Syracuse University
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EMG Tracking Controller with Integral Anti-Windup Compensation in Motorized FES Cycling Experiments

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Introduction

- People with spinal cord injury experience weak muscle activations
- Functional Electrical Stimulation (FES) activates paralyzed muscles and facilitates leg movement
- An electric motor assists to delay the onset of fatigue
- Electromyography sensor (EMG) measure muscle activity and can be used to customize the muscle stimulation patterns

Apparatus

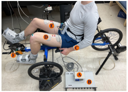


Fig.3. Motorized FES-cycling test bed.
A) Current-controlled muscle stimulator. B) Electromyography Sensor. C) Brushed DC motor. D) FES Surface Electrodes E) EMG Surface Electrodes

Control Scheme

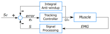


Fig.1. Closed-loop feedback control to apply stimulation in kinematic efficient (FES) regions

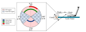


Fig.2. Personalized FES regions

$$\sigma(q) = \begin{Bmatrix} RQ & q \in \mathcal{Q}_{RQ} \\ LQ & q \in \mathcal{Q}_{LQ} \\ RH & q \in \mathcal{Q}_{RH} \\ LH & q \in \mathcal{Q}_{LH} \\ KDZ & q \notin \mathcal{Q}_{RQ} \cup \mathcal{Q}_{LQ} \\ & \cup \mathcal{Q}_{RH} \cup \mathcal{Q}_{LH} \end{Bmatrix} \quad sat_{\beta_m}(u_m) \triangleq \begin{Bmatrix} u_m & |u_m| \leq \beta_m \\ \beta_m sgn(u_m) & |u_m| > \beta_m \end{Bmatrix}$$

EMG Signal Processing

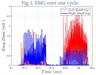
Apply a 3rd order Butterworth filter, cutoff frequency 10 Hz; Blank EMG vector

$$EMG^f_{i,k} = \begin{bmatrix} 0_{10} & EMG^f_{i,k}(11)...EMG^f_{i,k}(L-6) & 0_5, \end{bmatrix}$$

Average EMG activation over each stimulus (16 ms)

$$s = \frac{1}{L-15}||EMG^e_{i,k}||_1$$

Fig.3. EMG over one cycle



Control Design

- Integrate EMG sensor to motorized FES-cycling to incorporate human feedback
- Incorporate integral anti-windup compensation to ensure sporadic muscle contractions do not command high FES input

Dynamic System
A single degree-of-freedom stationary cycle and rider

$$M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) + P(q,\dot{q}) + d(t) = \tau_e(q,\dot{q},t) + \tau_m(q,\dot{q},t)$$

Kinematic Errors

$$e(t) \triangleq q_d(t) - q(t).$$
$$r(t) \triangleq \dot{e}(t) + \beta e(t).$$

e, r are position and velocity performance, respectively

EMG Error with Anti-Windup

$$e_{s,i} \triangleq (s_{d,i} - s_i) - \int_{t_0}^{t} k_{aw}(u_m - sat_{\beta_m}(u_m))d\psi$$

Control Input

An adaptive and robust controller that compensates for uncertain parameters in the system

Muscle

$$u_m \triangleq k_1 e_s + k_{\dot{s}_d} sgn(e_s) + y\hat{\theta} + k_2||y|||\hat{\theta}||sgn(e_s) \qquad y = [s], \theta = [-\frac{1}{T_a}]$$

Motor

$$u_e = k_4 r + \left(k_5 + k_6\|z\| + k_7\|z\|^2\right)\text{sgn}(r)$$

Fig.4. FES muscle stimulation pattern

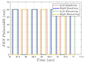
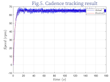


Fig.5. Cadence tracking result



Future Work

- Conduct experiments on healthy bodied individuals
- Implement experiments in participants with movement disorders
- Develop Extremum seeking controller to minimize fatigue