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Man-Machine System For Controlling Triple Inverted Pendulum

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ABSTRACT : Though fuzzy control is very popular at present, the application field of fuzzy system will be wider if we design it as a man-machine system. We suggest, in this paper, a man-machine cooperating system which makes easy the manual control of a triple inverted pendulum by simple fuzzy controller, and verify its effectiveness by experiments.

1 Introduction

Fuzzy control is very popular now, but its application field must be wider if design not only automatic system but also man-machine system.

We have studied fuzzy control systems which kept stable a double inverted pendulum. However, the identification of control rules is so difficult and also their membership functions are so sensitive that their design is not easy.

We suggest, in this paper, a man-machine cooperating system where a beginner operator can manipulate easily a triple inverted pendulum assisted by a simple fuzzy controller.

2 Automatic Fuzzy control System

The control object is a triple inverted pendulum as shown Fig.1. In this figure, θ, ϕ, ξ, are vertical incline angles of each arm, u is the position of platform, and L is the arm length.

The dynamics of the object is approximated by following linear differential equation under the assumption of small vertical deviation.

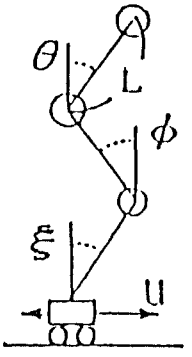

Fig.1 Triple Inverted pendulum

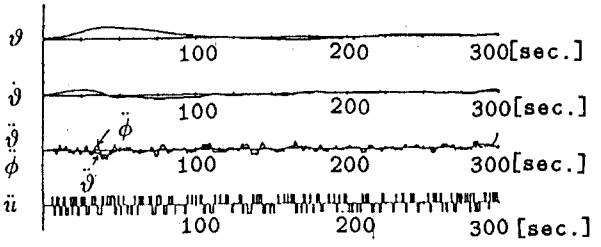

Fig.2 Result of manual control by skilled operator

$$\theta^{(6)}\text{-}9A\theta^{(4)}+18A^2\ddot{\theta}\text{-}6A^3\theta\cdot = -6A^2\ddot{u}/L \quad (1)$$

where A is equal to G/L, and G is the acceleration of gravity. We assume that L is 100m and G is equal to 1/50 of natural acceleration of gravity.

The motion of this system is simulated by a computer. An operator is required to the system stable by operating key board starting from the initial small deviate condition.The key board generates four sizes of step function in both plus and minus direction.

In this experiment,we choose $\theta, \dot{\theta}, \ddot{\theta}, \ddot{\phi}$ as the displayed state variables and $\ddot{u}$ as the manipulating variable. The operator manipulates $\ddot{u}$ to keep system stable.

Fig.2 shows a result of manual control by a skilled operator. It is seen that skilled operator can control such an unstable system stability. Aften observation and analyzing the operation of skilled persons, it is known that the performance of human is changed in accordance with the situation.

Therefore, a hierarchical structure is considered as an automatic fuzzy control system, where the rules are switched according to the states of system.

This fuzzy automatic control system goes well at the first 100 seconds, but can not stop the divergence after that.

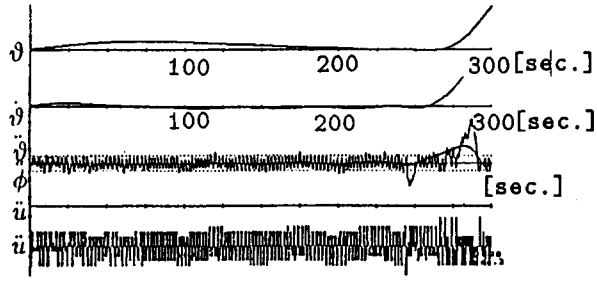

Fig.3 Result of fuzzy controller

Then, a counter plan, which modifies the membership functions of antecedents in accordance with the importance of variables, is put into practice. Fig.3 shows a result of this system. The control results are improved, but the divergence is not yet prevented completely. Moreover, the performance gets worse when the membership function or parameters are slightly changed. As the result, it is known difficult to keep stable the triple inverted pendulum automatically by such a simple fuzzy controller that has only the 32 rules.

