COMPARATIVE STUDY ON MATHEMATICAL AND BLACK BOX MODELLING APPROACHES OF MUSCULOSKELETAL SYSTEM

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Functional electrical stimulation (FES) is used to restore the functional of paralyzed muscle using electrical signals due to spinal cord injury (SCI). Modelling and hence simulation study can greatly facilitate to test and tune various FES control strategies. A few techniques for the modelling of musculoskeletal system are described. Modelling of musculoskeletal system with spinal cord injury is challenging because of the complexity of the system. The main objective of this study is to do the comparative study on the mathematical and black box modelling approaches of musculoskeletal system. Black box modeling approaches are found more appropriate for musculoskeletal system due to complexity of this system.

Keywords: musculoskeletal system, SCI, FES, black box model.

1.0 INTRODUCTION

Modelling of muscloskelatal systems of the people with spinal cord injury (SCI) has been a topic of active research for several decades.A musculoskeletal system is an organ system that gives humans the ability to move using the muscular and skeletal system. The musculoskeletal provides form, support, stability, and movement to the body. Musculoskeletal system is a complex system since it is highly non linear and time-varying nature. Therefore the modeling process becomes more difficult. Many researchers have developed musculoskeletal models ranging in levels of sophistication from simple to complex.

Functional electrical stimulation (FES) is a promising way to restore mobility for individuals paralyzed due to SCI by applying low-level electrical current is to an individual with disability so as to enhance the person's ability to function and live independently. Figure 1 shows the basic electrical stimulation system.
Models of the musculoskeletal system are valuable tools in the study of human movement in order to test and tune various FES control strategies. In order to develop a control strategies for the FES to move the leg correctly, a proper model of the stimulated muscle has to be used.

Most musculoskeletal models built either on experimental or physiological bases are not appropriate for control applications, since these models characterize each muscle feature alone, and sometimes there is no connection betweenthe modelled features which may prevent from modelling the whole muscle as one model (Massaoud, 2007). There are two approaches that are commonly used to model the musculoskletal systems, mathematical and black box modeling approaches. This paper presents comparative assessment between a mathematical and black box model for musculoskeletal system for the FES control development. The advantages and disadvantages of mathematical and black box model approaches are outlined. Different types of black box modeling techniques such as the adaptive fuzzy modeling, fuzzy modeling with genetic algorithm optimization, and fuzzy neural network are investigated.

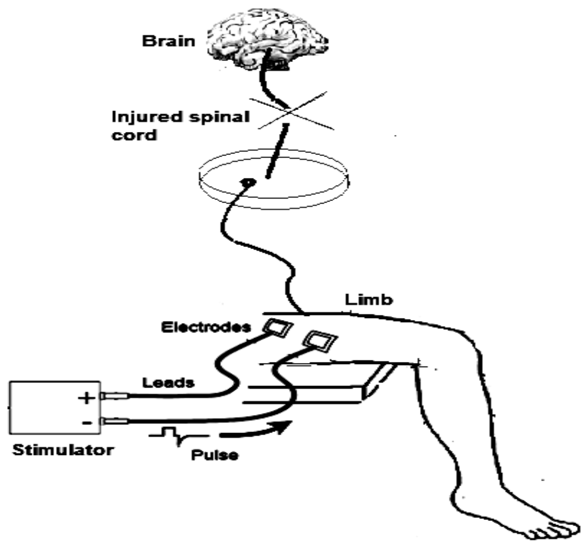

Figure 1: A Basic Electrical Stimulation System

2.0 MATHEMATICAL MODELLING APPROACHES

Most models built on analytical bases are not suitable for FES control applications (Massoud, 2007). One way to develop this model for FES control application is to use mathematical models. Thus, empirical model strategies, which aim to describe the input-output characteristics of muscle (often limited to conditions common in FES applications), and whose structure is suitable for the design of stimulation controllers, become useful. As a result, many researchers have developed mathematical models of electrically stimulated muscle based on Hill-type (Ding, 2002; Shue and Crago, 1998), Huxley-type (Zahalak and Ma, 1990), analytical approaches (Bobet and Stein, 1998, Ferrarin and Pedotti, 2000) and physiology approach (Riener and Fuhr, 1998). A review of empirical modelling approaches for muscle is given in Durfee (1992).

The use of mathematical models can significantly enhance the design and evaluation of closed loop control strategies applied to FES (Reiner, 1999). In fact, mathematical models can be used to promote an understanding of the system and they can be used to predict the behaviour of the system (Zahalak, 1992). Mathematical models of artificial muscle activation in healthy or paraplegic subjects have been developed but the complexities of the system resulting mathematical representation have a large number of parameters that make the model identification process difficult.

