EMG Assignment 2024
Biomedical Robotics

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Exercise 1

Why is the down-sampling performed after the envelope computation?

With down-sampling, we refer to the process in signal analysis by which the signal's sampling rate is reduced by a certain factor. Consequently, this process is useful in terms of computational cost, as it reduces the amount of data that need to be processed and its complexity.

This operation is performed after the envelope computation to avoid removing significant information from the pre-processed and pre-filtered signal. Otherwise, the data sample, which then undergoes the filtering process, is incomplete and thus different from the original one, causing an incorrect analysis afterwards.

On the other hand, the envelope still contains all the required signal information, as it's obtained by extracting the lower frequency components and gradual variations of the signal and removing its higher frequency components and noise. Therefore, performing the down-sampling after the envelope computation does not cause a loss of significant signal information.

In our implementation, we use a downsampling factor of 2, increasing the sampling frequency from 2000 Hz to 1000 Hz. This value is chosen to respect the Nyquist theorem. Indeed, the definition of a new maximum frequency of 450 Hz ensures that the Nyquist condition still holds, preventing us from aliasing.

Based on the motion signal, when does the muscle activation commence in relation to the movement?

In order to understand how muscle activation and movement are related, we plotted them together as shown in Figure (1). Please note that, for the plot to be better understandable:

- the envelope signal was normalized between 0 and 1;
- the movement signal was retrieved by calculating the norm of the movement acceleration along the three directions.

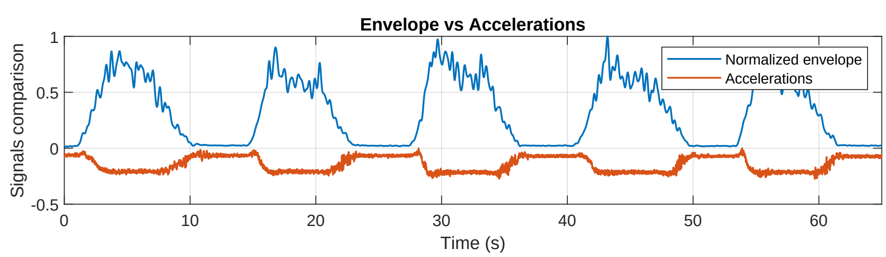

Figure 1: Movement signal and envelope plot.

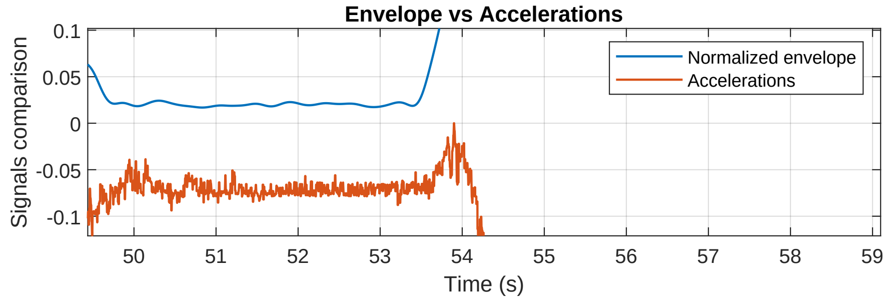

Figure 2: Movement signal and envelope plot zoomed.

By looking at the results plotted in Figure (2), it is possible to conclude that the muscle activation envelope has a slight activation delay with respect to the movement control signal. This early activation is probably due to the muscle preparation that precedes the movement: muscle electrical activity begins at the cellular level, and it takes some time to reach the muscles through the nervous system, finally stimulating their contraction.

Exercise 2

How can you reach the four cardinal directions displayed on the screen?

To reach the four directions displayed on the scene we performed the following steps.

First of all, we decided to normalize the muscle signals between 0 and 1, to ensure that every muscle has the same influence on the final motion; this was necessary as the biceps generate a higher amplitude signal than the trapezius. Moreover, we extracted the time vector from the provided data.

