

Chapter 1

Material and methods

1.1 Hardware

The following devices have been used for the affective BCI:

1. Empatica E4 wristband by a Massachusetts Institute of Technology (MIT) spin-off.
2. OpenBCI hardware for the EEG acquisition system.
3. A standard webcam.

1.1.1 Empatica E4

The E4 is a medical-grade wearable device that offers real-time physiological data acquisition. It measures blood volume pulse, from which heart rate variability can be derived, captures motion-based activity with a three-axis accelerometer, measures the constantly fluctuating changes in certain electrical properties of the skin (GSR), and reads peripheral skin temperature. It allows the synchronization of such signals by the use of an internal clock. The GSR and temperature sensors have a sampling rate of $4Hz$ while the accelerometers and the BVP signal are measured at $64Hz$. The combination of the GSR and BVP sensors enables to simultaneously measure the balance of sympathetic nervous system activity and heart rate. More detailed information can be found at <https://www.empatica.com/en-eu/research/e4/>.

1.1.2 OpenBCI hardware for the EEG acquisition system

The OpenBCI system is a collection of headsets, boards, sensors, and electrodes that allow the research on brain-computer interfacing to purchase high-quality equipment at affordable prices. In this research the OpenBCI Cyton Board, an Arduino-compatible 8-channel neural interface with a 32-bit processor, is used. At its core, the OpenBCI Cyton Board implements the PIC32MX250F128B microcontroller, giving it lots of local memory and fast processing speeds. The board comes pre-flashed with the chipKIT™ bootloader, and the latest OpenBCI firmware. Data is sampled at 250Hz on each of the eight channels.

The OpenBCI Cyton Board can be used to sample brain activity (EEG), muscle activity (EMG), and heart activity (ECG). The board communicates wirelessly to a computer via the OpenBCI USB dongle using RFDuino radio modules. It can also communicate wirelessly to any mobile device or tablet compatible with Bluetooth Low Energy. More detailed information can be found at <https://openbci.com/>.

1.2 Software

Wearable devices are tools of particular interest because of the possibilities they offer for brain-computer interface (BCI) related research, such as motor imagery, emotion estimation, or attention-related studies, which could benefit from open source applications. Pragmatically, a project of this type requires technical solutions to be provided. All the code has been developed with pure python libraries in an object-oriented paradigm. The software engineering process was carried out taking into account cohesion and coupling for proper modularization. This allows GePHYCAM application to be modular, scalable, and easy to maintain; in fact, this is a key aspect of any scientific tool to allow researchers to make modifications and to fulfill the specific requirements of each experimental scenario.

The philosophy of GePHYCAM is based on a supervised machine learning approach and therefore they offer two modes of interaction:

- The first allows for real-time acquisition and processing to generate a database and build models.
- The second provides online signal processing using pre-trained models to classify brain patterns.

The proposed application is versatile and easily adaptable to different experimental designs while maintaining high-performance real-time signal processing. Aware that pattern recognition is in constant development, GePHYCAM offers the option of importing python external scripts, which must have a predefined structure, to include self-developed machine learning methodologies. Besides, as experimental designs require event synchronization, a TCP/IP interface has been provided. GePHYCAM is expected to be accessible to the entire scientific community, providing a resourceful tool for experimental paradigms of human behavior, which encompasses the following functionalities:

- Real-time acquisition and visualization of physiological signals.
- Trigger synchronization by a TCP/IP interface that allows start/stop the recordings remotely.
- Recording of data on European Data Format (EDF) for physiological signals.
- Online behavior labeling interface whose labels are synchronized and stored in the EDF files.
- Online signal processing with self-developed methodologies through the possibility of importing external python scripts.

1.2.1 GePHYCAM application

Title: GePHYCAM: General electrophysiological and camera acquisition system for human behaviour recordings in real-time

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URL: <https://github.com/mikelval82/GePHYCAM>

License: GNU General Public License v3.0

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This application looks forward to providing a resourceful tool for human-behavior experimental paradigms using several information sources such as EEG, GSR, BVP, TMP, ACC, and VIDEO. Figure 1.1 shows the layout of the GePHYCAM interface. Each section has been numbered to properly explain the role of each of the components:

