.

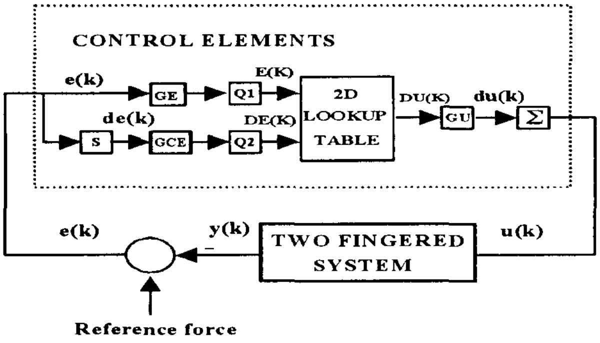

Fig. 4 Scheme of fuzzy rule-based system

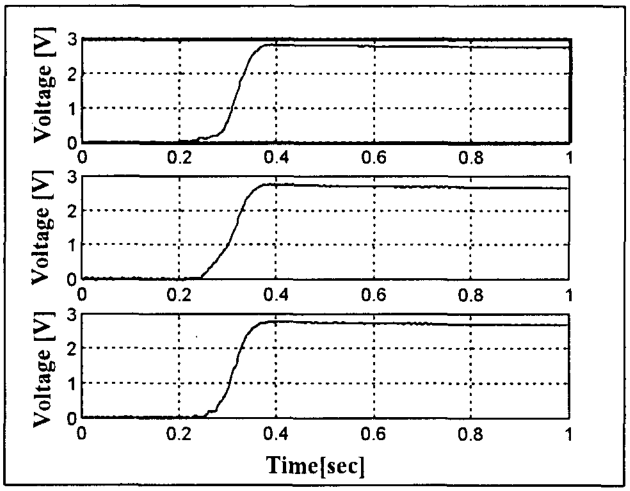

Fig. 5 Fuzzy force control with respect to different stiffness; Upper: plastic material, Middle: sponge rubber, Last:rubber

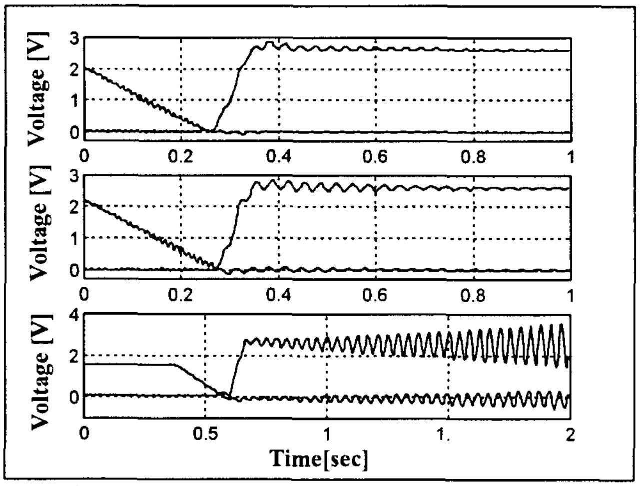

Fig.6 fuzzy position/force control with respect to different weight capturing a rigid object;upper; 2.61[g], middle3.6[g], last 5.4[g]

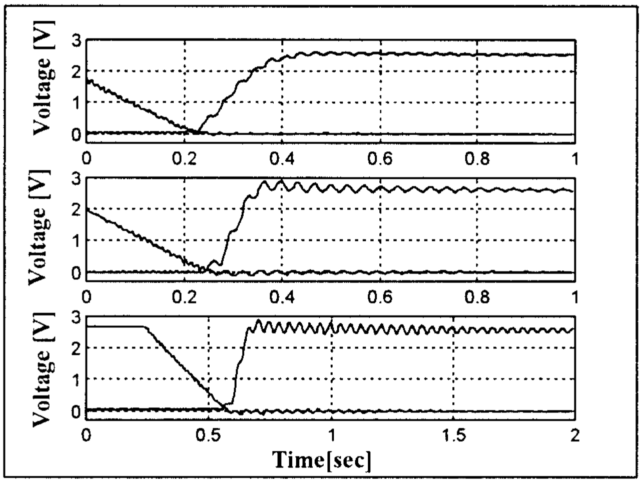

Fig. 7 Fuzzy position/force control with respect to the variation of sacling factors; upper; 2.61[g], middle; 3.6[g], last; 5.4[g]

