广西科学 Guangxi Sciences 1 (3)：66～68，40　1994

基于模糊推理的机器人混合控制补偿方法*

A Compensated Method Based on Fuzzy Reasoning for Hybrid Control of Manipulators

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摘要　提出了一种基于模糊推理的机器人混合控制补偿方法。该方法用于复杂环境装配操作的混合控制后，提高了混合控制的精度。插孔实验表明，用该方法可以有效地消除环境干扰产生的振动。

关键词　机器人　混合控制　模糊推理

Abstract　Based on fuzzy reasoning, a compensated method for hybrid control of manipulators is proposed here, in which the hybrid control can be improved in performing assembly operation on complicated environment. Experiments on a peg-and-hole task show that the method is effective in eliminating the vibration produced by the environmental disturbances.

Key words　robot, hybrid control, fuzzy reasoning

1 Introduction

When a robot is used to complete assembly tasks, it is inevitable for the robot to contact with environment so that the control of contacting force must be considered. Generally, a peg-and-hole task is taken as the research object because it is widely present in assembly operation[1]. The hybrid position/force control proposed by Raibert and Craig[2] is a good approach to complete assembly tasks. But in complicated environment, the effectiveness of this approach may be influenced by the disturbances such as slide, friction, impact, stiffness and so on. Yamashita et al [3] used a robot with a force-torque sensor mounted on a wrist to complete the simulation and the experiment of a peg-and-hole task, in which there is no chamfer on the peg's edge and the hole's edge. But from their results of the experiments, the intense vibration was observed in the output of the force directions, which influenced the completion of the task. In our previous research, the vibration was analysed and a stiffness compensator was designed to eliminate the disturbances stemming from the interaction between the joints so that the vibration could be reduced[4]. In order to further reduce the vibration, we added the position compensation to the force control loop to avoid the excessive motion produced by imposing the force on the weak constraint direction[5]. The excessive motion could make the contacting force change frequently and produce the intense disturbances to influence the force control. Although this method is a good solution for reducing the vibration, the parameters of the position compensation are determined difficultly. In the present research, a method to determine the parameters by fuzzy reasoning is proposed, in which the value of the parameters can be tuned automatically according to the changing information of the environment. Experiments on a peg-and-hole task show that this method is effective in eliminating the vibration and improving the force control in assembly operation.

2 Configuration of control system

The configuration of the control system, which is

1994-05-07收稿。

* 将于10月14日在第二届亚洲机器人国际会议上宣读。

used to complete assembly tasks, is shown in Fig. 1. The variables in Fig. 1 are defined as follows:

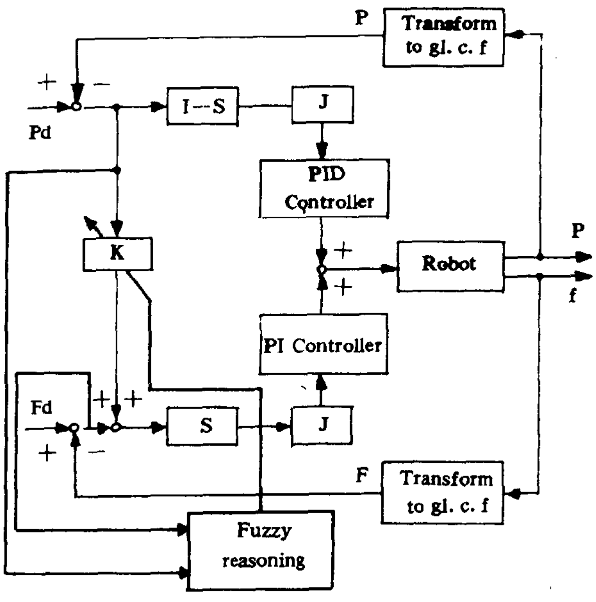

Fig. 1 Configuration of control system

F : the force vector in the global coordinate frame;

F_d : the desired vector of F ;

f : the force vector of the force-torque sensor;

P : the position vector in the global coordinate frame;

P_d : the desired vector of P ;

p : the position vector in the joint coordinate frame;

J : jacobian matrix;

I : identity matrix;

S : the diagonal matrix to select control type by giving the value of its elements (1 and 0 to mean the force control and the position control respectively);

K : the parameter diagonal matrix as the position compensation for the force control.

In Fig. 1, the product of K and the position error is added to the force control loop to construct a position compensator , which can avoid an excessive motion in the force directions and reduce the change of the force. As a result of it, the vibration produced by the disturbances of slide, friction, impact and so on can be reduced. Different from the fixed parameters, K is automatically tuned according to the fuzzy reasoning results based on the information of the environment so that the compensation can be more effective.

