Chapter 7
Evolutionary Optimization of Artificial Neural Networks for Prosthetic Knee Control

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ABSTRACT
This chapter discusses closed-loop control development and simulation results for a semi-active above-knee prosthesis. This closed-loop control is a delta control that is added to previously developed open-loop control. The control signal consists of two hydraulic valve settings. These valves control a rotary actuator that provides torque to the prosthetic knee. Closed-loop control using artificial neural networks (ANNs) are developed, which is an intelligent control method. The ANNs are trained with biogeography-based optimization (BBO), which is a recently developed evolutionary algorithm. This research contributes to the field of evolutionary algorithms by demonstrating that BBO is successful at finding optimal solutions to real-world, nonlinear, time varying control problems. The research contributes to the field of prosthetics by showing that it is possible to find effective closed-loop control signals for a newly proposed semi-active hydraulic knee prosthesis. The research also contributes to the field of ANNs; it shows that they are able to mitigate some of the effects of noise and disturbances that will be common in normal operation of a prosthesis and that they can provide better robustness and safer operation with less risk of stumbles and falls. It is demonstrated that ANNs are able to improve average performance over open-loop control by up to 8% and that they show the greatest improvement in performance when there is high risk of stumbles.

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INTRODUCTION

We propose using artificial neural networks (ANNs) for closed-loop control of a newly designed hydraulic prosthetic knee for above knee amputees. The prosthesis harvests energy and provides controlled release of energy during the gait cycle with a spring loaded high pressure hydraulic chamber, a low pressure hydraulic chamber, and a rotary actuator. An onboard microprocessor controls the pressure in the hydraulic accumulators via two valves. We have found that solving the control problem by analytical means is not feasible, but that ANNs can provide control after evolutionary training with biogeography-based optimization (BBO). This demonstrates the effectiveness of ANNs for nonlinear model-independent control in real-world biomedical problems, and the effectiveness of BBO for finding solutions to difficult optimization problems.

Prostheses have long been known to produce degenerative side effects such as arthritis and spinal pain because of the unnatural and high torques that a user’s hip produces to compensate for the inadequacy of his prosthesis (Kulkarni, Gaine, Buckley, Rankine, & Adams, 2005; Gailey, Allen, Castles, Kucharik, & Roeder, 2008; Modan et al., 1998). This provides motivation to develop semi-active prostheses that store and release energy in order to reduce the need for these abnormal torques (Seymour et al., 2007). Further, semi-active prostheses use less power than their fully active counterparts at the cost of limiting the power available for use by the prosthesis at any given moment (Kim & Oh, 2001). For these reasons, semi-active prostheses seek to find a balance between efficiency and efficacy. However, because the reactive energy that a semi-active knee prosthesis can produce is limited by the energy that it can harvest from the user, its performance cannot perfectly match a biological knee (Seymour et al., 2007). Thus, our goal is to produce a controller that tracks able-bodied human gait parameters as closely as possible.

Because of the degenerative effects associated with unnatural hip torques, we place a high priority not only on the appearance of normal gait through tracking reference angles and coordinates, but also on the hip torques that the amputee has to produce to use the prosthesis. We use these criteria for the performance evaluation of our prosthetic controller.

In previous work, we developed open-loop prosthetic control via biogeography-based optimization (BBO), which is a recently developed evolutionary algorithm (EA) (Wilmot et al., 2013). We have found that although the open-loop control produced by BBO is locally optimal, it is sensitive to noise and to the initial conditions of each gait cycle. We observed instability in the open-loop control when noise and disturbances were injected into simulations of our prosthetic system. This fact helped motivate us to develop closed-loop control to compensate for the sensitivity of the open-loop control.

Our closed-loop control approach focuses on using an ANN to add a delta control to the open-loop control to compensate for disturbances and measurement noise. We use BBO to train the network to input error signals, and to output delta controls that compensate for disturbances and noise. As with open-loop control, BBO optimizes the parameters of the closed-loop controller.

BACKGROUND

Microprocessor control has been used successfully in several different commercial prostheses. Most notably, the Otto Bock C-Leg has become the benchmark for microprocessor controlled prosthetic knees. The performance of the C-Leg depends on the controls embedded in its