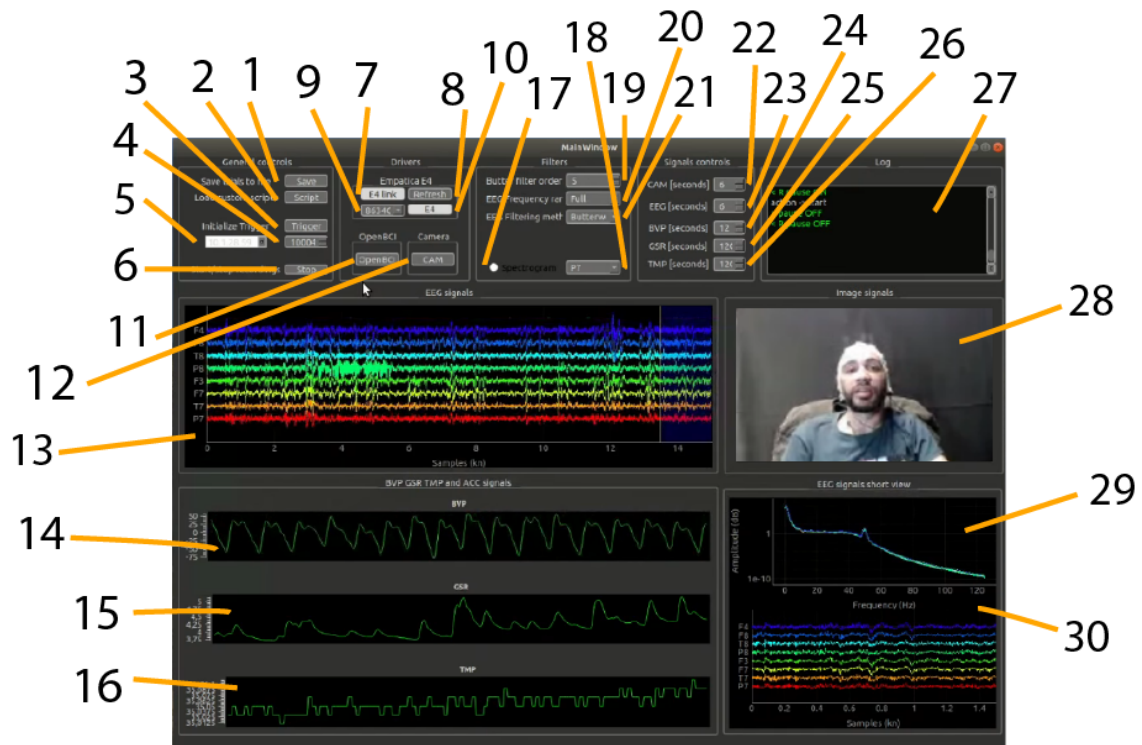


Figure 1.1: GePHYCAM: General electrophysiological and camera acquisition system for human behaviour recordings in real-time.

1. Save: Allows for setting the name of the user files where acquired data will be stored.
2. Script: For loading external python scripts developed by users for specific experiments.
3. Trigger: Starts the trigger server for event synchronization.
4. Trigger PORT: A Spin Box to specify the PORT to be used.
5. Trigger IP: A Spin Box to specify the IP direction to be used.
6. Start: Starts and stops real-time visualization.
7. Empatica Server Connect/Disconnect: Enables the connection and disconnection between the Empatica Server and the GePHYCAM.
8. Refresh: Requests to the Empatica Server the ID of Empatica E4 devices available.
9. Empatica ID: A spin box to specify to which Empatica E4 device to connect.
10. E4: Enables the connection and disconnection between the specified device through the Empatica Server and the GePHYCAM E4 driver.
11. OpenBCI: Enables the connection and disconnection between the OpenBCI and the GePHYCAM BCI driver through the corresponding serial device.
12. CAM: Enables the connection and disconnection between the webcam and the GePHYCAM CAM driver.
13. Long Term View: Allows the visualization in real-time of acquired EEG signals.

