THE MONITORING AND CONTROL OF AN ARM CRANK SYSTEM USING FUZZY LOGIC FOR MULTI-HANDICAPPED YOUTHS WITH MENTAL RETARDATION

JIANN-SHING SHIEH, JEN-TSANG HUNG

Department of Mechanical Engineering, Yuan Ze University, Taoyuan, Taiwan

ABSTRACT

In this paper, we try to cope with National Special School in Taoyuan in order to fit the special requirements for multi-handicapped youths with mental retardation using current high technology, such as microcomputer control, sensing technology, and fuzzy logic control. The prototype device of this paper is focused on designing an arm crank system using a fuzzy logic controller (FLC) to exercise for the upper limb. The rotation velocity of this system was controlled via adjusting the electric current of the brake in order to increase the training motivation. Hence, a FLC was designed into this system in comparison with a manual control by an expert (i.e., physical therapist). Fifteen multi-handicapped youths with mental retardation were treated using the manual control as a control group, and another fifteen youths were treated using FLC as an experimental group. The root mean square deviation (RMSD) of the change of rotation velocity of arm crank was no significant difference ($p > 0.05$) using Student t test analysis. It means that FLC can be replaced the manual control by the qualified physical therapist. Therefore, it can be seen as a demonstration of feasibility of the applicability of this FLC for monitoring and control the velocity of the arm crank. But, it still needs a longer series of multi-handicapped youths with mental retardation, perhaps to refine the rule-bases, and certainly to see how widely they are applicable.

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1. INTRODUCTION

The National Special School in Taoyuan is to educate the youths of moderate/severe mental retardation and multi-handicap (ex., crippled and cerebral palsied). In the rehabilitation room of school, there are several exercise training and assistive devices for multi-handicapped students with mental retardation in order to exercise their upper and lower limbs. Also, a qualified physical therapist is always present during

training exercise. However, the devices in the rehabilitation room are mostly bought from either commercial exercise or rehabilitation devices combined with some parts of special design. Hence, they are very difficult to fit the multi-handicapped students with mental retardation due to their special requirements. Nevertheless, there are several disadvantages for students of using these devices according to the school's experience during the past few years, such as lack of training motivation, difficult to teach the standard operation, large individual variations, and lack of quantitative evaluation.

One problem with feedback control in biomedicine is that there are enormous patient-to-patient variations in dynamic model parameters. This is compounded by large time-varying parameters for an individual patient during the course in the rehabilitation

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Correspondence: Dr. Jiann-Shing Shieh, Department of Mechanical Engineering, Yuan Ze University, Taoyuan, Taiwan.

Fig 1. The schematic diagram of an arm crank system for either right or left arm

room. This makes it difficult to design a fixed-parameter PID controller which will be suitable in all cases. This led to the need to investigate self-adaptive control strategies, and later self-organizing controllers. A model-based self-tuning PID approach has been implemented in a series of clinical trials [1]. Although the self-tuning trials have been successful, they have involved considerable work in selecting the design parameters and mathematical models of the patient. However, the lack of training motivation, difficult to teach the standard operation, large individual variations, and lack of quantitative evaluation for the youths of moderate/severe mental retardation and multi-handicap in the rehabilitation room of school have made this approach more difficult.

Fuzzy logic control (FLC) is a simple and effective technique for controlling non-linear and uncertain processes [2,3]. Fuzzy logic not only accommodates uncertainty by dealing in imprecise, qualitative terms such as low, medium and high but also provides control rules which are easy to understand and modify when discussing with experts. In 1965, fuzzy set theory was introduced by Zadeh [4] and it has been used successfully in a number of control applications [5,6]. Much of human problem solving and inference is uncertain, inexact and partial, i.e. it is fuzzy. In many circumstances where decisions have to be made, the facts are far from precise. This paradigm seems to be specially suitable for biomedical processes [7-10], since it

depends upon expert experience which are not precisely quantifiable, such as patient's subjective sensations, interpretation of clinical signs and effects of instrument accuracy.

Hence, the prototype device of this paper is focused on designing an arm crank system using a FLC to exercise for the upper limb [11-15]. Except the basic requirements of these exercise training devices (such as pedaling and rotating), we still need to consider the sensing and biofeedback, computer fuzzy logic control (especially for the individual control of left and right sides), and automated record and keeping system. Hopefully, the research results can not only solve the current problems in National Special School in Taoyuan but also apply to other special schools, handicapped people, and elderly society in Taiwan.