After that, we imported the signals into a Simulink model and treated them consequently. The first step was to add a bottom threshold of 0.4 to ensure that the signal noise did not generate any motion for the cursor. In particular, this value was chosen after analysing the trapezius signal, which had a way more significant noise than the biceps.
For the sake of coherence, we decided to set the same lower bound for all the signals.

The cursor movements were then performed according to the intensity of the signal. This way, we simulated the behaviour of a human-robot interface, changing the cursor velocity according to the muscle signal intensity instead of manually setting a value after which the cursor needed to move towards the desired direction with a certain velocity.
Please note that it was not necessary to set a top threshold since the signals were previously normalized, with 1 as their maximum.

In the following step, the contributions of antagonist muscles were subtracted, in order to retrieve the dominant direction toward which the cursor needed to move.
The two vectors, respectively one for the trapezius and one for the biceps, were then concatenated, so that the X and Y positions of the cursor over time could be given as input to the Virtual Sink Block to display the cursor motion on the simulator according to the muscle signals. As for the Z, it was set to a constant value of 0.02 as it could be retrieved from the Virtual Sink Block details.
After the concatenation, we introduced a rate limiter block, with the purpose of performing a smoother motion activation.

To let the simulation run properly and the cursor stop on the desired points, we dampened the value of our signals by multiplying them by a 0.1 gain. This value was decided after looking at the Virtual Sink Block properties, where we found out that the circumference the coloured dots laid on had a 0.1 radius. Given that we previously normalized all the muscle signals from 0 to 1, this gain allowed us to scale them from 0 to 0.1, as wanted to fit the problem.

How can you reach the other 4 directions displayed on the screen? Determine and implement a method to reach the remaining four targets in the diagonal directions.

To reach the four remaining directions, we decided to replicate and finally rotate by 45° around the z-axis of the Virtual Sink plot that was done in the previous question, thus obtaining the desired behaviour on the diagonals.

To do so, we created a rotation matrix with the requirements above and pre-multiplied it with the input of the Virtual Sink Block.

Can you think about a different way to map the muscles and be able to reach all 8 targets with the activation of these muscles? Explore an alternative mapping approach between muscles and cursor movement that enables reaching all 8 targets. Identify any potential drawbacks associated with this alternative mapping method.

To reach all eight points, we decided to give as input to the Virtual Sink Block the alternation of the first and second questions. This was done by adding a Switch block before giving the signal as input to the Virtual Sink block. The threshold of the Switch was set to 15, in order to let the standard simulation, which reached the four cardinal directions, run in the first 15 seconds, and the rotated simulation, which reached the diagonal directions, in the second 15 seconds. In the latter, the muscle signals were pre-multiplied by the rotation matrix as before.

The main drawback is that this mapping does not work on a generic signal, which presents simultaneous activation of different types of muscles. However, this solution was exactly created to adapt to this particular set of inputs.

Can you think of a different way to map the EMG activity to control the cursor? There is no need for implementation, just answer the question, motivating your answer.

Assuming to have the same inputs, we could think of mapping each muscle in two different directions, one cardinal and one diagonal, to control the cursor movement. For example, considering the right bicep, its first activation could move the cursor towards the east direction, while the second towards the north-east diagonal. In this case, only the strongest activation should contribute to the movement, ignoring the difference between antagonist muscles. This behaviour could be implemented with a boolean flag that toggles every time a certain muscle goes over the activation threshold. Consequently, with an even number of activations, the muscle would be mapped with the cardinal direction, while, with an odd one, it would be mapped with the diagonal.

On the other hand, considering more general signals, another way to map the EMG activity to control the cursor movement is to consider the combination of the muscle signals. In this method, each muscle is assigned with a cardinal direction, for example:

- Right bicep: east
- Left bicep: west
- Right trapezius: north
- Left trapezius: south

which is analogue to the setup of our previously implemented method. However, the main change is for the diagonals, as they can now be reached with the simultaneous activation of two muscles. For example, if the right biceps and the right trapezius activate concurrently, the cursor will move to the north-east diagonal.
This method allows for complete control of the cursor, which can now move along the whole circumference and stay still if antagonist muscles are activated concurrently.