Towards Open and affordable Real-world Brain-computer Interface: The BASIL Project

Roman Mouček (moucek@kiv.zcu.cz)
University of West Bohemia, Faculty of Applied Sciences https://orcid.org/0000-0002-4665-8946
Lukáš Vařeka
University of West Bohemia, Faculty of Applied Sciences, New Technologies for the Information Society
Petr Brůha
University of West Bohemia, Faculty of Applied Sceinces
Petr Ježek
University of West Bohemia, Faculty of Applied Sciences
Pavel Mautner
University of West Bohemia, Faculty of Applied Sciences
Irena Holečková
University of West Bohemia, Faculty of Applied Sciences
Johannes Summer
Loschelder Rechtsanwälte Partnerschaftsgesellschaft mbB: Loschelder Rechtsanwalte Partnerschaftsgesellschaft mbB
Peter Lopuszanski
Strategische Partnerschaft Sensorik e.V.

Research

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Abstract

Background: Independent and open brain-computer interfaces (BCIs) working outside the laboratory environment are still rare. Their most limiting factors include low classification accuracy, information transfer bit-rate, low variability of used approaches, and closeness of the hardware and software components of the system. The presented BASIL project has focused on the design, development and testing of an open and affordable BCI system that is built on low-cost hardware and open-source software components. It provides people with motor impairments with an opportunity to control their basic home environment.

Methods: The concept of the BASIL prototype follows the best practices that are known within the construction of BCI systems, adds the concept of the cloud for remote BCI computations, relies on testing and customization of the whole system to the needs of individuals, and focuses on the open solution affordable for ordinary users. The core components of the BASIL project solution include hardware components for signal acquisition and software components for local execution of online BCIs.

Results: The BASIL system was tested on ten participants in laboratory conditions. We failed to evoke a reliable P300 component with eight-trial averages. Eyes blinks, alpha activity, and steady-state visually evoked potentials were clearly observable. Dry electrodes with long pins were preferred by most users. Out of ten participants, six were able to control the system online, achieving more than 70 % accuracy.

Conclusions: The results show that a successful BCI system can be built on low-cost hardware for EEG signal acquisition and amplification. The current solution, the prototype of the open and affordable BASIL BCI system, is prepared for further community development and testing.

Full Text

This preprint is available for download as a PDF.