2. CONTROL SYSTEM DESIGN

The current devices in the rehabilitation room for arm cranks are mostly bought from either commercial exercise or rehabilitation devices combined with some parts of special design. They are very difficult to fit the multi-handicapped students with mental retardation due to their special requirements. Hence, we redesigned the commercial product in order to fit their special requirements, especially for the individual control of left and right sides. Three parts have been designed into the arm crank system as shown in Fig. 1, which are two magnetic brake devices for controlling the resistances of each arm, two potentiometer sensors for measuring the each side of the velocity of the arm crank, and an electronic circuit for computer control of this system.

Manual adjustment of the arm crank prescription is currently the method by which an expert physical therapist can be accommodated. In this paper, we not only keep a manual control but also develop a fuzzy logic control applied in this device in order to replace an expert that controls the rotation velocity of an arm crank via a signal from the electric current of the brake of this device as shown in Fig. 2.

Fig. 3 shows the FLC control structure. The

Table. 1 The qualified physical therapists' rule-base for controlling the rotation velocity of an arm crank system using change of electric current of the brake inside the device

Δ Current		Rate		
		S	SB	B
Δ Rate	NB	NB	NS	NS
	NS	NS	Z	Z
	Z	Z	Z	PS
	PS	Z	PS	PS
	PB	PS	PS	PB

fuzzy logic controller was designed to control the rotation velocity of the arm crank exercise via a signal from the electric current of the brake. Control rules, membership functions and defuzzification are three essential elements in the fuzzy logic control. To perform fuzzy inference and describe the arm crank control system, we chose two inputs which were the rotation velocity (Rate) and the change of the rotation velocity (Δ Rate) of each arm, and one output which was the change of the electric current of the brake (Δ Current) of each arm. In order to fuzzify the inputs and output, the rotation velocity was divided into three levels which were the big (B), between small and big (SB), and small (S). There is no any negative fuzzy set because of the non-feasible nature for rotation velocity. And, the change of rotation velocity was divided into five levels which were the negative big (NB), negative small (NS), zero (Z), positive small (PS), and positive big (PB). Also, the change of the electric current of the brake was divided into five levels which were the negative big (NB), negative small (NS), zero (Z), positive small (PS), and positive big (PB). According to the qualified physical therapists' experience, the following fifteen rules were developed to control the arm crank system as shown in Table 1. There are many shapes of possible membership functions, such as triangle, trapezoid etc. which can be used in the fuzzy logic controller. For simplicity and popularity, a triangle shape is used and a 25 percent overlap for contiguous fuzzy sets is reckoned [16] as shown in Fig. 4 for

two inputs (Rate and Δ Rate), and one output (Δ Current).

When Rate and Δ Rate have been obtained, one can decide which quantized levels belong to them. There are two main procedures for the rules implication and inference which are used in most controllers, Max-Min and Max-Product procedures [17]. The former method was adopted in this study. Also, the inference engine works by using Gupta et al's [18] method, which involves the decomposition of multivariable fuzzy system into a set of one-dimensional systems. The input, output variables and fuzzy relations are described by the following equations:

$$R_{ij} = \bigvee_{k=1}^p [X_i(k) \wedge Y_j(k)]$$

$$Y_j = \bigwedge_{i=1}^m (X_i \circ R_{ij})$$

where X_i is the fuzzy value of the i -input variable; Y_j is the fuzzy value of the j -output variable; R_{ij} is the fuzzy relation of the i -input and j -output variable; m are the number of input variables; p are the number of rules; $\circ$ is the max-min composition; $\wedge$ is the min operator; $\bigvee$ is the max operator.

Finally, there are two main methods for defuzzification procedures, mean of maximum (MOM) and centre of area (COA) [19]. The latter procedure has been adopted because it gives smoother signals. Therefore, the equation of COA procedure for the control input can be written in the following equation [20]:

Fig. 2 The block diagram of manual control and fuzzy logic control of an arm crank system

Fig. 3 A fuzzy logic controller structure of an arm crank system

$$I = \frac{\sum_{i=1}^n (Mn \times Un)}{\sum_{i=1}^n Mn}$$

Where M is the membership function; U is the universe of discourse; n is the number of rules.

3. PATIENTS AND METHODS

Thirty multi-handicapped youths with mental retardation was divided into two groups. Group 1 (i.e., 15 youths) was the control group using the manual control by a qualified physical therapist. Group 2 (i.e., 15 youths) was the experimental group using a fuzzy logic control. During 10 min training exercise experiments either a manual or FLC control, a qualified physical therapist involved in the study was always present and responsible for standard monitoring of the multi-handicapped youths with mental retardation. Also, one investigator who designed this monitoring and control system is always present and responsible for handling any device or computer malfunction in order to bring the system back to control by the qualified physical therapist. The analog signals were done via PCL-812PG ADDA card (Advantech Co. Ltd, Taipei, Taiwan) which were interfaced to the arm crank system. The whole system was programmed in language "Visual Basic" and an IBM compatible computer was used for collection, display, control and storage of data of an arm crank system as shown in Fig. 5, which was installed in National Special School in Taoyuan. In addition, the whole system was still under supervision by the qualified physical therapist.

