A NEURO-GENETIC MODEL FOR STANDING UP AND SITTING DOWN IN PARAPLEGIA

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Abstract
The design of an optimal controller that improves standing and sitting manoeuvres is a difficult task due to the high nonlinearity and the absence of any a priori knowledge about the movement dynamics. In addition, both the upper limbs forces and the stimulation of the extensor muscles of the lower limbs have to be considered.
The aim of this research was to design a neuro-genetic model for FES supported standing and sitting. A preliminary controller was designed in which the stimulation of the lower limbs depended on the hand force during standing up and the knee angle during sitting down. The data collected during this process was used to design a model for standing up and another for sitting down using Radial Basis Function Neural Networks and Genetic Algorithms as the learning strategy. Each model consisted of three modules representing the relationships between the stimulation pulse width, the knee angle, the angular velocity and the upper limbs forces.
The models were verified and found to be consistent with the testing data and it is proposed that they may facilitate the design of many optimal control systems.

Introduction

Standing and sitting are a prerequisite for walking and independent mobility and are considered two of the most demanding activities. Most models for the dynamics of standing up are complex and have not been integrated with models for sitting and quiet standing. This provides an obstacle in designing optimal and robust controllers that could be used for these integrated activities both within and outside the laboratory.

Donaldson et al. [12] used a theoretical approach called "Control by handle reactions of leg muscle stimulation" (CHRELMS), in which stimulation of the lower limbs depends on body efforts. They gave guidelines for reducing muscle fatigue and body efforts during standing up manoeuvre. Riener et al. [9] provided an alternative strategy called "Patient-driven motion reinforcement" (PDMR) which accounts for voluntary upper body efforts as well, but does not require estimation of hand reactions. They showed that both CHRELMS and PDMR are comparable using an inverse dynamic model.

The aim of this research was to develop and integrate simple models for standing up, quiet standing and sitting down. It is proposed that these models could be used to design FES controllers for these integrated functions.

Methods

A model was developed that integrated upper limbs forces with the stimulation output to the extensor muscles of the lower limbs for both standing up and sitting down.

Initially a preliminary controller was designed, which used upper limbs forces and knee angles as the input parameters during standing up and the knee angle during sitting down. Then, separate models for standing up and sitting down were built using neuro-genetic methods and the data obtained from the results of the preliminary controller. Each of the designed models consisted of three modules representing the relationships between the stimulation pulse width, the knee angle, the knee angular velocity and the upper limbs forces. These models were tested for several trials with one complete paraplegic subject.

The subject had a complete lesion at the level of T6 and minimal lower limb spasticity and was modelled as a two-bar linkage in the sagital plane. FES was applied bilaterally to the knee extensors at a frequency of 25Hz. The amplitude of the stimulation to each leg was adjusted at the beginning to a level that produced 'strong' knee extension.

1-Experimental design

A preliminary controller was designed to minimise the upper limbs forces and to achieve a smooth manoeuvre that was close to a normal subject. In addition the design of the controller was such that the data collected from the experiments had a wide dynamic range. In standing up, the stimulation pulse width increased as the upper limbs forces increased. This was to have the overall effect of decreasing the amount of the upper body efforts during standing up. For sitting down, the stimulation increased as the subject approached mid-position of the manoeuvre then decreased until the subject reached a seated position. In all experiments the Strathclyde Research Stimulator was used with surface electrodes applied bilaterally to the quadriceps. A Biometrics flexible goniometer

was placed across the left knee to measure the knee angle and strain gauged transducers were attached to the standing frame to measure the total force applied to the standing frame.

2-Model design

The design of a complete model for the subject dynamics for either standing up or sitting down was divided into the modelling of three different relationships between the knee angle, the knee angular velocity, the upper limbs forces and the stimulation pulse width. These relations were:

$\theta'[t+1]=f_1(\theta[t],\theta'[t],P[t])$ (1)

$\theta[t+1]=\theta[t]+\Delta\theta'[t+1]$ (2)

$F[t]=f_2(\theta[t],\theta'[t],P[t])$ (3)

Where, $\theta[t]$ is the knee angle, $\theta'[t]$ is the knee angular velocity, P[t] is the pulse width, F[t] is the normalised force support and Δ is the sampling interval.

