Towards Adaptive Self-Configuring Control for Powered Prosthetic Knee: A Simulation Study

Yue Wen[1], Stephanie Huang[1], Jennie Si[2], and He (Helen) Huang[1]

[1] UNC/NC State Joint Department of Biomedical Engineering, NC State University and University Of North Carolina, NC, USA

[2]Department of Electrical, Computer, and Energy Engineering, Arizona State University, Tempe, AZ, USA

1 Introduction

Powered lower limb prostheses have shown great promise to enable lower limb amputees to regain their natural gait (1-3). Most of powered lower limb prostheses use finite state machine and impedance control (FSM-IC) to operate the device because compliant behavior of legs is fundamental to human walking (4, 5). One bottleneck to implement such a control on the powered prostheses is the difficulty in defining the desired joint impedance for each individual amputee because the joint impedance varies across human physical conditions (such as weight, size, muscle strength etc.). Clinically, these impedance control parameters are defined *manually* and *heuristically,* which is time and cost intensive. In order to further enhance the practical value of advanced powered artificial legs, advanced technology is needed to configure the impedance control automatically.

This simulation study aimed at demonstrating the potential of an optimal adaptive control based on approximate dynamic programing (ADP) (6) for powered knee prosthesis that can automatically define knee impedance adaptively to meet individual user's need while maintaining an optimal gait pattern. The ADP rests on learning from failures with a goal of optimizing the system performance. This simulation study may guide the future design of not only auto-configuring impedance control for powered lower limb prostheses, but also possibly adaptive control according to a user's physical capability and intent in the future.

2 Methods

An OpenSim (7) forward dynamic walking model was built. The walking model consisted of a rigid level platform for the ground and a five rigid-body segment linkage for the human body (i.e. pelvis segment, left and right thigh segment, left and right shank segment). We linked the rigid-body segments using one degree-of-freedom pin joints (i.e. left and right hip joint, left and right knee joint). We linked the pelvis segment and the ground platform using a free joint, which allowed free motion between the body and the ground. To simulate human-prosthesis integrated system, one knee joint was controlled by FSM-IC, and all other joints, presumed to be controlled by human, are driven by fixed joint trajectory in walking.

ADP was designed to adjust the impedance values in FSM-IC. In this simulation, the goal of ADP was to reproduce the desired knee joint trajectory, obtained from able-bodied persons (8), since generating near-normal joint motion in walking has been used to evaluate the performance of artificial legs (1, 2). Therefore, the inputs of ADP tuner were the system state that includes the errors and derivative of errors of knee joint profile (both peak value and phase duration) in each gait phase; the outputs of ADP tuner were the impedance update. In each simulation trial, initial impedance values were randomly assigned from values within a limit for each phase. ADP updated the values after each stride cycle in simulation based on the performance of the dynamic model. A successful trial was defined as the system state entered the acceptable target range and remained in the target range for the completion of 500 iterations.

We used three metrics to evaluate the simulation results: 1) ADP success rate, 2) ADP learning speed (i.e. number of iterations needed to achieve the success in a trial), and 3) root-mean-square (RMS) error between knee trajectory in walking and target trajectory.

3 Results and Conclusions

Twenty-six out of thirty simulation trials were success and the success rate was 87%. Among the successful trials, the learning speed was 215±134. The ADP tuner successfully reduces the RMS of knee angle in one stride cycle from 4.03 ±1.05 to 0.84±0.41. These results showed feasibility of ADP in self-configuring the knee joint impedance to achieve desired gait pattern.

References

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