Human Cyber-Physical Systems

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Self-Optimizing Control for Muscle Effort Distribution Targeting

Real-time control of machines to meet training and rehabilitation goals was a major objective of this project. A new concept for muscular effort distribution targeting was conceived and furthered. Extremum-seeking control was adopted and suitably tailored to this problem, leading to a user-specific but model-free method to find the set of machine impedances and target motions that produce the best match to and intended muscular effort distribution. Pilot efforts included studies to cross-verify the optima generated with extremum-seeking and those obtained by an evolutionary optimization method. In turn, limited human-subject tests were conducted to test the practical validity of the algorithm, its convergence and its ability to produce personalized training. Tests were conducted with our custom CSU4OptimX robot and with a 4-dof WAM arm (Barrett Technology, Inc.).

Single-variable and multivariable forms of the Extremum Seeking algorithm were used as a basis for a real-time system that finds the combination of machine reference trajectory (to be tracked by the user through visual gamelike feedback) and machine impedance that produces the best match to a preset, desired muscular effort distribution. The target distribution is specified as a weighted sum of muscle activations read with electromyography sensors. A significant engineering effort was required to successfully operate this system, including signal processing, moving averaging and convergence criteria. We used an optimization cost function driven by real-time, EMG readings conditioned by rectification, low-pass filtering and moving averaging:

$$\min_{\theta} \qquad y = \frac{t_s}{t_{rev}} \sum_{i=t-t_{rev}/t_s}^{t} \left(W_m M_{act} \right)$$

where W_m are the optimization weights applied to muscle activations M_{act}. Pilot tests confirmed the validity, convergence, repeatability and overall practicality of the approach. As shown in Fig. 1 different weights indicative of muscle effort priorities lead to different trajectories to be tracked by the user against the machine's resistance [1].

These methods require further study and promise user-specific, model-free concepts for training and rehabilitation.

References

[1] H. De las Casas, H. Warner, and H. Richter. Real-time optimization of an ellipsoidal trajectory orientation using muscle effort with extremum seeking control. *Medical Engineering & Physics (submitted)*, 2021.

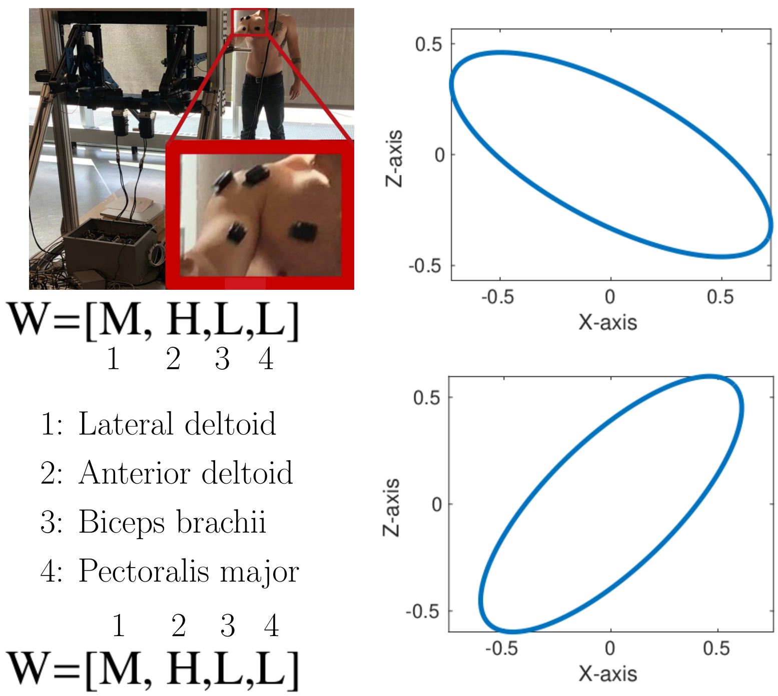

Figure 1: Muscle effort distribution targeting: different optimization weights indicative of muscle effort priorities result in convergence to different reference paths to be tracked by the user.