14. BVP Long Term View: Allows the visualization in real-time of acquired BVP signals.
15. GSR Long Term View: Allows the visualization in real-time of acquired GSR signals.
16. TMP Long Term View: Allows the visualization in real-time of acquired TMP signals.
17. Spectrogram: Activates/deactivates the visualization of the spectrogram in the spectrogram term view. When it is activated the spectrogram is shown, otherwise, power spectral density function is shown for each EEG channel.
18. Channel_ID: A spin box that selects the EEG channel to be shown for the spectrogram.
19. Butter filter order: A Spin Box to set the order of the Butterworth filter.
20. Frequency range: Sets the frequency range of the Butterworth filter applied to signals.
21. Filtering method: Determines the EEG online artifact removal (OAR) method to be applied.
22. CAM Window size (seconds): A Spin Box to set the window size of the webcam video signal.
23. EEG Window size (seconds): A Spin Box to set the window size of the EEG signals.
24. BVP Window size (seconds): A Spin Box to set the window size of the BVP signal.
25. GSR Window size (seconds): A Spin Box to set the window size of the GSR signal.
26. TMP Window size (seconds): A Spin Box to set the window size of the TMP signal.
27. Log viewer: Shows information regarding the internal state of the application.
28. Webcam viewer: Allows the visualization in real-time of acquired webcam signal.
29. Spectrogram Term View: Allows the visualization of each EEG channel spectrogram in real-time.
30. Short Term View: Allows the visualization in real-time of acquired EEG signals falling inside the length and temporal location of the adjustable sliding window.

1.2.2 Software design principles

As mentioned before, the design principles have been followed taking into account cohesion and coupling for proper modularization. All of the aforementioned applications follow the same structural design approach and share the core structure so it would be redundant a specific explanation for each of them. Therefore, a high-level description is provided that allows us to understand the design principles of each application. As can be noted in figure 1.2 where the high-level flow diagram scheme is detailed, one of the key points of the design is focused on drivers and the data managers. Hence, each device has its driver specification which in turn is assigned a specific data manager. That means, BIOSIGNALS and GEERT have only one driver each but for GePHYCAM three drivers are needed running in parallel with their corresponding data managers. As a result, each application requires a specific graphical interface definition but overall the logic is versatile, easy to maintain, and scalable.

- APP: This class serves as the main software module that builds the application. It has been designed using PyQt5, a Python binding of the cross-platform graphical user interface (GUI) toolkit Qt, implemented as a Python plug-in. It launches all the other modules and forks several processes. First, the APP main fork. Second, a Driver is forked for each device, using the multiprocessing python library. Finally, it forks a thread for each Data Manager, using the multithreading python library.

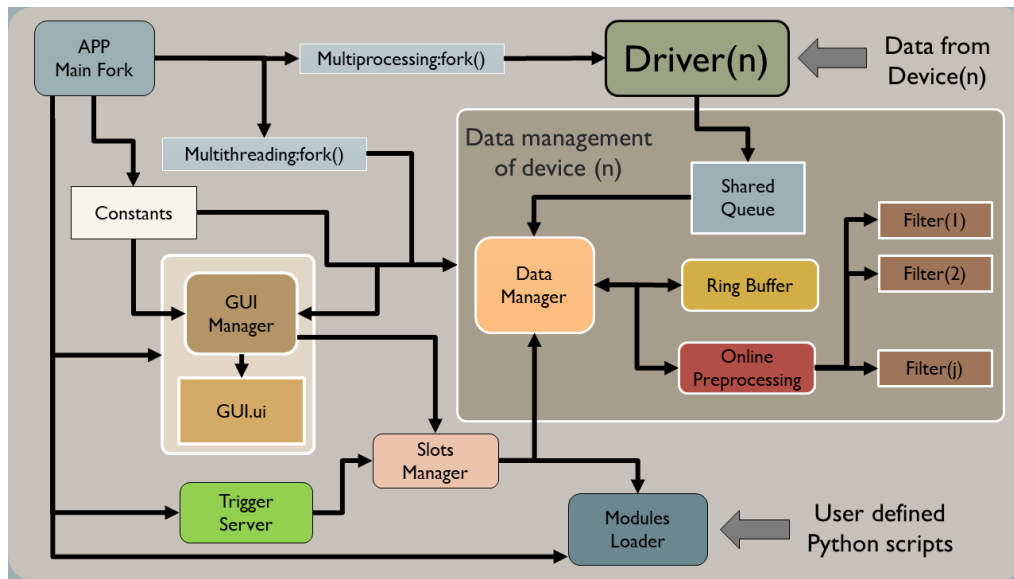


Figure 1.2: Flow diagram.