Next, we consider a man-machine system which can control this triple inverted pendulum by a beginner operator who is supported by a simple fuzzy controller.

3 Man-Machine Cooperating System

Comparing human with controller, it is known that human is superior in the recognition of a whole situation, discernment, adaptability, and the robustness. But he is inferior in the speed and exactness, and also he can not keep the best condition for long time.

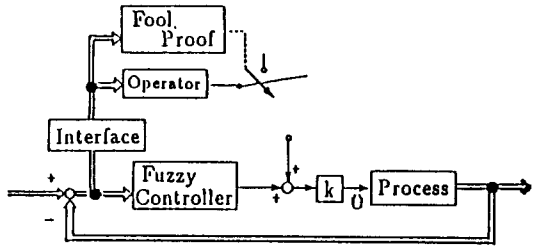

Fig.4 Block diagram of operation suport system

On the other hand, the fuzzy controller knows the control rules of skilled operator, and also is superior in the speed, exactness and durability. Man-machine cooperating system combines both the strong points and covers the defect points. In this system, controller lightens the human load and human covers the controller's sensitiveness.

The Block diagram of man-machine cooperation system is shown in Fig.4.

Table.1 Fool proof rules

θ	$\dot{\theta}$	$\ddot{\theta}$	$\dddot{\theta}$	o p	s w
+	+	+	+	−	off
+	+	+	−	+	off
+	+	−	−	+	off
+	+	−	+	+ −	on
+	−	−	+	+ −	on
+	−	−	−	+	off
+	−	+	−	+	off
+	−	+	+	−	off

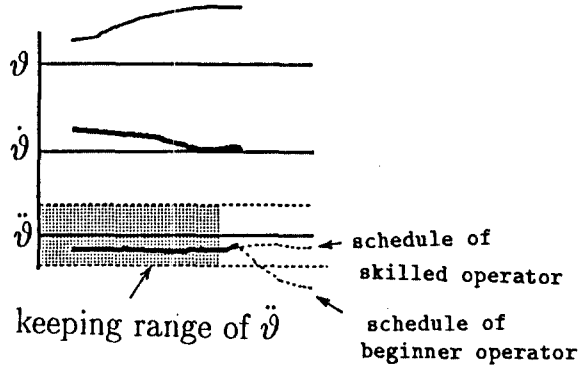

Fig.5 Display of keeping range

The fool proof controller in this figure has special switching rules as shown in Table.1 which covers the misoperation of human and prevents the divergency of fuzzy controller in almost stable condition. This protect rules are defined by the sign of $\theta, \dot{\theta}, \ddot{\theta}, \dddot{\theta}$ and of the control gain of human operation. For example, if $\theta > 0$ and $\dot{\theta} > 0$ and $\ddot{\theta} < 0$ and $\dddot{\theta} < 0$ and control gain> 0 then switch off.

The display and the operating board are also revised. The cause of over control by a beginner is that he can not keep $\ddot{\theta}$ within a certain range. Then, a criterion of θ is displayed as Fig.5 with dotted line. And also, the key is revised to generate two kinds of step function for preventing the over operation.

Moreover, the future values of state variables calculated from a mathematical model are displayed to compensate the delay of human action. The predication time of $\theta and \dot{\theta}$ is one second, and that of $\ddot{\theta}$ is three second.

The effect of the prediction time is shown in Fig.6 and Fig.7. Fig.6 is the care when prediction time is 3 second, and Fig.7 is the care when prediction time is zero. This man-machine cooperating system make the beginner to keep stable the triple inverted pendulum after few times of training.

Next, the value of G is changed from 1/50 to 1/35 of G natural acceleration of gravity. This means that the controllability of the object is decreased drastically. Fig.8 and Fig.9 show the effects predication time when G is equal to 1/35.