Figures

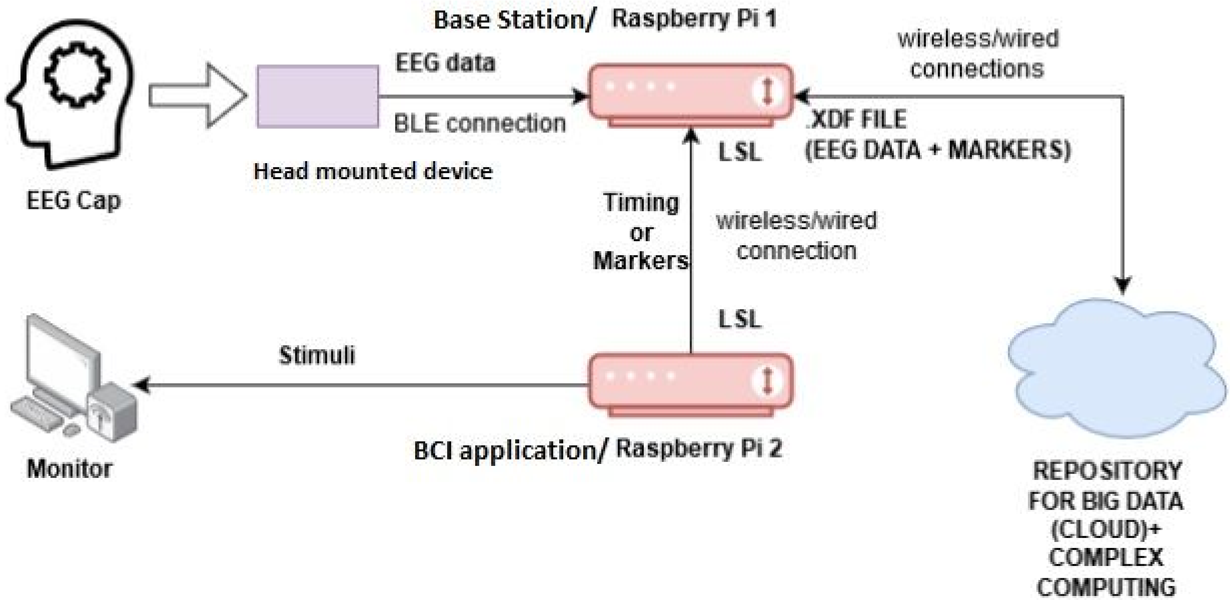

Figure 1

BASIL system architecture. Its main components are a head-mounted device connected with electrodes for EEG data capturing, base station for EEG data receiving, synchronizing with event (stimuli) markers, and processing (all running on Raspberry Pi 1), BCI application implementing the stimulation protocol (running on Raspberry Pi 2), and remote repository (cloud) for long-term data preserving and complex computing.

