Neuroengineering 2024-2025

Exam 3 July 2025

Part II

How to submit your answers.
The answers can be typed in the provided text file, following the template. Do not modify or move the lines containing the headers.

Keep your answers tidy. Messy, hard-to-read answers may penalize your mark.

The maximum total score for part II is **8**.

Carefully read the following text and answer the questions listed below.

A startup, *MyoGrasp Robotics*, is finalizing the design of a low-cost, non-invasive neuroprosthetic hand. The device is controlled using surface electromyography (sEMG) from the user's residual forearm muscles.

Control Paradigm The prosthesis uses a 2-channel differential recording to measure activity from the primary flexor and extensor muscle groups. The processed amplitude of the flexor sEMG controls the grasping force, while the extensor sEMG controls the speed of release. To conserve power, the hand remains in a low-power "*standby*" mode and only becomes "*active*" when a muscle contraction is intentionally initiated by the user. During operation, the prosthesis's own motors are known to generate a $50\ Hz$ common-mode electrical hum with an amplitude of $150\ mV$ at the skin's surface.

Hardware Specifications

- **sEMG Electrodes:** Bipolar pairs of Ag/AgCl electrodes are used for each of the two channels.
- **Analog Subsystem:** A single 2-channel instrumentation amplifier provides a differential gain $G_d = 60\ dB$ (i.e., a voltage gain of 1000). The manufacturer specifies a Common-Mode Rejection Ratio (CMRR) of $110\ dB$. The analog signal is band-pass filtered between $20\ Hz$ and $450\ Hz$.
- **Analog-to-Digital Converter (ADC):** An ADC with a maximum sampling frequency of $200\ Hz$ is used. It has a resolution of 12 bits and a symmetric input voltage range of $\pm 1.5\ V$.
- **Microcontroller:** A low-power microcontroller processes the digitized signal in real-time.

Signal Processing Pipeline

1. **Onset Detection:** To transition the prosthesis from "*standby*" to "*active*" mode, the microcontroller continuously analyzes the sEMG stream from the flexor muscle (see Figure 1, top panel). It estimates the signal envelope by calculating a moving average of the full-wave rectified signal over a $50\ ms$ sliding window. This envelope value is checked for a potential onset every $10\ ms$ (see Figure 1, bottom panel). A double-threshold algorithm is used to detect a muscle onset event, using a time threshold $t_c = 60\ ms$ and an amplitude threshold $A_c = 15\ \mu V$.

2. **Control Signal Generation:** Once in "active" mode, the digitized sEMG from both channels is full-wave rectified. The rectified signal is then smoothed using a $250\ ms$ moving average filter ([1]) to produce a stable control signal proportional to the muscle contraction force.

Performance Validation Protocol To test the system, a user performs a series of cued trials. In each trial, a "GRASP" cue appears on a screen. The user must initiate a contraction, and performance is evaluated based on the *Control Signal Stability*, calculated as the standard deviation of the smoothed control signal during a steady hold period.

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[1] Reminder: The output of a moving average filter of length L is the average of the last L input samples

Questions

Write all your answers in the provided text file, following the template

Q1. (2 points) Acquisition Setup

a) What is the minimum number of sEMG electrodes required for the system?

b) Critically evaluate the hardware specifications. Is there any significant compatibility issues between the analog and digital subsystems?

Justify your answers (max 300 characters total).

Q2. (2 points) ADC Parameters & Noise

a) What is the quantization step size (in microvolts) of the ADC?

b) What is the amplitude (in microvolts) of the $50\ Hz$ motor hum at the amplifier's output?

Justify your answers (max 400 characters total).

Q3. (2 points) Muscle Onset Detection

The graph in Figure 1 shows the estimated signal envelope from the flexor muscle at the beginning of a trial. According to the double-threshold algorithm, what is the latency of the **start** of the muscle activity that successfully triggers the switch to *'active'* mode?

Justify your answer by explaining how the detection rule is met (max 200 characters).

Q4. (2 points) Control Signal Smoothing

The control algorithm uses a moving average filter to smooth the rectified sEMG.

a) Is a moving average filter a Finite Impulse Response (FIR) or an Infinite Impulse Response (IIR) type?

b) The lead engineer considers two alternative window lengths for this filter: $100\ ms$ and $500\ ms$. For each alternative, how would the *Control Signal Stability* primarily change compared to the original $250\ ms$ window? (Write: 'increase', 'decrease', or 'no change').

