Implementing Human-in-the-Loop Optimization on Prosthesis Emulators

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We are working to implement human-in-the-loop optimization on ankle-foot prosthesis emulators. In general, the subject provides an input to the controller and the controller then varies parameters in an attempt to minimize an objective function. Based on our pilot work so far, we have discovered several challenges that we are working to resolve. Some of these challenges are related to the optimization algorithm and others are related to the subject's behaviors.

Many of the software challenges have to do with objective function convergence. The optimization algorithm samples the objective function at different parameter settings and uses the data to try and move towards a minimum. However, when optimizing on humans, function evaluations are slower and more limited than on a computer. For example, metabolic rate takes time to converge and subjects can only walk for a certain amount of time in a single trial. Thus it is important to set up the optimization properly to achieve results quickly and effectively.

Parameter selection is extremely important to optimization problems. Certain inputs have little effect on particular objective functions. For example, in one test we varied two heel parameters to minimize metabolic rate. However, throughout the optimization there was little variation in metabolic rate despite a large variation in heel parameters. Either the parameters selected or the heel itself had little effect on metabolic rate. In a different test we varied five plantarflexion parameters to minimize metabolic rate. Unfortunately, when one parameter went to zero, it negated the effects of three other parameters, which made it difficult for the algorithm to converge. Parameter selection is not straightforward but critical for effective human-in-the-loop optimization.

Having a human as the plant for the control system introduces additional complexities to the optimization. The subject is obviously not a simple transfer function; instead we believe the subject and the device co-adapt to each other over the course of the optimization. For example, in one test we presented near-identical parameters to a subject on different days and the metabolic rates were vastly different. We also think exposing the subject to a wide variety of parameters is important to the optimization process. The intention is to force the subject to use their foot differently from how they are used to operating their prescribed foot. We hope this exploration aids the algorithm in discovering new minima. However, not all subjects respond to these changes as we expect. Some subjects are flexible and are open to exploring new behaviors while others are more conservative and tend to avoid using the device when the behavior becomes too different. Avoidance can include not putting much weight and/or having a short stance time on the device.

Our future work for the near term includes exploring different objective functions and parameterizations. We are working on optimizing subjective preference where the subject rates the current condition "better" or "worse" than the previous condition. We are also looking at how to best select device parameters to facilitate effective optimization.

Acknowledgments: This material is based upon work supported by the National Science Foundation under Grant No. 1511177.