3 Procedure of fuzzy reasoning

In the position compensation, it is very important to select the value of K . Large K can increase the compensated effectiveness. But if K is too large, the force control may be intensely influenced by the change of the position so that assembly tasks can not be completed smoothly. Generally, K is decided by the position error and the force error. According to the relationship of K and the errors, which was proven in the previous experiments, the fuzzy rules shown in table 1 are given. In talbe 1 , $\triangle P$ and $\triangle F$ are the position error and the force error respectively. K is calculated by the focusing method.

Table 1 Fuzzy rule table

$\triangle F$ \ $\triangle P$	NB	NS	ZO	PS	PB
NB	PB	PM	PS	PM	PB
NS	PM	PS	ZO	PS	PM
ZO	PS	ZO	ZO	ZO	PS
PS	PM	PS	ZO	PS	PM
PB	PB	PM	PS	PM	PB

4 Experiment

In our research, a peg-and-hole task is taken as the experiment object. A planar Cartesian robot with three degrees of freedom, which is shown in Fig. 2, is used to complete the insertion task.

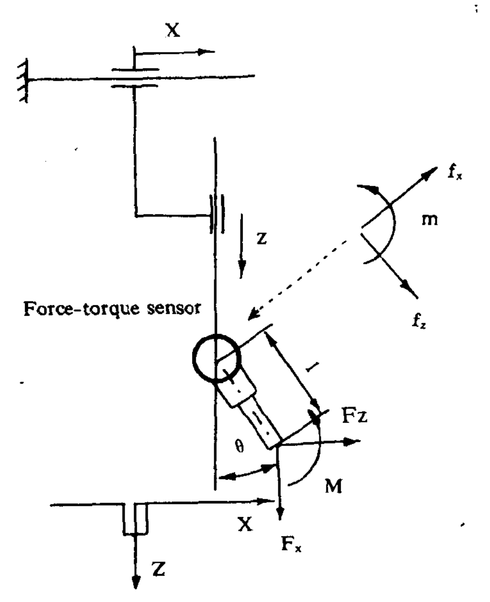

Fig. 2 Configuration of planar Cartesian robot

As shown in Fig. 2, no edge chamfer is provided both on the peg's edge and on the hole's edge, and a force-torque sensor is mounted on the wrist of the robot. The vectors in all coordinate frames are defined as follows:

$$F = [F_X, F_Z, M]^T;$$

$$f = [f_x, f_z, m]^T;$$

$$P = [X, Z, 0]^T;$$

$$p = [x, z, 0]^T.$$

The diameters of the hole and the peg are 12 mm and 11.95 mm respectively. The hole depth is 20 mm. The task is completed by dividing it into four steps (location, contacting, rotation, insertion), in which the control approach shown in Fig. 1 is used. The experimental results of the force and the position are shown in Fig. 3 and Fig. 4, respectively.

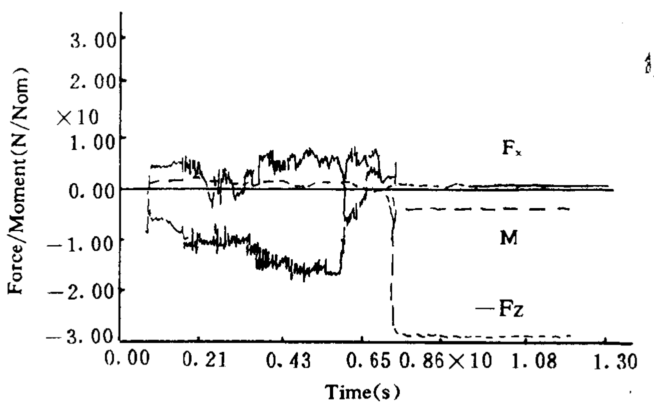

Fig. 3 Time-force diagram with the variable compensated parameters

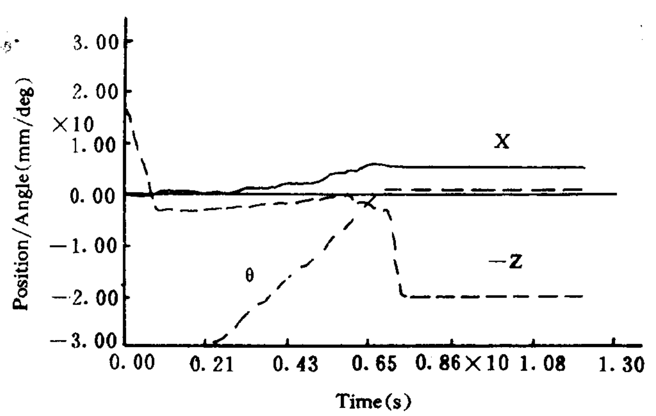

Fig. 4 Time-position diagram with the variable compensated parameters

Fig. 5 and Fig. 6 show the experimental results with the fixed compensated parameters.