The most appropriate complete model that can be used for FES control applications have been developed by Riener et al. (1999) and Ferrarin and Pedotti (2000). Ferrarin and Pedotti (2000) have presented a straightforward and simple approach to model the knee through identification of the relationship between stimulation parameter, pulse width and active knee joint torque produces by the stimulated quadriceps muscle in a non-isometric condition. A mathematical in the first order transfer function obtained by a least square error method has been developed. It has been optimally modelled as a single pole autoregressive with exogenous terms (ARX) model relating pulsewidth (input) and active muscle torque (output). However, the accuracy of this model has been criticized as in Ferrarin et al. (2001) and Massoud (2007).

The model has been found to perform quite well in terms of model prediction tests with passive pendulum test, isometric moment vs. pulsewidth and different stimulation patterns for freely swinging shank. Riener et al. (1999) has developed a mathematical model based on the muscle physiology. However, this model requires many individualized parameters to be identified and therefore it makes the modelling process more complicated.

3.0 BLACK BOX MODELLING APPROACHES

A black box is a representation of the system which can be viewed solely in terms of its input, output and transfer characteristics without any knowledge of its internal workings, that is, its implementation is "opaque" (black). It also can define as a computer program into which users enter information and the system utilizes pre-programmed logic to return output to the user.

There are some modeling approaches have been used to develop a black box model such as fuzzy logic, neural network, genetic algorithm, or hybrid. A black box model is used where the response of a system is not broken into its underlying mechanisms. It also represented by an empirical description that do not describe any internal physics.

The advantage of black box model is that it is fast running. Because black box models usually consist of a set of rules and equations, they are easy to optimize and can run very rapidly. Black box model also have minimal computing power. Because a black box model is relative simple, it does not require a great deal of computing power. In this paper different types of black box modeling techniques such as adaptive fuzzy modeling, fuzzy modeling with genetic algorithm optimization, and fuzzy neural network are investigated.

A. Adaptive fuzzy modeling

Fuzzy logic techniques have been widely applied to modeling of complex non-linear plants [3]. Fuzzy logic is the fastest growing soft computing in medicine and biomedical engineering [4]. An on line adaptive modelling and control scheme based on T-S fuzzy model has been proposed. Both the structure and parameters of the T-S model can be update on line [3]. From that, makes it capable of approximating complex nonlinear dynamic systems.

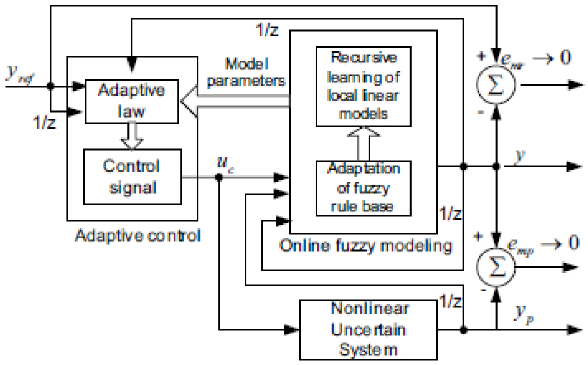

Figure 2: Adaptive control based on T-S fuzzy model

Figure 2 shows a diagram of the overall control system structure. The scheme consists of two parts: a dynamic T-S fuzzy model and adaptive controller based on the model. Both the structure and parameters of the T-S model can be updated on-line, which makes its capable of approximation complex nonlinear dynamic systems. The scheme is computationally efficient and suitable for real time implementation as the rule base evolution is recursive based on unsupervised learning and the parameters are adjust by RLSE.

B. Fuzzy Neural network (ANFIS)

The fuzzy neural network approach to nonlinear process modeling provides a way of opening up the purely 'black box' approach normally seen in neural network models [5]. Fuzzy neural network models are easier to interpret than conventional neural network models. The fuzzy neural can be trained using any of a number of training methods, such as the back propagation.

Fuzzy logic and neural network relational models show great potential for modeling highly non-linear system. The two techniques can be targeted at the same role, they are fundamentally different.

The big disadvantage that relational modeling has over rule-based system is that the values in the relational model can be identified directly from process input output data [6]. J. Zhang and A.J Morris (1995) consider to model the nonlinear dynamic behavior of a pH reactor and two static nonlinear systems by using the fuzzy neural network algorithm.