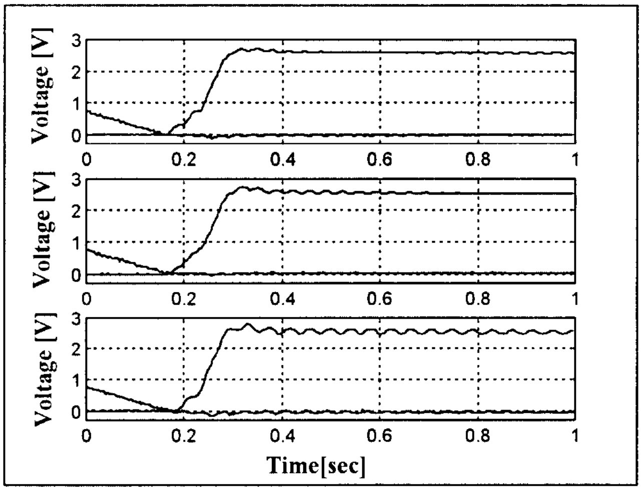

Fig. 8 Fuzzy position/force control according to adjust motor speed; upper; 2.61[g], middle; 3.6[g], last; 5.4[g]

These objects are the steel ball and the weights are 2.61[g],3.6[g],and 5.4[g],respectively. The ball is fixed by the thread with the length 20mm. Because of this reason, it works as a disturbance of system. It could bring about a different initial conditions, so the system has a unstable characteristics as a last results of Fig. 6.

Fig. 7 shows grasping results of varying with tuning of scaling factors. The parameters are scaling factors, GE = 0.009, GCE = 0.01, GU = 5, and with same motor speed of Fig. 5 and Fig. 6. In these results, there are a litter oscillation, however the fuzzy controller comparatively works well in spite of the variation of weight.

In Fig. 8, we consider the impact effect according to change of motor speed with same scaling parameters used in Fig. 6. It shows that the system performance can be raised by applying slower impact speed than results of figure 6. It means that ,in the position/force control, the system stability has close relationship according to initial impact speed.

The comparison of results between Fig. 6 and Fig. 7 is shown that one of the most important factors to the system performance is tuning of scaling factors.

Another comparison of results between Fig. 6 and Fig. 8 also shows that the initial impact speed has effectively reduced the steady state error, nevertheless, in the case of the largest weight, it has the characteristics of critical damped system.

Finally we have to consider the roles of strain gauge in comparisons among Fig.6, Fig.7 and Fig.8, we could make the relationship equation between the output voltage of strain gauge and force. Its relationship is acquired from the static condition, however the use of this sensor is the condition of dynamic situation. It means that the result signal has the possibility of two appearances, the real force components and the vibration components caused by the vibration of a flexible beam at the impact instance. Based on these facts, the result have revealed that the strain gauges attached to the beam should take signal sources of a force controller, which is for real purpose, of a vibration suppression controller induced by vibration of two flexible beams and of a position control at the tip of beam.

5. CONCLUSION

This paper is concerned with the problem of position/force control for a flexible miniature gripper driven by piezoelectric bimorph actuator from the point of view of fuzzy control theory. we considered two significant factors; impact speed and the tuning of scaling parameters, to get the stable system performance. It also showed that two semiconductor strain gauges located in the flexible beam play an important roles for force control, position control and vibration suppression control. Fuzzy controller was appropriate for control of a flexible miniature gripper to catch a soft and a rigid object.

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