Comparing Fig. 3 and Fig. 4 with Fig. 5 and Fig. 6, we find that by using the variable compensated parameters based on fuzzy reasoning, the vibration produced by the environmental disturbances can be eliminated and the assembly task can be completed smoothly.

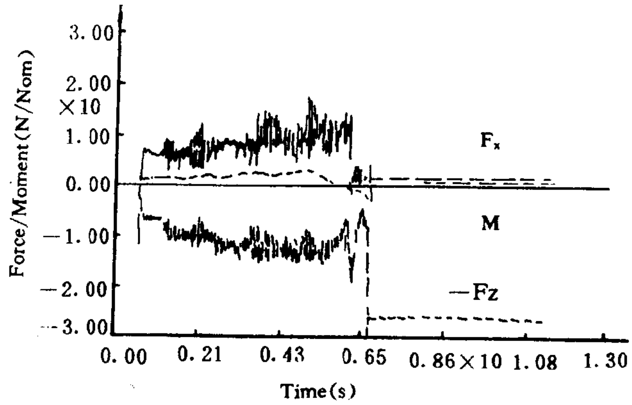

Fig. 5 Time-force diagram with the fixed compensated parameters

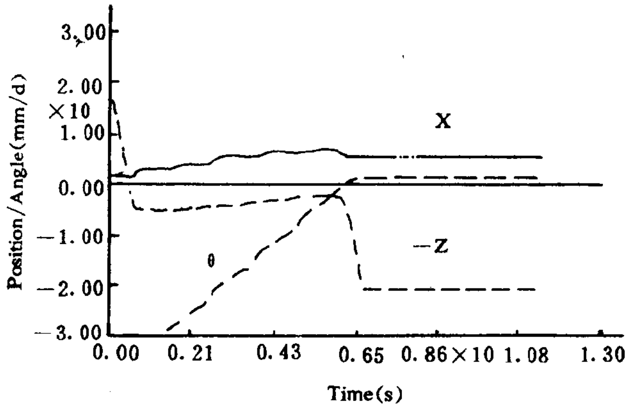

Fig. 6 Time-position diagram with the fixed compensated parameters

5 Conclusion

On the complicated environment, the force and position control of robots become difficult because the disturbances produced by contacting with the environment can not be modelled. Therefore, fuzzy control is a good solution for this problem. In this paper, a compensated method based on fuzzy reasoning is proposed and used to improve the hybrid control in assembly operation. The experimental results on a peg-and-hole task show that the method is effective in eliminating the vibration in the force directions.

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posing gene or genes in common with all tumors , including both the malignant and the benign ones, and every different tumor has it's own characteristic genes or environmental factors in addition.

Another phenomenon seeming to be consistent with the supposition was noted in Fusui where altogether seven communes were investigated. The lowest incidence of HM among the seven communes occurred in that one where the incidence of liver cancer and the incidence of malignancies in all were also the lowest while it was not true for the highest incidence of them (Table 4).

Familial aggregation of HM itself is not so common as a genetic tumor usually exhibits though there do have been a few number of sporadic cases reported in the literature. This perhaps might be explained by the followings: (1) HM can only occur in pregnant women; (2) the diagnosis can be missed in a number of early spontaneous abortion; (3) the mole itself can't survive and reproduce; (4) according to the well known theory of androgenesis, the development of HM would in quite a great measure depend on paternal factor; these would greatly reduce the chances for the disease to reccur in a same family.

Table 4 Distribution of incidence of HM in comparison with mortality of liver cancer and mortality of malignancies in all in seven communes of Fusui county

Name of commune	*Mortality of all malignancies (1/100 000)	*Mortality of liver cancer (1/100 000)	Incidence of HM (1/100 000 women)
Quli	101.54	63.22	273
Bapan	84.14	59.55	290
Zhongdong	72.06	51.04	395
Changping	71.95	62.96	142
Longtou	71.76	41.00	206
Funan	71.43	42.04	534
Liuqiao	52.68	39.51	137

* From *Fusui Liver Cancer Research*, 1979

According to a vast majority of relevant reports in the literature, there are two peaks of age incidence of HM, one before 30 and the other after 40 years , the later being higher than the former one. Whether the phenomenon implicates heterogeneity and the lower peak before 20 represants a genetic type of the disease also deserves consideration.

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