4. RESULTS

Fifteen multi-handicapped youths with mental retardation using manual control as group 1 and another fifteen youths using FLC control as group 2 were studied at 10 min training exercise period. The root mean square deviation (RMSD) of the change of rotation velocity of arm crank was calculated in these two groups for each experiment. The mean (SD) of RMSD of the change of rotation velocity for the group 1 and group 2 methods as shown in Table 2 were 0.02410 (0.01146) and 0.02650 (0.00896) rad/s, respectively. The RMSD of the change of rotation velocity of arm crank was no significant difference ($p > 0.05$) using Student t test analysis. It means that FLC can be replaced the manual control by the qualified physical therapist. Finally, the full graphical results from two clinical trials are shown in Fig. 6 to demonstrate the performance of rotation velocity, change of rotation velocity and change of current of the arm crank system during the manual and

Fig. 4 Membership functions of two inputs and one output (a) Rate (b) Δ Rate (c) Δ Current

Fig. 5. An IBM compatible computer used for collection, display, control and storage of data for an arm crank system during a clinical trial in National Special School in Taoyuan.

FLC control.

5. DISCUSSIONS

Currently, the fuzzy rules were derived from expert experience and have been shown to be similar to the qualified physical therapist in the clinical trials. However, there are some drawbacks to this design approach. Firstly, a reliable linguistic model of the

Table 2 The root mean square deviation (RMSD) of the change of rotation velocity of arm crank system for different groups (Group 1: Manual control; Group 2: Fuzzy logic control)

Patient No.	RMSD of Group 1	RMSD of Group 2 (rad/s)
1	0.01586	0.02091
2	0.01968	0.01749
3	0.01178	0.02323
4	0.01920	0.02123
5	0.05844	0.02567
6	0.02929	0.02374
7	0.01739	0.02487
8	0.02204	0.02522
9	0.03597	0.01035
10	0.01630	0.02212
11	0.01652	0.02820
12	0.01941	0.04520
13	0.02603	0.03411
14	0.02354	0.04106
15	0.03001	0.03405
Mean	0.02410	0.02650
SD	0.01146	0.00896
<i>t</i> -test	$p = 0.54$	

physical therapist's control strategy may not always be obtainable. Secondly, some significant system changes may be outside the physical therapist's experience. Thirdly, some system combined with multi-handicapped youths with mental retardation may always have large uncertainty due to characteristics of inter-variations. Therefore, the applications of fuzzy controllers are limited and they need to be enhanced. Hence, much research will have to be carried out especially in the area of self-tuning rules. There are many publications [21-23] investigating this area of self-organizing fuzzy logic control (SOFLC). It can provide an adaptive rule-learning capability to complement a fuzzy logic control strategy. Using SOFLC will permit more accurate control of an arm crank system to benefit multi-handicapped youths with mental retardation.

Movement and position of limbs are controlled by electric signals traveling back and forth between the muscles and peripheral and central nervous system. When pathologic conditions arise in the motor system, whether in the spinal cord, the motor neurons, the muscle, or the neuromuscular junctions, the characteristics of the electrical signals in the muscle change. Careful registration and study of electrical signals in muscle (i.e., electromyograms) can thus be a valuable aid in discovering and diagnosing abnormalities not only in the muscles but also in the motor system as a whole. Electromyography (EMG) is the registration and interpretation of the muscle action potentials [24]. Hence, the future work in our arm crank system is

needed to consider not only the monitoring EMG signals but also the using the EMG as a biofeedback signal into system

6. CONCLUSION

Clinically this FLC system was useful. It provided the similar RMSD of the change of rotation velocity of an arm crank compared with the manual control. It can reduce the need for the qualified physical therapist to spend time controlling the rotation velocity of an arm crank system. Also, it can be seen as a demonstration of feasibility of the applicability of this FLC for monitoring and control the rotation velocity of the arm crank. But, it still needs a longer series of multi-handicapped youths with mental retardation, perhaps to refine the rule-bases, and certainly to see how widely they are applicable.

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Fig. 6 The performance of rotation velocity, change of rotation velocity and change of current of the arm crank system during the manual and FLC control (a) Manual control of left arm (b) Manual control of right arm (c) FLC control of left arm (d) FLC control of right arm. Notation in the figures: V_L , the rotation velocity of the left arm; ΔV_L , the change of rotation velocity of the left arm; $Current_L$, the electric current of the brake of the left arm.

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