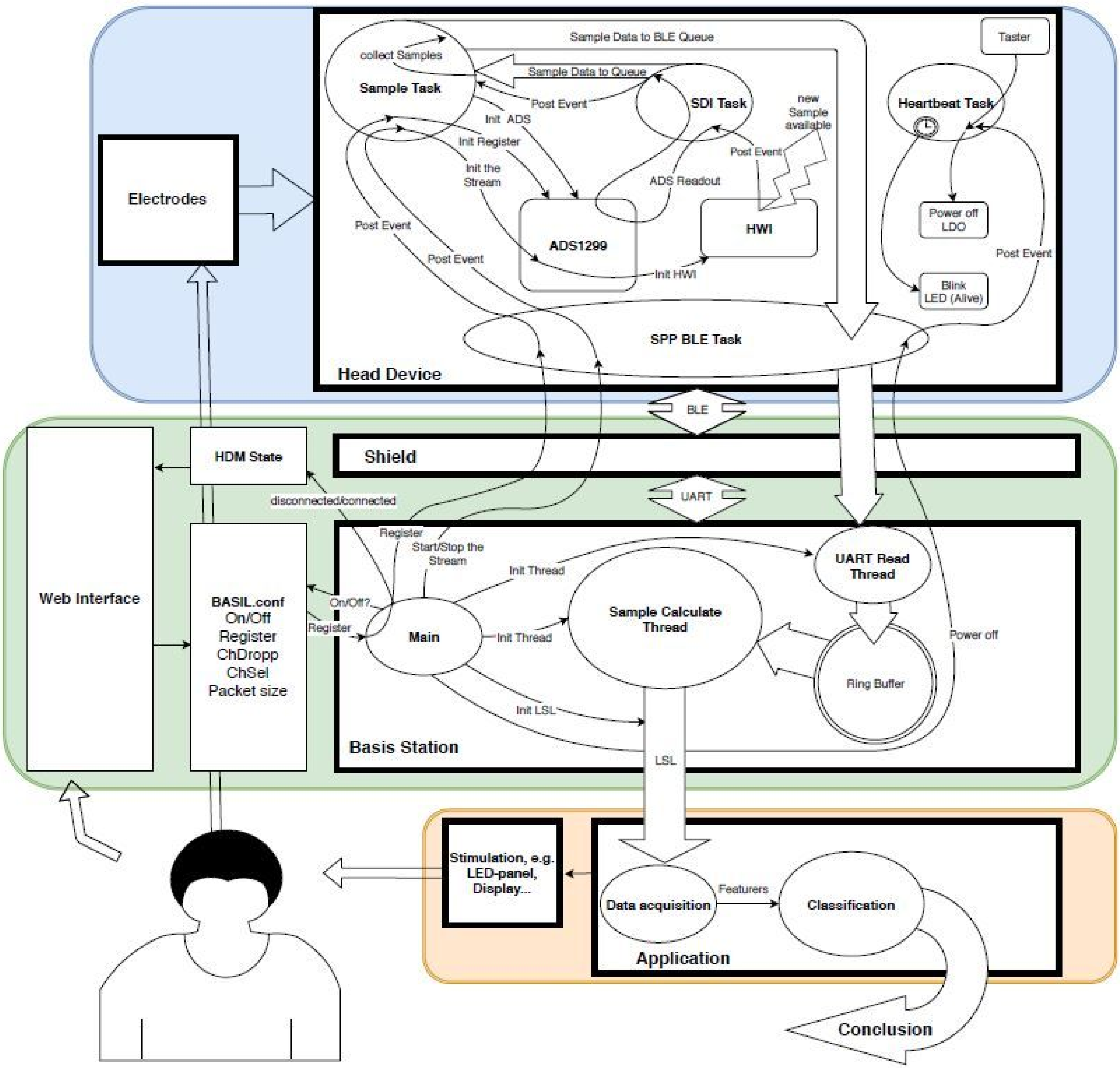

Figure 2

Detailed overview of the BASIL hardware. On the blue background, you can see the head-mounted device and the internal signal flow from the electrodes to the BLE connection. The base station with the BLE counterpart is shown on the green background. It processes all the data and sends them over LSL to the BCI application (the orange background).

