Neurotechnology ELA411 – Project 4.5 hp

The aim of the project is to develop a complete real-time neurorobotic system to control, using the mind, the gripping of an object by a robotic hand. As a team, you will need to collaborate and work together to be able to successfully implement a functional system. As illustrated in figure 1, the system can be divided into three components; 1) Signal acquisition, 2) Real-time data interpretation, and 3) the Robotic hand. You will each work within one of the components as your main responsibility but, as a team member you are also expected to help out with the other components if time allows.

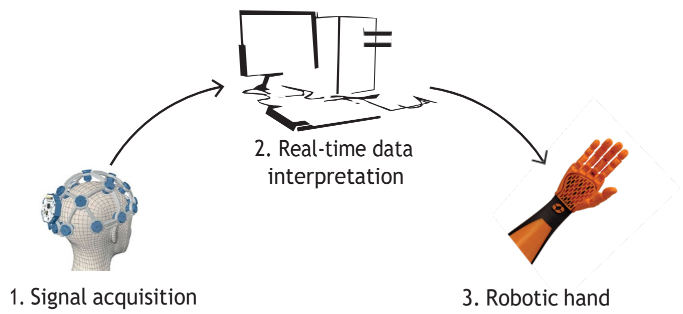

Figure 1. System overview.

For the overall project, you will be working in a Teams group created for the project. The final working code should be put in a map entitled "FinalVersionCode", also including a *getting started* guide to how to start and operate the system. The real-time requirements for the project can be decided by you as a group, but keep in mind that very long delays in a BCI system may be detrimental to its usability.

Component 1

This component is composed of the signal acquisition and thus the data collection. Obtaining high quality brain signals will be crucial for the outcome of the neurorobotic system. In addition to measuring EEG signals, this component will be largely dealing with real-time/online data streaming from 3rd-party software to be collected and synchronized in one module. Component 2 may need information regarding how often data is sent and the structure of the data, so consider streaming data or reading the manual to find out the structure and properties of the data that will be sent to MATLAB (for component 2).

The requirements and tasks are specified as follows and illustrated in figure 2:

- OpenBCI 16-channel EEG system should be used to collect brain signals.
- EEG Data should be streamed to LabVIEW on a PC.
- The instruction program (task protocol) for the model training phase can be programmed in Unity or in LabVIEW. Instruction images should be shown on screen, and time stamps for when the instructions are shown must be synchronized with the EEG data stream.
- From LabVIEW, structured data (in packets) should be streamed in real time (i.e. continually online) to MATLAB (or equivalent).
- Streamed data should also be saved to disk, such that it can be analyzed offline.

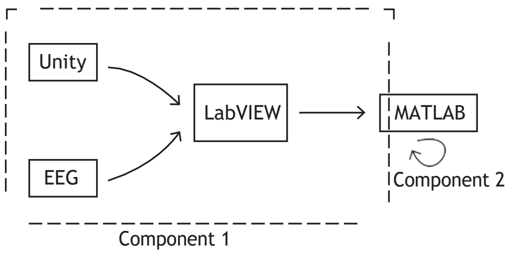

Figure 2. Overview of component 1.

Component 2

This component is composed of real-time data interpretation and focus will be on signal processing to produce a control command to the robotic hand. This component relies on high quality signals, but it is also crucial to correctly interpret the data in order to develop a truly mind-controlled robotic hand. Therefore, it is especially important that you communicate regularly with component 1 to define and specify the specifics of the data together. From the work in component 1, you will receive a stream of data in MATLAB that you will work with. At the start, before component 1 has recorded sample EEG data for you to work on, start investigating what functions and analysis tools you will use by reading articles (Literature), and figure out how to use these functions in MATLAB (or write them). It may be valuable to have the data structure even if component 1 hasn't produced real data yet, so ask if they can create some trash data. This way, you will know how many channels and datapoints each EEG packet has, and how often they are sent. The control command that you extract should be sent to LabVIEW so that component 3 can take over. Be sure to discuss with component 3 so they know what type of signal they will receive and at which rate they will receive it.

The requirements and tasks are specified as follows and illustrated in figure 3:

- MATLAB should be used for online signal processing and extraction of information on a PC.
- EEG signals should be pre-processed online to remove irrelevant frequency information.
- Time-frequency EEG features may be extracted and used as features, but you may also use some other feature (e.g. Common spatial patterns, P300-detection etc).
- At a minimum, binary mental states should be detectable, for example {grip, rest}.
- The command extracted from the data should be sent back to LabVIEW.

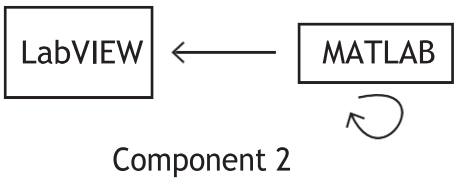

Figure 3. Overview of Component 2.

Component 3

This component is composed of real-time control and optimization of the robotic hand. From the work in component 2, LabVIEW will receive a command that will be the basis for the movement of the robotic hand. The focus in this component is to receive the command and ensure that the robotic hand grips an object when instructed.

The requirements and tasks are specified as follows and illustrated in figure 4:

- A RoboRIO should be used to control the robotic hand.
- 2 commands should be received in LabVIEW, 0, meaning release hand if already in grip or rest/do nothing and 1, meaning close hand around abject.
- 2 movements of the hand should be implemented: 1) grip and object (i.e. close hand) and 2) release or rest hand (depending on the current position of the hand).
- By analyzing the information provided by the servo, the robotic hand should be able to grip objects of different size.

