Neuroengineering 2024-2025

Exam 3 July 2025 - group 'even'

Part II

Solutions

Q1. (2 points) Acquisition Setup

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

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

Justify your answers (max 300 characters total).

Number of electrodes: 5

Issues (Yes/No): Yes

--- Justifications ---

a) Two bipolar channels placed on different muscular groups require 4 electrodes (2 per channel). A single shared ground electrode is also required for the subject (4+1=5). See Figure Q1 below.

b) The setup has an issue: the 450 Hz analog filter will not prevent aliasing for frequencies between 100 Hz and 450 Hz, as the ADC can only properly represent signals below 100 Hz ($f_s/2$).

Q2. (2 points) ADC Parameters & Noise

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

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

Justify your answers (max 400 characters total).

V_LSB (uV): 732.4 µV

Hum amplitude (uV): 474 µV

--- Justifications ---

a) The LSB is the total voltage range divided by the number of levels:

$$V_{LSB} = ((+1.5) - (-1.5))V/2^{12} = 3V/4096 \approx 732.4\mu V.$$

c) $A_d = 60\ dB,\ \text{CMRR} = 110\ dB$. Thus, the common-mode gain A_{cm} is:

$$A_{cm} = A_d - \text{CMRR} = 60\ dB - 110\ dB = -50\ dB = 20\log_{10}(-50) \approx 0.00316$$

The amplitude of the output artifact V_{cm}^{out} is:

$$V_{cm}^{\text{out}} = V_{cm}^{\text{in}} \cdot A_{cm} = 150\ mV \times 0.00316 \approx 474\mu V$$

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).

Start time (ms): 590 ms

--- Justification ---

The latency of the valid onset is 590 ms. In fact, at this latency, the envelope crosses the 15 µV threshold and remains above it for the required 60 ms duration. The earlier crossings at 400, 440 and 570 ms are ignored as they do not meet the duration criterion. See Figure Q3 below.

(For completeness: since the microcontroller must wait 60 ms since the amplitude threshold crossing to detect a valid onset, the switch to the 'active' mode will only occur later, at 650 ms.)

Q4. (2 points) Control Signal Smoothing

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

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

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).

Filter type (FIR/IIR): FIR

Change @100ms (increase/decrease/no-change): Increase

Change @500ms (increase/decrease/no-change): Decrease

--- Justifications ---

a) A moving average is an FIR filter because its current output depends only on a finite history of input samples (convolutive system). Conversely, a IIR filter would also depend on past output samples (recursive system).

b) The *Control Signal Stability* [1]is defined as the *standard deviation* of the signal.
   - A shorter averaging window (100 ms) results in a less smooth, more variable signal, which means its standard deviation will **increase**.
   - A longer averaging window (500 ms) results in a smoother, less variable signal, which means its standard deviation will **decrease**.

   This is a direct consequence of the Central Limit Theorem, where averaging more samples reduces the variance/standard deviation of the result.

[1] While the metric is named "*Stability*," a lower value actually corresponds to a more stable/less variable signal.

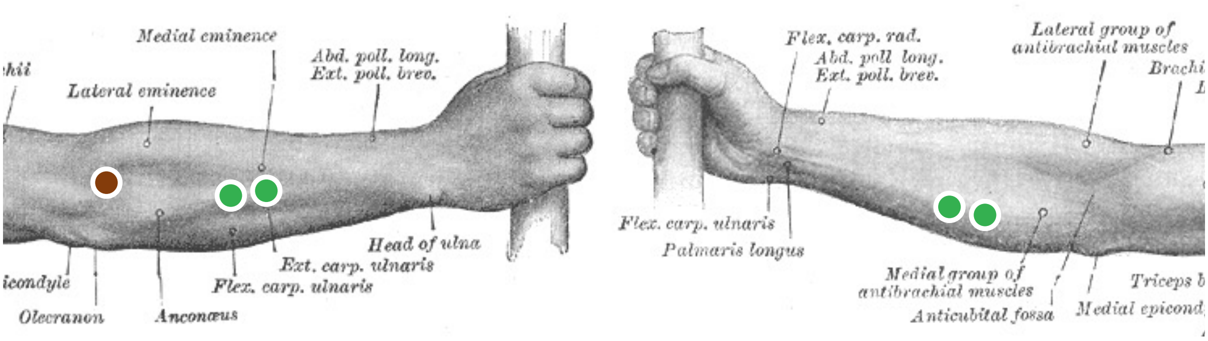

Figure Q1. Positions of the 5 recording electrodes.

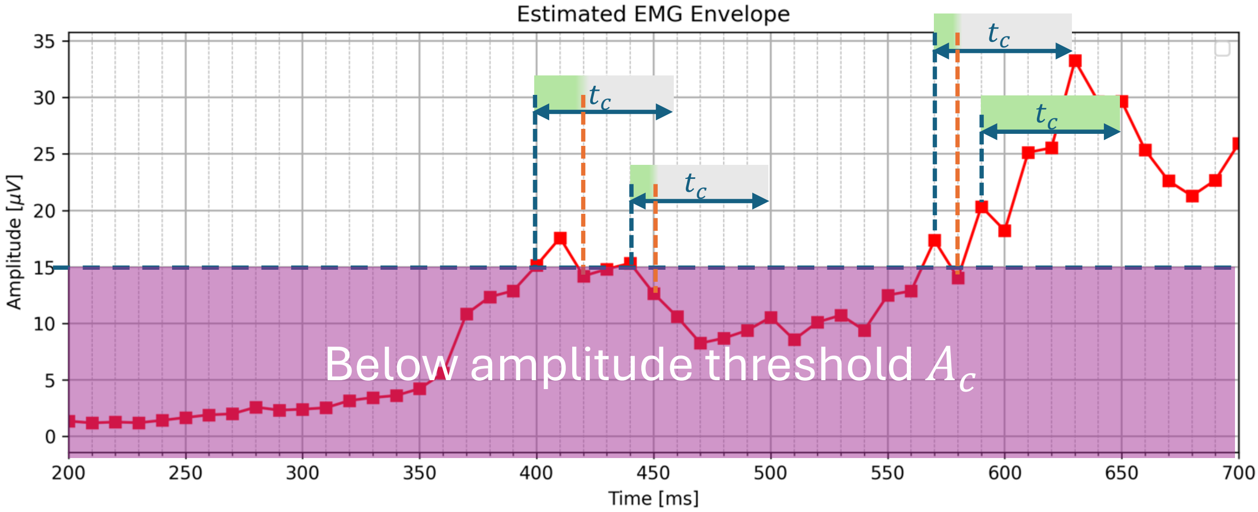

Figure Q3. False alarms and actual trigger according to the double-threshold algorithm.