Fuzzy Logic Control of Cyclical Leg Motion

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Abstract

The aim of this paper is to investigate modelling and control of paraplegic leg cyclical motion. A humanoid leg is developed in Visual Nastran software in the setting position, and used with Matlab/Simulink to develop a fuzzy logic control (FLC) strategy to control the knee joint movement. The FLC output is the FES stimulation signal which stimulates the knee extensors providing torque to the knee joint. The control of such a plant (leg with knee extensors) is a complex task as only the knee extensors are stimulated to extent the knee and then the knee is left freely to flex in the flexion period.

FLC shows effectiveness in controlling especially in the absence of mathematical model for the plant. This control strategy can also be used for functional cyclical exercises such as ergometry cycling and rowing. Simulation results verifying the control strategy are presented and discussed.

Two types of knee joint functional movements are investigated and the tracking performance is satisfactory.

1. INTRODUCTION

Many people throughout the world suffer from spinal cord injury, which is usually caused by accident or disease. Spinal cord injury (SCI) results in loss of mobility and sensation. Despite the damage that blocks the transmission of motor signals to the functional muscles, the muscles are still working and can be activated by external stimulators [1], so a person who has no voluntary control of his muscle will be able to move with external stimulators. Functional electrical stimulation (FES) aims to generate movements or functions which mimic normal voluntary movements, and so to restore the functions which those movements serve [2].

The success of any FES system depends on its control system which qualifies the requirements of the control problem addressed by the disability. User supervision for the system may be sufficient in some applications; but in other applications, other levels of control could be desirable.

Many studies have used different nonlinear control strategies to control the knee joint movement by using the quadriceps stimulation [4] [6] [7]]. [9] used FLC to control cycling movement induced by FES through stimulating both quadriceps and hamstrings muscle groups. Using model-free FL controller to control cyclical leg motion through stimulating the quadriceps only has not been reported.

The control of single limb movements of paraplegics represents an important preliminary stage towards more complex motor functions such as standing and cycling in paraplegia [3].

A leg model with knee extensors is developed in this study and used to develop a suitable strategy for controlling a sinusoidal movement of the knee joint; the developed controller can be use to control more complex cyclical movements, such as rehabilitation cycling and rowing exercises.

2. METHODS

2.1. Leg model

The leg model has been designed in Visual Nastran (VN) software, which is used to build mechanical models and simulate them in real time. Models drawn in other specified computer aided design CAD programs can also be transferred to VN to be simulated.

It is of vital importance that the dimensions of the leg are chosen correctly. This is because the simulation results will be dependent upon the dimensions. In this study, the human model is assumed to be of 175cm in height and 75 kg in weight. Using the data given in Winter's standard human dimensions [8], the thigh length is 42.8 cm and its weight is 7.5 kg, also the shank length is 43 cm and its weight is 3.49kg. The leg model can thus be created in VN software using these parameters.

A thigh and a shank were built in VN software and connected with a motor joint, which forms the knee joint (see Figure 1). The angle between the thigh and the shank is measured in the simulation process and imported to a Matlab/Simulink design to be controlled. The control signal applied to the VN model is the torque at the knee joint.

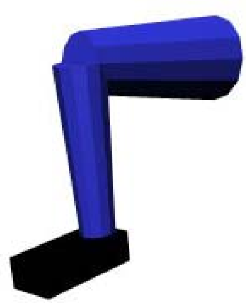

Figure 1 Leg model in Visual Nastran software.

2.2. Muscle model

The muscle model is a transfer function between electrical stimulation and the resultant knee torque [5]. This function was identified by means of a parametric approach that considered the family of ARX models and using a least square method on the error between real data and the output of the model.

A simple single pole model with a static gain dependent on stimulation frequency proved able to identify the relationship between stimulation and active joint torque fairly accurately [5]. This muscle model is suitable for the range of the knee movement in this study. The muscle model is to mimic the quadriceps muscle group in the thigh, which straighten the knee joint. Thus, the muscle model works as a knee extensor.

2.3. Controller

A fuzzy logic (FL) controller was developed to control the leg movement and force the leg to follow a reference sinusoidal signal. Choosing fuzzy controller inputs and outputs is a very critical process, because it is important to be sure that all the information needed about the plant is available through the controller inputs. As can be seen from Figure 2, the control signal is the stimulation pulses applied to the muscle model, which in turn produces a torque to the knee joint in VN model. The inputs of the FL controller are the error (between the actual and reference knee trajectories), and the change of error. The reference signal is chosen as a sine wave which has a frequency of π rad/sec. This signal aims to move the knee joint sinusoidal, from 81.7° to 101.7°, as a result the shank of the lower limb will move in a cyclical movement, and this movement will be controlled by the FL controller.