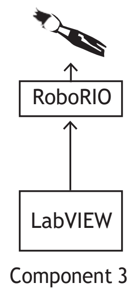

Figure 4. Overview of component 3.

Project status meeting 1

During the first project status meeting, all components should have a solution for connecting the entire BMI system, either fully working or decisions how to implement the inter-component communication. This is to ensure that the entire system can be connected before the first project lab. Each component group should also present the status of their work and challenges that they have encountered. The purpose is to be able to overcome the challenges and identify parts in the system that need to be focused on. An indicative 10-15 minutes per presentation is proposed but there will be no strict time limit and/or requirements since the purpose of the meeting is to accelerate the progress of the work.

Project Lab 1

During the lab, you will demonstrate your current work. At the time of this lab, you should be able to connect the components such that real-time communication through the full system works on a minimal level. More specifically, an acquired signal from the EEG cap should be passed through component 2 and be able to activate the end effector in component 3. Your real-time requirements should be demonstrated. After demonstrating the full system, each component should demonstrate component-specific solutions, for example by

1) How EEG data is streamed and stored in comp 1
2) How training data is stored/loaded to train the model in comp 2
3) How various expected input causes predictable behavior in comp 3

After demonstrations, the teachers may provide helpful feedback if any component is struggling with their development.

Project status meeting 2

During the second project status meeting, each component should have explored and decided upon all the solutions required for the system to meet all requirements. Each component will present the status of their work, same as in the first project meeting.

Project Lab 2

During this lab, the system should be demonstrated in full, and all basic functionality should work as intended. This lab occurs shortly before the final demonstration of the BMI system, and should at maximum reveal minor flaws which can be easily addressed before the demonstration day. This day is also the deadline for submitting the full report.

Project Demonstration

Today you give the oral presentation and demonstration of the finished system. This is an examination moment (see **Oral presentation** and **Demonstration** under ‘Examination’).

Examination

Written report: A written report (max 10 pages) according to a template should be uploaded to Canvas. The report should be a unified report of the complete neurorobotic system covering all the components. This report thus needs to be partially written in collaboration between all participants. Each section should be written by those who developed / worked on the solution, and the section titles should include the authors' names. The report should thoroughly describe each component and each part required for the system. The report should contain

1) Hardware and hardware configurations for all hardware used. If you tried several solutions, motivate your choice. Plots or statistics of hardware performance can be valuable.
2) Software, software functions and configurations if applicable, both for code you write yourself and built-in functions. Plots or statistics of performance or effectiveness from different solutions/settings can be valuable information.
3) Description of test runs made with the system, how it was performed and the results from the test runs. Test run descriptions should include meta data and all information needed to recreate the test run, such as settings, subject (id, not name), EEG data (which should be saved for offline analysis and recreating results) and performance during the test run (such as accuracy and end effector movement in time).
4) Results from offline analysis of the data and comparisons to the test runs. If multiple sessions were performed, compare the results from them.
5) Instruction how to run the system, explaining the user interface should be in the report. Issues or limitations with the system should also be described to avoid misuse of the system.

Oral presentation: A presentation of the project should be carried out on a general level (i.e. to allow people that are not in the field/course to understand) presenting the work performed during the project. The presentation should include introduction to the task, system overview, solutions and results, and last conclusions and future work.

Demonstration: A demonstration should be carried out after the presentation to test the functionality of the neurorobotic system in real time.

Grading criteria: The grading will be performed on an individual basis and it is therefore important to explicitly state in the report the work of each participant. For more details on grading criteria, check out the study guide.

Basic and advanced solutions for the different components:

The prioritized goal of the project is to develop a functioning real-time system through team collaboration. Therefore, if you have managed to develop a basic functioning solution in your component group, helping another component group to develop its basic functioning solution will have high merit, meaning that you will be eligible for grade 4 and 5 (even though you did not develop an advanced solution). **Therefore, in all components,the task is to start developing the basic solution and then help each other out until all components are functioning in real time.** However, receiving help can never lower your grade, so feel free to accept any help you want. Ultimately, you all work together to produce a BMI system. If you identify great challenges in some component, then you are encouraged to temporarily (or permanently) switch component. If you do, contact a teacher to inform us of your decision.

Basic solution:
Component 1: Data recording system (incl. protocol) to enable offline model training and online model testing (performed in 2nd component) .
Component 2: Threshold-based generation of commands (extracting commonly used EEG features for detecting mental tasks).
Component 3: Pre-programmed approach to enable gripping of objects with different sizes.

Advanced solution:
Component 1: Data recording system (incl. protocol) for online model training and testing (performed in component 2) and an intuitive/easy to use interface for running experiments (preferably in LabVIEW).
Component 2: An enhanced signal processing pipeline based on offline analysis of the EEG data, which leads to better performance or feedback from relevant EEG features.
Component 3: A graphical representation of the hands current status and/or pose (preferably integrated in the LabVIEW interface). Independently move the thumb from other fingers to allow two degrees of freedom (DoF) in the hand movements.

Final note:
Document your work throughout this course! If you do not document your work you may end up forgetting what you did, but it is important that you document both the final solution and abandoned solutions, and why they were not used. This will be discussed on the project meetings, and the result of your individual work should be in the project report.