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Modeling and control of non-linear systems using soft computing techniques

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Abstract

This work is an attempt to illustrate the utility and effectiveness of soft computing approaches in handling the modeling and control of complex systems. Soft computing research is concerned with the integration of artificial intelligent tools (neural networks, fuzzy technology, evolutionary algorithms, . . .) in a complementary hybrid framework for solving real world problems. There are several approaches to integrate neural networks and fuzzy logic to form a neuro-fuzzy system. The present work will concentrate on the pioneering neuro-fuzzy system, Adaptive Neuro-Fuzzy Inference System (ANFIS). ANFIS is first used to model non-linear knee-joint dynamics from recorded clinical data. The established model is then used to predict the behavior of the underlying system and for the design and evaluation of various intelligent control strategies.

Keywords: ANFIS; Neural networks; Modeling; Intelligent control

1. Introduction

The current trend in intelligent systems or soft computing research is concerned with the integration of artificial intelligent tools (neural networks, fuzzy technology, evolutionary algorithms, . . .) in a complementary hybrid framework for solving complex problems.

Fuzzy logic offers the important concept of fuzzy set theory, fuzzy if-then rules and approximate reasoning which deals with imprecision and information granularity. Neural networks have on their side the capability for learning and adaptation by adjusting the interconnections between layers, while genetic algorithms make use of a systemized random search and are important for optimization.

Neuro-fuzzy techniques have emerged from the fusion of Artificial Neural Networks (ANN) and Fuzzy Inference Systems (FIS) and form a popular framework for solving real world problems. A neuro-fuzzy system is based on a fuzzy system which is trained by a learning algorithm derived from neural network theory. While the learning capability is an advantage from the viewpoint of FIS, the formation of linguistic rule base will be advantageous from the viewpoint of ANN. There are several approaches to integrate ANN and FIS and very often the choice depends on the application [1,2].

The growing interest in the field is demonstrated by the ever-increasing applications in various areas extending from image and pattern recognition to identification and control applications.

Intelligent control emerged as a viable alternative to conventional model-based control schemes. This is because with fuzzy logic and neural networks issues such as uncertainty or unknown variations in plant parameters and structure can be dealt with more effectively and hence improving the robustness of the control system.

The present work will concentrate on the pioneering neuro-fuzzy system, Adaptive Neuro-Fuzzy Inference System (ANFIS) [3], which is presently available in MatLab®. ANFIS belongs to the class of rules extracting systems using a decompositional strategy, where rules are extracted at the level of individual nodes within the neural network and then aggregating these rules to form global behavior descriptions. The objective of this research work is to explore a number of control strategies for Functional Electrical Stimulation (FES) induced gait.

FES is a rehabilitative technology that can restore muscle activity to people who have suffered spinal cord injury and become paralyzed. The technique consists of applying a variable pulsewidth input signal in order to alter the level of

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contraction of the quadriceps muscle group to perform the motion of the shank. The output signal of the system is the angle between the thigh and shank.

High performance FES control system design relies heavily on the availability of a precise knee-joint model. ANFIS like systems have proven to be able to deliver very accurate models and are therefore suitable candidates for such applications [4].

The non-linear, time-variant behavior of the knee-joint dynamics under FES has led us to investigate various control strategies based on neural networks and adaptive neuro-fuzzy approaches.

It has been shown that with the aid of ANFIS, it is possible to create a Fuzzy Inference System that emulates the behavior of the neuromuscular system on the basis of available recorded real-time data.

For controller design and performance evaluation purposes this ANFIS based knee-joint model will be is used in the simulation study.

2. Neuro-fuzzy modeling approach

Conventional approaches to system modeling rely heavily on mathematical tools which emphasizes a precise description of the physical quantities involved. By contrast, modeling approaches based on neural networks and fuzzy logic are becoming a viable alternative where the former conventional techniques fail to achieve satisfactory results.

Neuro-fuzzy modeling is concerned with the extraction of models from numerical data representing the behavioral dynamics of a system.

This modeling approach has a two-fold purpose:

- It provides a model that can be used to predict the behavior of the underlying system.
- This model may be used for controller design.

The main steps of a fuzzy inference, i.e. fuzzyfication of the input physical variables and computation of the degree of satisfaction of the available linguistic terms, the conjunction of the premises as well as the actual fuzzy inference and defuzzyfication, are realized in sequentially ordered layers of a neural network with an architecture such that the weights to be adjusted in the network (usually by means of a gradient descent algorithm) have a meaning as parameters of the rules to be extracted.

2.1. Overview of ANFIS

ANFIS implements a Takagi Sugeno FIS and has a five-layered architecture as shown in Fig. 1.

- The first layer represents fuzzy membership functions.
- The second and the third layers contain nodes that form the antecedent parts in each rule.
- The fourth layer calculates the first-order Takagi-Sugeno rules for each fuzzy rule.
- The fifth layer—the output layer, calculates the weighted global output of the system.

ANFIS uses backpropagation learning to determine premise parameters and least mean squares estimation to determine the consequent parameters. This is referred to as hybrid learning. A step in the learning procedure has got two passes: in the first or forward pass, the input patterns are propagated, and the optimal consequent parameters are estimated by an iterative least mean square procedure, while the premise parameters are assumed to be fixed for the current cycle through the training set. In the second or backward pass the patterns are propagated again, and in this epoch, back propagation is used to modify the premise parameters, while the consequent parameters remain fixed. This procedure is then iterated until the error criterion is satisfied. A detailed description on ANFIS architecture and learning procedure is given in Appendix A.

2.2. ANFIS based modeling of knee-joint dynamics

Given the real time input–output data of the knee-joint system, ANFIS as part of MatLab's Fuzzy Logic Toolbox has

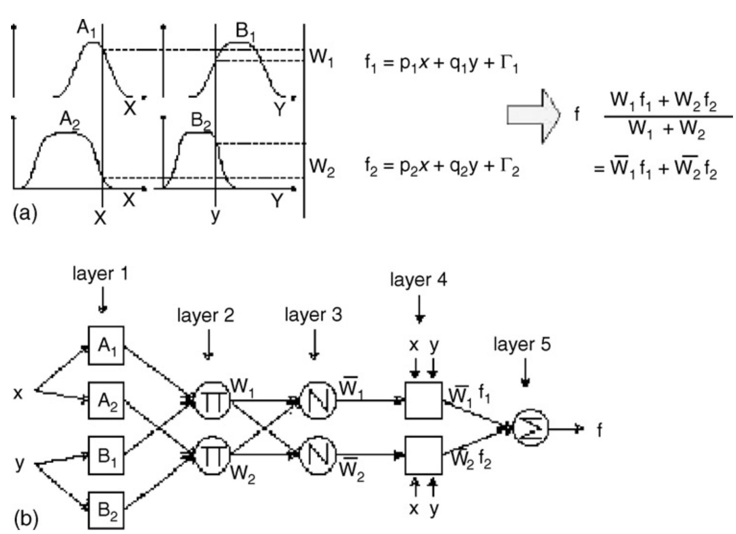

Fig. 1. (a) A two-input first-order Sugeno fuzzy model and (b) equivalent ANFIS architecture for two rules.