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Adaptive Fuzzy Control of Yo-yo System Using Neural Network

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Abstract

The yo-yo system has been introduced as an interesting plant to demonstrate the effectiveness of intelligent controllers. Having nonlinear and asymmetric characteristics, the yo-yo plant requires a controller quite different from conventional controllers such as PID. In this paper is presented an adaptive method of controlling the yo-yo system. Fuzzy logic controller based on human expertise is referred at first. Then, an adaptive fuzzy controller which has adaptation features against the variation of plant parameters is proposed. Finally, experimental results are presented.

Key words : Yo-yo, Neuro-fuzzy, Adaptive Fuzzy. Benchmark Plant, Motor Control

1. Introduction

The effectiveness of a new controller or a novel control methodology is often demonstrated by applying it to a well-known benchmark plant. The inverted pendulum system(IPS) is one of the most frequently used plants of this kind.[1] Considering the IPS as a difficult problem involving nonlinearity, the plant has been widely used for the evaluation of various intelligent controllers in which novel techniques such as fuzzy logic, artificial neural-network, and/or genetic algorithms are employed.[1,2]

However, it should be pointed out that controllers other than those intelligent controllers such as a linear controller or a bang-bang controller, can successfully balance the inverted pendulum as well[1]. Therefore, it may well be said that the IPS does not reveal a clear evidence of the superiority of those intelligent controllers.

Therefore, authors have introduced the yo-yo system as an alternative benchmark plant, which may work better in demonstrating the superiority of the intelligent controllers [3]. Overall control system of the yo-yo system is shown in Figure 1.

The control objective of the IPS is to regulate the pole angle to be zero, whereas that of the yo-yo system is to continue up-and-down motion of the yo-yo disk.

Specifically, the control of the yo-yo system requires an asymmetric non-trivial controller with high nonlinearity due to the unique characteristics of the yo-yo system: a large force should be applied upwards in a short time to rewind up the thick disk especially when the disk nearly reaches to the lower end, while a small or zero force in downward direction may accelerate the disk to be unwounded down when the disk nearly reaches to the upper end because the gravitational force is always exerted on the disk.

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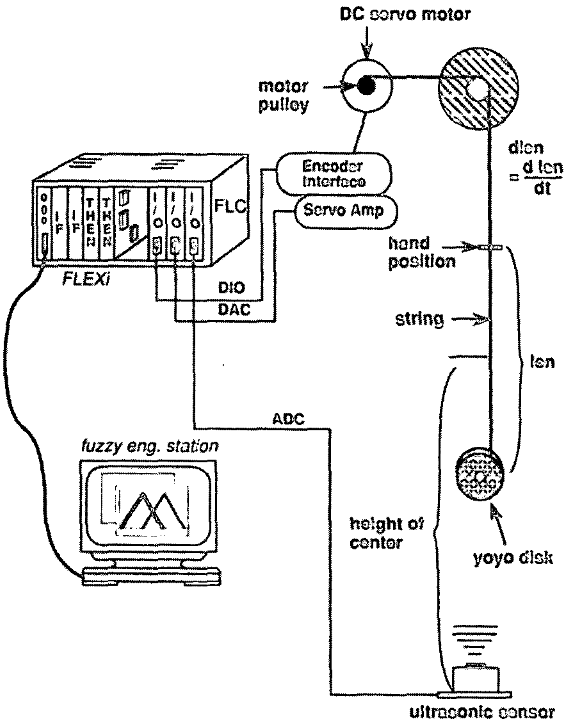

Fig. 1. Overall configuration of the yo-yo system

Due to this asymmetric nonlinearity, it seems more difficult to control the yo-yo system either by a linear controller or by a bang-bang controller.

In this paper is presented a new method of controlling the yo-yo system. In addition to the fuzzy logic controller based on human expertise, an adaptive fuzzy controller which has adaptation features against the variation of plant parameters is introduced. Also, the simulation result and the experimental result using those two types of controllers are compared.

