Adaptive Mapping for the Control of Standing with Functional Neuromuscular Stimulation

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Abstract - The objective this work is to develop an adaptive system for controlling posture during stance. In our standing system, command signals from the user specify a desired postural orientation (e.g. location of the pelvis with respect to the feet) which is mapped to determine the stimulation pattern for a set of muscles. The purpose of the adaptive mapping component is to achieve a linear input/output (command signal/posture) that utilizes the entire command range and maintains these input/output properties as system properties may change.

Results from computer simulation studies indicate that the adaptive mapping scheme can automatically adjust the stimulation parameters to account for nonlinear muscle recruitment properties and to account for muscle fatigue. In future work, this component of the control system will be implemented in conjunction with feedback control algorithms and will be evaluated in experiments on human subjects.

I. Introduction
An important limitation of existing Functional Neuromuscular Stimulation (FNS) control systems is that stimulation parameters must be tailored to each individual. In previous work\cite{1,2}, we have developed adaptive feedforward controllers for generating cyclic contractions and movements that automatically adjusted to account for variability in system parameters across individuals. The design of this control system (the PG/PS control system) took advantage of the cyclic nature of the task in order to achieve rapid adaptation of the stimulation pattern. Here, we report on a modified version of the PG/PS control system that has been configured to address the needs of posture control during stance. In particular, this control system is designed to address the input/output nonlinearities of the posture control system that may change with time due to muscle fatigue.

II. Methods
The feedforward control system consists of an adaptive nonlinear map that is implemented using a type of function approximation neural network. The input to the neural network is the command signal from the user (command for postural orientation or position) and the output of the neural network is the stimulation parameters to be sent to a set of muscles. The neural network includes one layer with 20 neurons and a second layer that includes as many neurons as muscles to be stimulated. Adaptation is only implemented for the weights in the second layer of neurons.

This stage of the evaluation has focused on 1) characterizing the ability of the adaptive mapping scheme to account for nonlinearities in muscle recruitment properties and 2) characterizing the ability of the adaptive mapping scheme to account for changes in the nonlinear muscle recruitment properties due to fatigue. The control system is intended for use in controlling posture, but this initial stage of evaluation utilized only a model of isometric muscle contraction. This model included a nonlinear recruitment curve and a model of fatigue which would result in changes in the recruitment curve over time. Therefore, the input to the controller was ‘percent command’ from the user and the output was isometric muscle torque from a single muscle. The objective of the controller in these simulations was to achieve and maintain a linear input/output characteristic as viewed by the user and to utilize the entire command range to regulate muscle torque over the operating range (chosen to be 0-25 Nm).

III. Results
Figure 1 shows the results of a simulation run that demonstrates how the adaptive mapping can account for nonlinear recruitment properties and utilize the entire command range. Before adaptation, the user input map consisted of a linear map which, when cascaded with the nonlinear recruitment curve resulted in a nonlinear input/output characteristic as viewed by the user that utilized approximately 30% of the command range to cover the desired output range. After adaptation, the user input/output characteristics are linear and the entire command range is utilized.

Figure 2 shows the results of simulations that demonstrate how the mapping scheme is adjusted on-line to account for muscle fatigue. The simulations demonstrate that the adaptive mapping scheme can maintain the desired linear user input/output characteristics even though the muscle input/output properties are changing as the muscle fatigues. Similar results (not shown) have been achieved for other models of fatigue.
input/output properties as seen by the user and to utilize the full range of command to regulate outputs over the range of 0-25 Nm. The dashed lines show the mapping function, recruitment curve and their cascade before adaptation has occurred. Note that the user input/output properties are nonlinear and that only approximately 30% of the command range is used to regulate outputs over the range of 0-25 Nm. The solid lines show the mapping function, recruitment curve and their cascade after 20 epochs of adaptation. Note that the nonlinear mapping function results in linear user input/output properties and that the full range of command is used to regulate outputs over the range of 0-25 Nm.

Figure 2. Simulation results demonstrating how the adaptive mapping scheme can maintain linear input/output properties as seen by the user as the muscle fatigues. The plots show the mapping function (left panel), recruitment properties (center panel) overall input/output as seen by the user (right panel). Each plot includes five lines that are ‘snapshots’ of the system as the trial proceeds. Note that changes in the recruitment properties result in changes in the mapping function, but that the linear input/output properties are maintained throughout the trial. The model of muscle fatigue used in these simulations includes an asymptotic drop in recruitment curve gain, shift to right of the recruitment curve, and drop in muscle gain. The absolute value of the error is maintained at below 5% throughout the trial.

IV. Discussion
These results indicate that the adaptive mapping scheme can address the two primary issues for which it was designed: nonlinear recruitment and muscle fatigue. The neural network algorithm used for the adaptive mapping component utilized a constrained learning algorithm to adapt only a single set of weights. This adaptive process has the disadvantage that its nonlinear function approximation capabilities that are limited, but offers the advantage that it provides rapid adaptation.

While results of these studies are encouraging, demonstration of the utility of this approach must include a demonstration that the adaptive algorithm can perform as well on more complex systems as it has performed on these relatively simple models. Future work will include further characterization and development of the adaptive component using computer simulated models that incorporate other musculoskeletal nonlinearities and dynamics as well as extensive evaluations on human subjects.

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References