The relationships f_1 and f_2 could be modelled using a type of neural networks called Radial Basis Functions Neural Networks which is usually used in curve fitting or approximation specially in high dimensional spaces[2]. Gaussian functions were used as radial basis functions and the neural network was described as

$$F(\mathbf{x})=\sum_{i=1}^{n} w_i G(\mathbf{x};\mathbf{t}_i) \quad (4)$$

$$G(\mathbf{x};\mathbf{t}_i)=\exp\left[-\frac{\|x-t_i\|^2}{2\sigma_i^2}\right];$$

i=1,2,……,n (5)

Where **x** are the input states, F is the output, $\mathbf{t}_i$ are the gaussian functions centres, σ_i are the standard deviations. For the designed models n random locations for the centres were chosen from the data set, the standard deviation was kept fixed at

$$\sigma = \frac{d}{\sqrt{2n}} \quad (6)$$

where d is the maximum distance between the chosen centres. **w** was determined using Genetic Algorithms (GA's) which are stochastic search methods that mimic natural biological evolution and model processes such as selection, recombination, mutation and migration. GA's operate on a population of potential solutions applying the principle of survival of the fittest to produce better approximations to a solution and have the advantage of searching in parallel without the requirement for derivative information or other auxiliary knowledge[6].

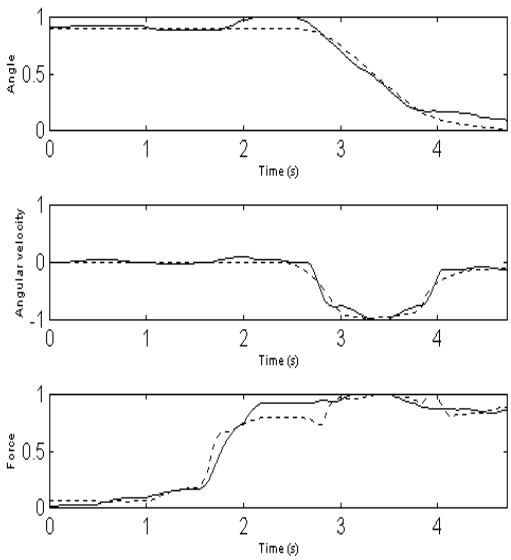
The data obtained from the experiments was used to train the neural networks the relationships described in equations 1 and 3 for both standing up and sitting down. For quiet standing the upper limb forces were approximated to the average value during the complete standing period.

Five perceptrons in the hidden layer for each neural network model were used as a minimum number that gives satisfactory response in order to avoid overfitting which could decrease the generality of the model dramatically.

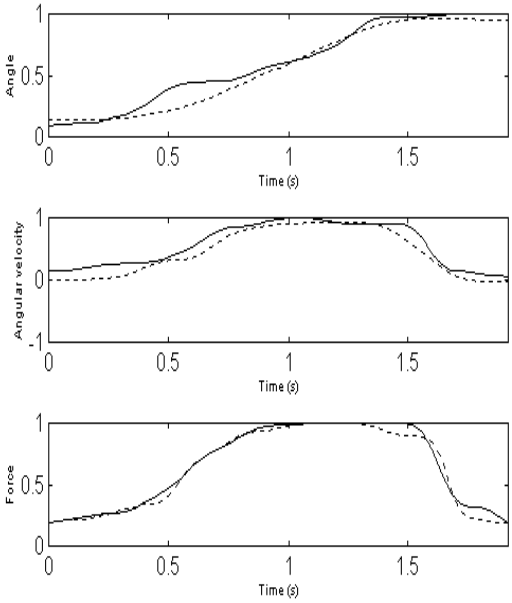
The programs which were used to design the models were run for each model separately for 300 generations using crossover probability with a value of 0.7, mutation probability with a value of 0.05 and population size with a value of 40.

Results

Figure 1 and figure 2 show simulations for the subject dynamics during standing and sitting for the knee angle, the knee angular velocity and the upper limbs forces. The initial values for the knee angle and the knee angular velocity were 100 deg and 0 deg/s respectively for standing and 0 deg and 0 deg/s respectively for sitting. These curves show a close approximation between the neural networks responses and the actual subject response.



Figure(1) shows the normalised knee angle, knee angular velocity and upper limbs forces for the actual (solid), and the predicted(dotted) values during standing up.



Figure(2) shows the normalised knee angle, knee angular velocity and upper limbs forces for the actual(solid), and the predicted(dotted) values during sitting down.

Discussion

This work demonstrated that the models of standing up, quiet standing and sitting down could be integrated into a single model which could be used for designing optimal controllers for the independent function of standing.

There was good consistency of the models with the testing data. This supports the proposition that alternative methods of control design could be used where the need for a patient would be in the final stages of the fine tuning and testing of the controller.

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