Justify your answers (max 300 characters total).

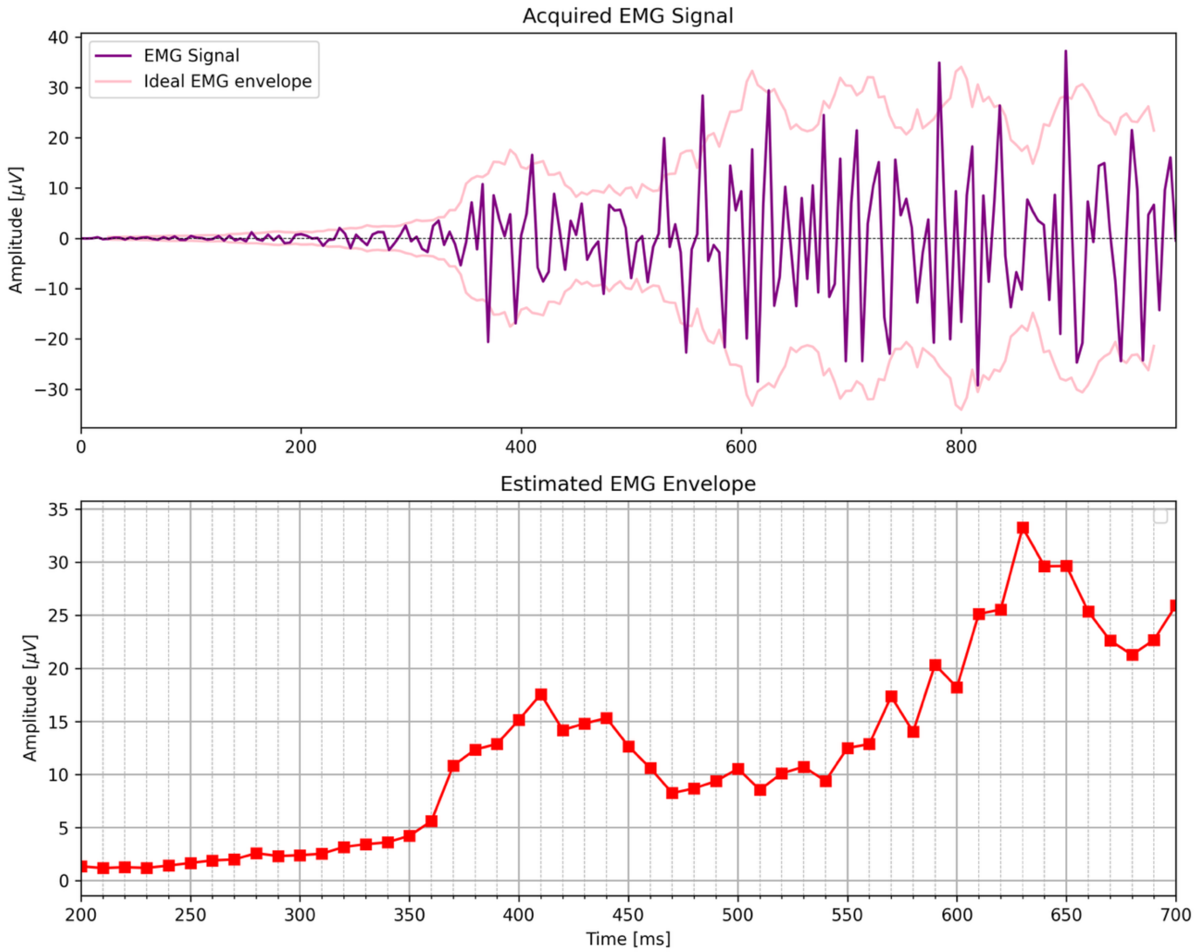

Figure 1. EMG activity from the flexor muscle. The horizontal axis represents the latency from the appearance of the 'GRASP' cue. **Top panel:** A segment of the acquired raw EMG signal and its ideal envelope. **Bottom panel:** The estimated signal envelope as computed by the microcontroller.

(End of the test)