2. Design of a fuzzy logic controller for the yo-yo system

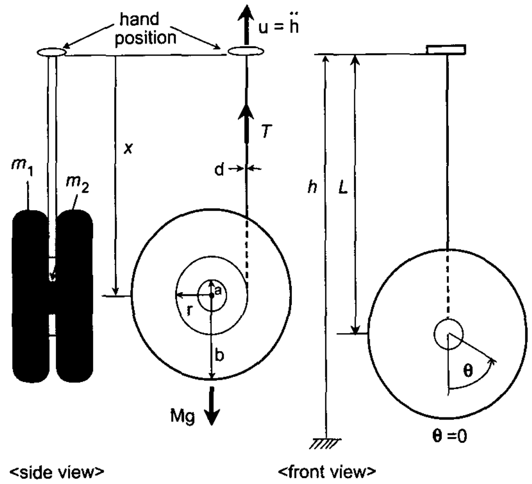

Fig. 2. Modeling parameters in the yo-yo system

Having parameters as in Figure 2, the dynamic equations of the yo-yo can be modeled as follows:

$$\ddot{\theta} = -\frac{g - u - \frac{d}{2\pi}\dot{\theta}^2 + K\theta sgn(\theta)}{\frac{I\theta}{M(a|\theta| + \frac{d}{2\pi}\theta^2)} + a \cdot sgn(\theta) + \frac{d}{2\pi}\theta}$$

$$\ddot{x} = -a \cdot sgn(\theta)\ddot{\theta} - \frac{d}{2\pi}(\dot{\theta}^2 + \theta\ddot{\theta})$$

The notations employed are found in [3].

Since the above yo-yo dynamics is not only highly nonlinear but also asymmetric, it is difficult to realize a controller by using conventional control theories. However, human beings with some training can control the yo-yo system very well without modeling the system.

Those control actions of human beings can be described by if-then rules and linguistic terms. It is well known that the if-then rules can be simply implemented as a machine controller by utilizing the fuzzy logic. So, the fuzzy logic controller(FLC) approach is considered at first.

The length of the yo-yo string (*len*), its time derivative (*dlen*) and height of center point (*center*) are used as input values of the FLC and the motor torque which moves the string of the yo-yo is calculated by the fuzzy inference.

After all, the control objectives of the FLC are to maintain the center value within a certain range and to continue the up-and-down motion of the yo-yo disk without reducing the length of the stroke.

14 rules are used to control the yo-yo system[3]. The rules and membership functions are obtained through the repetitive trial-and-error practices.

In the inference procedure of the FLC, the input values are fuzzified by the singleton fuzzy value while the Mamdani's Max-Min compositional rule of inference is used. For the defuzzification, the center of gravity method is utilized.

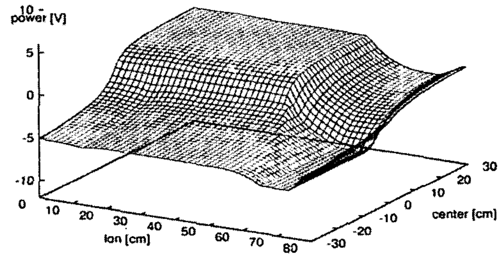

Fig. 3. The input and output relation when dlen=30cm/sec.

The input-output relation of the fuzzy controller is shown in Figure 3. As is stated in the introduction, the input-output relation of the FLC is asymmetric since the plant itself has such a characteristic. It is observed in the figure that the output value, *power*, is asymmetric along with the axis of *len*. Also, the magnitude of power is maximum just before the yo-yo disk reaches at the end of string, 80 cm, which means the controller takes into consideration the effect of time delay in the system. This kind of asymmetric behavior of the controller may not be obtained by any conventional PID controller.

The experimental data of the system states are shown in Figure 4. As shown in the experimental results, the values of the *len* and the *center* are periodically varied within respective uniform bounds.

This displays the fact that the FLC controls the yo-yo quite well as human beings do. It should be noted that the trajectory up to the moment of 48 seconds, results from the manual winding-up of the yo-yo disk in order to provide initial potential energy to the disk.