Each of the FL controller inputs has five membership functions (MFs). This results in 25 fuzzy rules described in Table 1, where e and Δe are the error and change of error respectively.

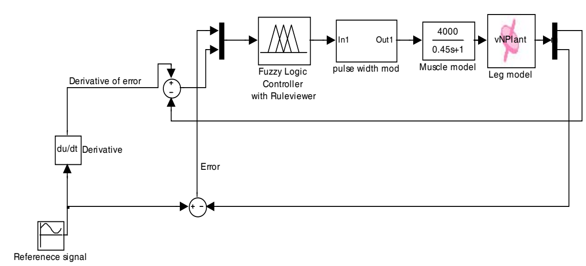

Figure 2 The controller design via Simulink

Table 1 The FL rule base.

e \ Δe	NB	NS	Z	PS	PB
NB	NB	NB	NS	Z	Z
NS	NB	NS	NS	Z	Z
Z	NB	NS	Z	PS	PB
PS	Z	Z	PS	PS	PB
PB	Z	Z	PB	PB	PB

NB=Negative big NS=Negative small Z=Zero
PS=Positive small PB=Positive big

3. RESULTS

The leg movement was controlled to follow a typical sine wave. The total movement range was 40°. The controller is tested for different ranges of motion. The FL controller controls only the knee extensors by applying stimulation pulses to the muscle model. The muscle model is controlled by changing the pulse width; however the amplitude and the frequency of the stimulation pulses are constant. It is too difficult to control such a system with linear controllers, because the plant is nonlinear. FLC is a very good alternative for controlling the (leg and muscle) system especially in the absence of mathematical models. Figure 3 show the error plot between the reference and actual knee trajectories, where the range of error is [-2°, 2°] for the typical sinusoidal movement, Figures 4 and 5 illustrate the actual and reference knee trajectories for two types of movement. It is noted that the output matches the desired trajectory closely.

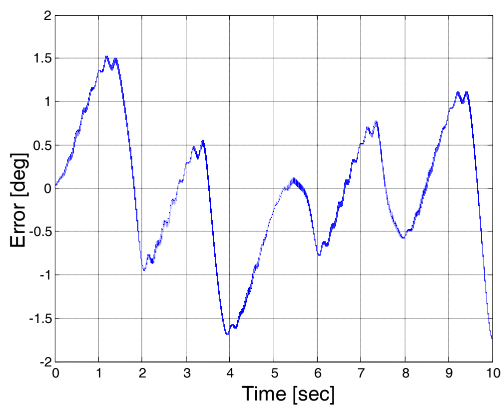

Figure 3 Error between the reference and actual knee trajectories for typical sinusoidal motion

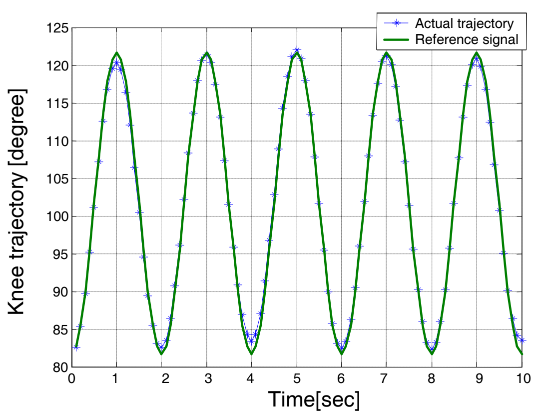

Figure 4 Actual and reference knee trajectories.

4. CONCLUSION

A fuzzy logic controller is used to move the leg in a predetermined sinusoidal movement. The controller performance is satisfactory, the knee joint followed the reference signal and the error is relatively small. The achieved tracking performance is equal to other published nonlinear controllers. This control strategy can be used for other functional cyclical movements such as ergometry cycling and rowing exercises. Further studies will investigate the use of more sophisticated muscle and leg models.

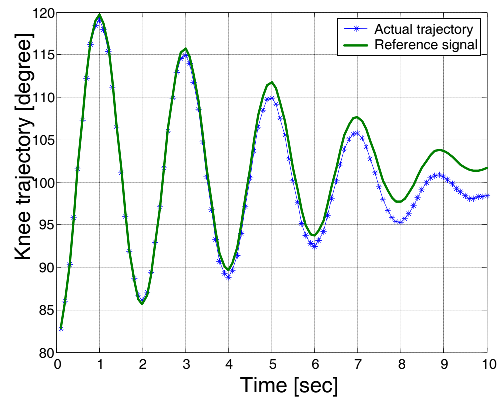

Figure 5 Actual and reference knee trajectories for decaying signal.

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