- Constants: Sets the whole constants used along with the application. Thus facilitating the specification of such general variables in a unique module. All adjustable parameters are set in this object.
- Queue: This Queue follows the FIFO rule.
- Ring Buffer: Stores the last values for each sampled source of information. The fixed size is defined by default in the Constants but it can also be dynamically modified during the GUI interaction through the 'Window size' Spin Box. Each time the fixed size is modified, the Ring Buffer is emptied.
- Driver: Meets the requirements of the real-time acquisition. It inherits from multiprocessing python library. It offers the interface between the APP and the hardware. Inter-process communication is facilitated by Queue. Once the fork starts running, iterates acquiring samples that are indefinitely queued.
- Data Manager: It is defined as an interface between the GUI and the Driver to properly separate the management of the acquired data. It inherits from a multithreading python library. It has access to the shared Queue so its role consist on extracting iteratively samples from the queue to insert them on a Ring Buffer.
- GUI Manager: Offers the management of each of the components of the GUI.
- GUI.ui: Implements the APP graphics. It has been designed using QtDesigner, the Qt tool for designing and building GUIs.
- Trigger Server: A TCP/IP server for event synchronization. It can receive client connections and handles each request by notifying the Slots Manager using a callback function.
- Slots Manager: The purpose of this module is to bring the application to the versatility of adding a set of callbacks that allow synchronizing the overall logic.
- Online Filtering: This module has been implemented as an interface for a set of real-time signal processing methods.

Algorithm 1.1 Imported python scripts required structure.

```
# -- Add imports --
# import numpy as np

# -- Class definition --
class pipeline():
    ''' Predefined structure. '''
    def __init__(self, app):
        # -- initialize variables --
        self.log = app.log

    def run(self):
        # -- code desired behaviour --
        self.log.update_text('Start_computing_the_user_module.')
```

- **Modules Loader:** The main purpose of this module is to expand the versatility of the APP for a wide range of research scenarios. It is required that users code the scripts with a predefined structure as shown in 1.1. The module will receive a reference to the APP instance so total access to the underlying object instances is offered.

Main workflow scheme: Once GePHYCAM is launched it can work as follows; Data Manager is threaded and starts iteratively trying to extract values from the queue. The thread runs a loop that is controlled by a logical condition. The iteration process cannot acquire data if the queue is empty. Then, the Driver is forked and automatically detects the corresponding device to connect with. Following, the driver starts iteratively stacking data into the Queue from the hardware. Both the thread and the fork form a consumer-producer system. The Ring Buffer acts as a short term memory. The Data Manager fills the Ring Buffer each time a new value is obtained from the Queue. Once the Ring Buffer is full, it starts overwriting the oldest data and so on. At this point, two stages are provided:

- **Stage 1:** Real-time visualization can be performed by pushing the start button. It does not imply user data storage. The start button has been designed to test the quality of the signal acquisition. The start button state will be changed, so pushing it again will stop visualization. Parameter settings (user filename, filter order, window size, online artifact removal method, and so on) should be done on this stage.
- **Stage 2:** Once the signals are properly acquired, the Trigger button can be pushed that initializes a TCP/IP server. The application only stores data in between a pair of client received requests. It is expected that one request indicates the start instant for event synchronization while the second, the stop instant. For the following, two pairs of events form a trial. During the trial duration, the Ring Buffer slots a callback to the Data Manager whenever an amount of data equal to the window size is fulfilled, that is, a sample is generated. At the end of the event, the Data Manager permanently stores acquired samples in the users' file with its corresponding metadata. Data Manager counts the number of samples generated and the number of trials, other metadata values are obtained from the Constants module.

Versatile workflow scheme Modules Loader allows the definition of own produced scripts. Each imported script must follow a predefined structure. The versatility comes due to the reference given to the imported script to the main object instance. Thus, different scenarios could be provided through this component.

- Offline scenario: The user could experiment with the main workflow scheme. After collecting the required data, a script could be loaded containing the coding for an offline analysis, i.e., training a machine learning model and store it on disk for future use.
- Online scenario: The user, could perform online computation thanks to the reference given, having access to all the underlying object instances. Access to the Data Manager to acquire EEG samples online is therefore provided. Moreover, applying OAR methods or even using pre-trained machine-learning models for online predictions can be also easily implemented.

The main highlights of the application consist of its versatility: First, modularizing the interaction between the GUI manager and the Driver, which allows the embedding of drivers for other acquisition systems. Second, the separation between the GUI and the logic, where the former allows future modifications and performance of the GUI components, without altering the logic, and vice-versa; Finally, the Modules Loader, further expands the versatility, by offering the flexibility of incorporating self-developed scripts for specific scenarios and workflow schemes. The proposed GePHYCAM application is versatile and easily adaptable to different experimental scenarios while maintaining high-performance signal processing in real-time.