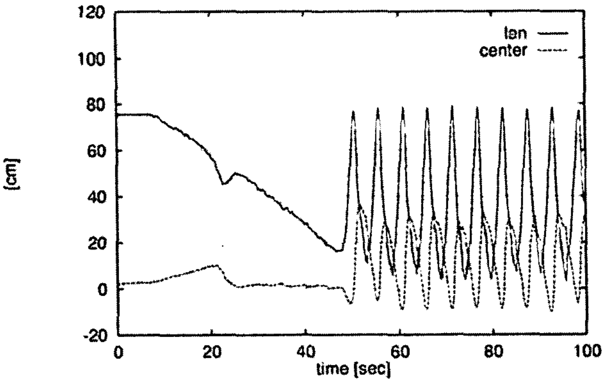

Fig. 4. State trajectories of the experimental results

3. An adaptive fuzzy approach to the yo-yo controller

As stated earlier, the main purpose of the yo-yo controller is to continue the dynamic motion of the yo-yo disk. There exist several factors, however, which make the yo-yo eventually to stop. In the experiment is observed that irregular disturbances due to the sway of the string or the friction between the guide strings and the disk prevent the yo-yo from stable or consistent movement. Despite these unfavorable factors, the designed FLC shows good performance if the values of I/O variables are within an allowable bound.

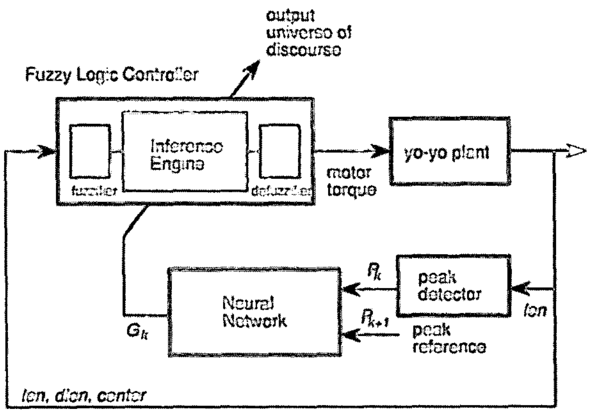

Fig. 5. The structure of the proposed adaptive fuzzy controller using neural network

When the yo-yo plant equipped with the FLC is put in the state of continuous operation, it is observed that the yo-yo motion may stop after an hour-long operation. Such failure may occur due to accumulated uncertainties caused by motion drifts and nonlinear frictions and the FLC has little adaptability for varying environment.

In order to overcome this problem, a neural network is introduced to adjust the output membership of the FLC. Actually, the shapes of output fuzzy labels are maintained, whereas the width of the output universe of discourse, denoted by G_k, is adjusted according to the performance of the FLC.

The performance of the controller is determined by using P_k and P_{k+1}, which denote the k-th and (k+1)th peak height of the yo-yo disk, respectively. It should be noted that the motion of the disk is continued if the P_k's are maintained within a bound, that is, the next peak height P_{k+1} should follow the previous peak height P_k.

Figure 5 shows the structure of the proposed adaptive fuzzy controller. The input to the neural network, P_{k+1}, is set to be a desired peak height in the controller operation. As a result, the FLC output is adjusted by the difference between the desired peak height and the current peak height of the yo-yo disk. The FLC in the figure has the same configuration as described in the previous section.

It is noted that obtaining a set of training data for the neural network that is sufficiently rich seems to be difficult in an experiment with a variety of P_k's and G_k's.

Therefore, a set of training data is first evaluated by simulating the FLC system utilizing the yo-yo model described in the section 2. About 500 P_{k+1}'s are obtained for various combinations of P_k's and G_k's. Utilizing the data, the neural network consisting of 2 input neurons, 1 output neuron and two hidden layers each of which has 10 neurons is trained by the well-known back propagation learning algorithm.