The fuzzy neural network modeling approach combines the advantages of both fuzzy modeling and neural networks. The network topology based on the structural approach is shown in figure 3. It contains four layers, namely fuzzification layer, rule layer, function layer, and defuzzification layer.

Referring to the references paper under review, the third - three presented the use of fuzzy logic in the modeling process. The advantage to the use of fuzzy logic based scheme when compared to conventional mathematical methods is that fuzzy logic is simpler to implement as it eliminates the complicated mathematical modeling process by using set of fuzzy rules instead.

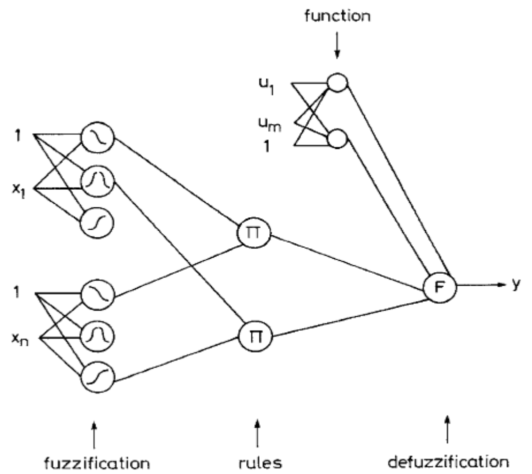

Figure 3: The structural approach fuzzy neural network

C. Fuzzy modeling with Genetic algorithm optimization

Ibrahim et al.(2011) proposed a new modeling technique based on fuzzy logic optimized using genetic algorithm to model the musculoskeletal system. The results showed a notable improvement in the modeling technique. The estimated models exhibited good prediction capabilities, it is comparatively less burdened with complex mathematics. Biological inspired computation technique, genetic algorithm is used in designing fuzzy modes, particularly for generating fuzzy rules and adjusting membership function The study has identified some of the potential benefits of using fuzzy logic and GA. In comparison with conventional quantitative techniques, fuzzy logic is simpler to implement as it eliminates the complicated mathematical modelling process and uses a set of fuzzy rules instead.

The optimization process is divided into two stages. Firstly, genetic algorithm is used to estimate the anthropometric inertia parameter and adjust the fuzzy parameters to represent by minimizing the error between the data obtained. These optimized equations are used in modeling. Secondly, the active properties are modeled based on input and output data from electrically stimulated test using MOGA (Multi Objective Genetic Algorithm). Figure 2 show the optimization of active properties using MOGA with integrating estimated joint viscoelasticity and optimized equation of motion based on experimental data.

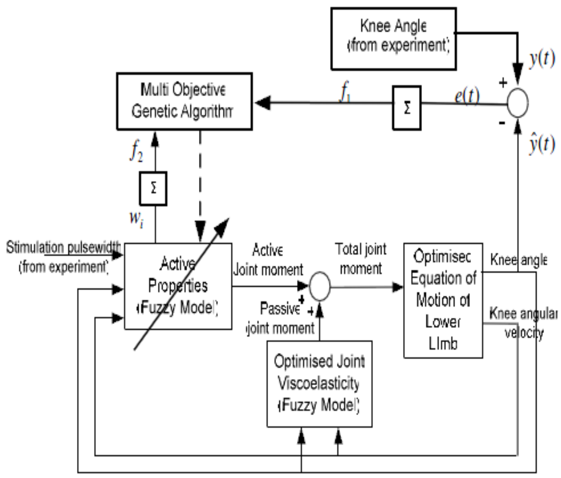

Figure 2: Optimization of active properties

4.0 DISCUSSION AND CONCLUSION

The survey of literature in this paper is intended to highlight the challenges and problems related to the muscloskeletal model of human lower limb for simulating FES applications. There are many techniques that can be used to model the musculoskeletal system. Most appropriate techniques for FES control development are based on mathematical modeling approach and black box modeling approach. In general, a model should be kept as simple as possible, that is, its order and number of parameters should be as low as possible. A too simple a model lacks depth of understanding the system properties and leads to inaccurate representation of system behaviour. Conversely, a too complex a model may lead to an inability to gain sufficient insight into system behaviour due to the tendency to get lost in model details such as parameter identification. In fact, musculoskeletal systems are complex, being inherently higher-order and nonlinear. Therefore from this study it shows that mathematical model is not applicable for this system because of mathematical representation has a large number of parameters that make the model identification process difficult. Black box modeling approaches exhibited good prediction capabilities; it is comparatively less burdened with complex mathematics. It is recommended to use a black box modeling approach for this system since it is simpler to implement as it eliminates the complicated mathematical modeling process.

5.0 REFERENCES

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