ROBUST INCLUSION OF EMG SIGNALS INTO THE CONTROL OF LOWER LIMB POWERED PROSTHESES

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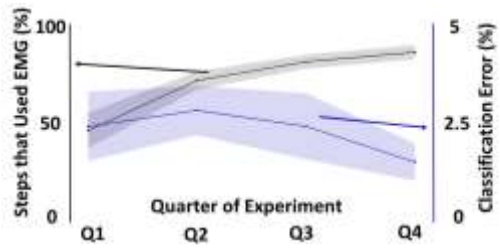
INTRODUCTION
Electromyographic (EMG) signals have been used to control powered upper-extremity prostheses for decades. However, they have not been used clinically to control microprocessor-controlled passive or powered lower-limb prostheses though research has shown EMG provides important control information[1]. This is primarily attributed to the difficulty in robustly capturing EMG signals from the lower extremity within a socket during locomotion. Changes in signal quality caused by volume fluctuation, perspiration, electrode liftoff, or excessive movement artifact must be accommodated to prevent deterioration of control. Here we present a control system that automatically accommodates EMG signal changes and learns to reincorporate information provided by EMG signals when they change over time. The entire system was embedded onto a microcontroller and used for online control a powered knee-ankle prosthesis.

METHODS
Six individuals with a unilateral above-knee amputation were fit to a third generation powered knee-ankle prosthesis designed by Vanderbilt University[2]. The prosthesis was controlled with an impedance-based model of the knee and ankle joints. All subjects had prior experience walking on this prosthesis. The prosthesis was configured for six activities including standing, level-ground walking, ramp ascent/descent, and stair ascent/descent. Eight channels of residual limb EMG and 22 channels of mechanical sensor data embedded on the knee-ankle prosthesis were recorded[2]. The experiment required two visits. In visit one, each participant performed a sequence of ambulation circuits that included all activities while the prosthesis was controlled by an experimenter using a key-fob. These data were used to train a pattern recognition system resistant to EMG signal changes[3], capable of predicting the desired mode. They were also used to create a gait model for each ambulation mode[4]. In session two, participants ambulated while the online pattern recognition system controlled the leg. The parameters of this system were adapted in real-time using semi-supervised covariance shift adaptation[5].

Outcome metrics included the percentage of decisions that used EMG signals and classification error. We used an analysis of variance to check for significant differences in metrics between each quarter of the online session.

RESULTS
Subjects on average took 2090 steps during the second session. The control system gradually learned to incorporate EMG signals over the duration of the session with a statistically significant increased EMG usage by the end of the experiment ($p<0.01$). The online experiment had an overall classification error rate of 2.3% percentage (Fig. 1)



Fig

Fig. 1: Percent of patterns where EMG was incorporated into predictions, and performance of the online system. The total amount of patterns was divided into quarters (Q1 – Q4) to the show the progression of EMG use/system performance throughout the experiment. Data are averages of six subjects (+/- 1 SEM).

DISCUSSION

Components of this adaptive system have previously been described and tested in offline experiments[3,4], but this is the first time we have demonstrated a fully adaptive system in online experiments. This is an important distinction because offline experiments may not capture user responses to any misclassifications. The error rates found in this experiment are much lower than previously reported values[1]. While this could partially be attributed to the adaptation, it could be caused by other factors such as using more mechanical sensors or having more experienced individuals walking on the prosthesis.

CONCLUSION
The pattern recognition system automatically accommodated to changes in EMG signals during session two and by the end of the session used EMG data for ~90% of decisions. The system operated within real-time constraints and users were able to seamlessly ambulate across the activities tested.

CLINICAL APPLICATIONS
In this work we have addressed a major limitation in clinical application of EMG signals to improve control of microprocessor lower-limb prostheses.

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