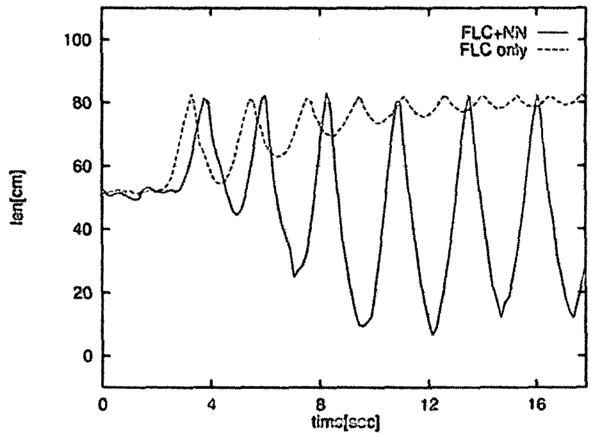

Fig. 6. Comparison between the two intelligent controllers

The proposed neuro-fuzzy controller is tested in the real yo-yo plant. Figure 6 shows the performance of the control system. Started with the same initial value, *len*=52cm, the FLC eventually stops moving, whereas the proposed adaptive fuzzy controller continues its motion. In the other experiment, it is observed that the movement of the yo-yo disk has longer life time than the case when the ony FLC is employed.

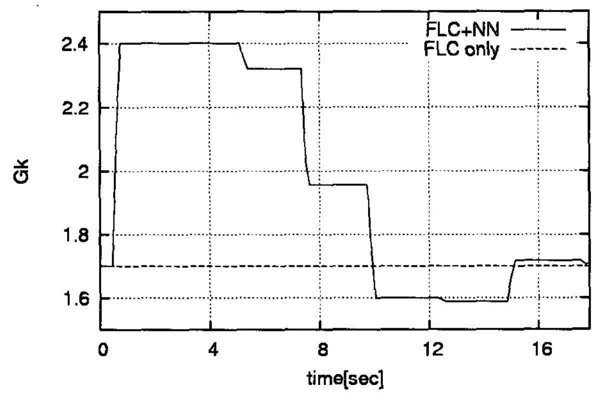

Fig. 7. Neural network output G_k with respect to time

The improvement of the performance is due to the on-line adaptation capability of the neuro-fuzzy controller. Fig. 7 reveals that the output of the neural network, G_k, is increased when the difference between the P_k and the P_{k+1} is large. By increasing the G_k, more power is delivered to the actuator to increase the peak height. Also, when the peak heights are regularized, G_k is regularized as well.

4. Concluding Remarks

It seems difficult to control the yo-yo plant by either a linear controller or a bang-bang controller because the yo-yo plant has an asymmetric nonlinear dynamics in nature.

As controllers for the yo-yo plant, two types of intelligent controllers are compared in this paper. The FLC, based on the fuzzy theory is designed by obtaining the if-then rules from the human experience.

Since the FLC has little adaptation characteristic to parameter variations, a neuro-fuzzy adaptive controller is designed and tested experimentally. The universe of discourse in the output membership functions in the FLC portion is adjusted by the neural network which is well trained to relate two peak heights of the yo-yo disk and the corresponding universe of discourse. With this adaptation feature, the adaptive fuzzy controller exhibits a longer life of the yo-yo motion than the case of FLC with no adaptation capability.

References

[1] S. Geva and J. Sitte, "A cartpole experiment benchmark for trainable controllers", IEEE Control Systems, pp. 40-51, Oct. 1993.

[2] A Barto, R. Sutton, and C. Anderson, "Neuronlike adaptive elements that can solve difficult learning control problems", IEEE Trans. Syst., Man, Cybern., vol. SMC-13, pp 834-846, 1983.

[3] Z.bien, Y. Lee, S. Lee, K. Shim, and S. Bang, "A new benchmark system for evaluation of intelligent controllers: An yo-yo system," in 4th IEEE Int. Conference on Fuzzy Systems, (Yokohama, Japan), pp. 1361-1366, Mar. 1995

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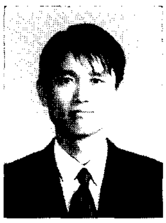

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