This man-machine cooperation system is successful to keep stable triple inverted pendulum by a beginner operator.

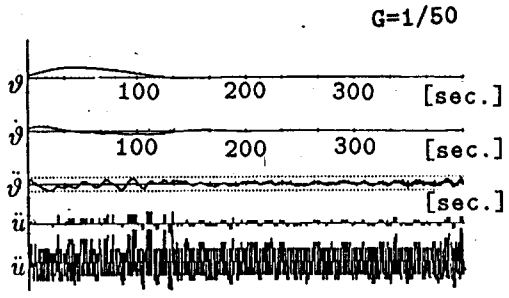

Fig.6 Prediction inteval (3sec.)

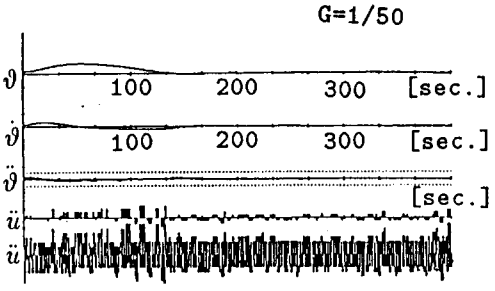

Fig.7 Control result of Fig.6 (0sec.)

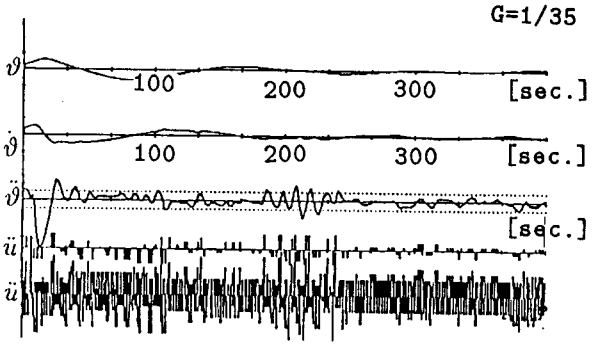

Fig.8 Prediction interval (3sec.)

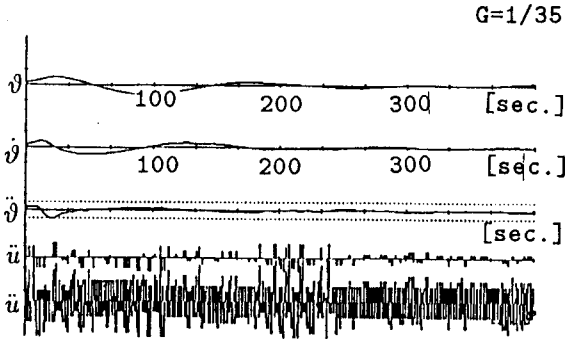

Fig.9 Control result of Fig.8 (0sec.)

4 Conclusion

Manual control of such a very unstable object as triple inverted pendulum is very difficult even for specially skilled persons and realized when future value of state variables are displayed. This action can be simulated by a fuzzy controller, but full automatic fuzzy control requires the identification of fuzzy rules and membership functions which are difficult and sensitive.

Man-machine cooperation system suggested here solves these problems completely.

That is, human operator and a simple fuzzy controller compensate their short points effectively.

As the result, even a beginner operator can keep stable the triple inverted pendulum easily. We shall develop many other applications of this automatic fuzzy control system.

References

[1] S.Masui, T.Terano, Y.Sugaya : Identification of Fuzzy Rules in a Manual Control System, Proceedings of the Congress,pp71/74.,(1989)

[2] S.Masui, T.Terano, Y.Sugaya : Prediction Effect on Manual Control of Unstable System,trans.IFE,pp79/85.,(1990),in Japanese

[3] S.Masui, T.Terano, Y.Sugaya : Identification of Fuzzy Rule on Manual Control of an Unstable System,trans.IFE,pp75/80(1991),in Japanese