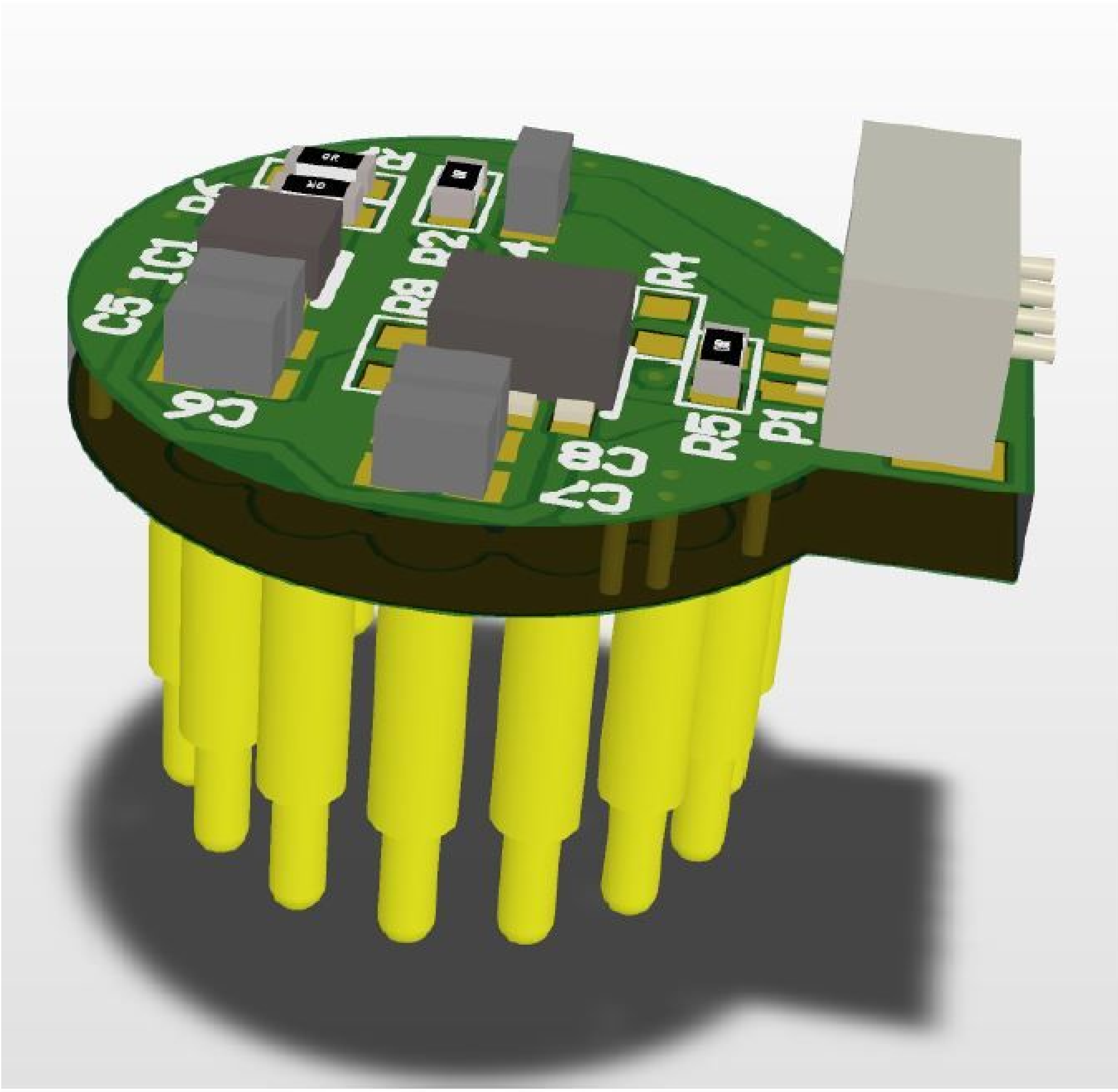

Figure 3

Dry electrodes designed for the BASIL project. They consist of a printed circuit board (PCB) with an amplifier and spring-loaded gold-coated pins. The contacts are arranged in a circle. The electrodes have four connections: the 5V power supply, the output signal, and the shielding.

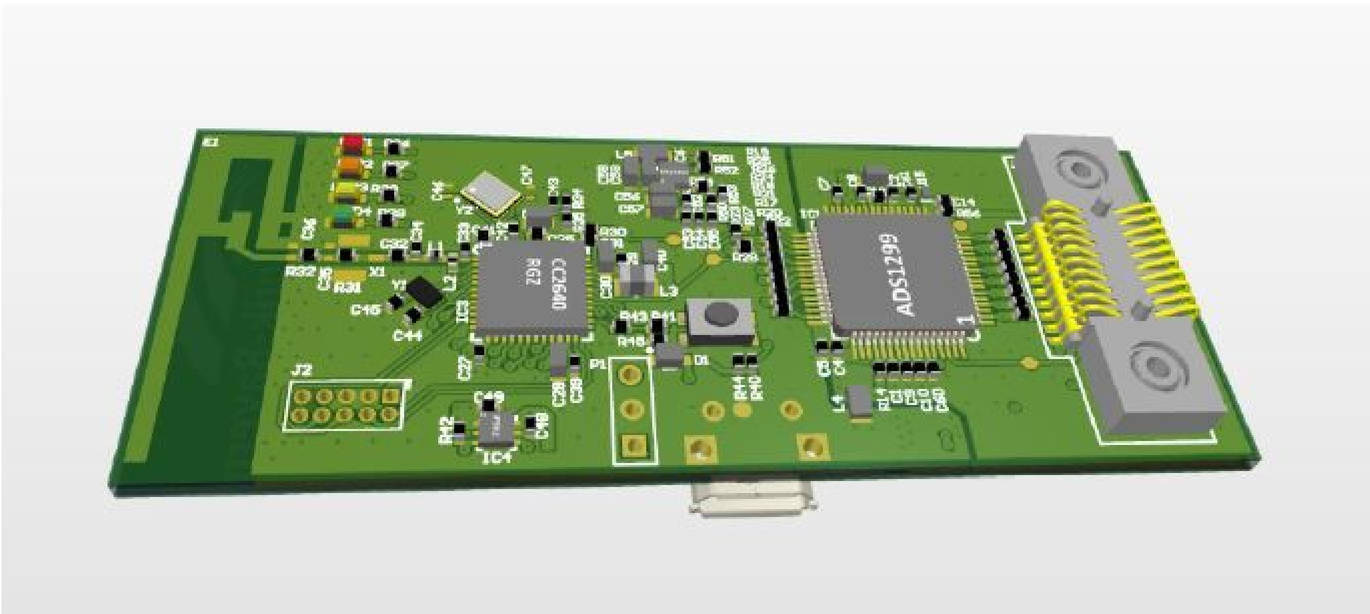

Figure 4

Head-Mounted Device. It is a mobile battery-powered device; signals are forwarded over the BLE protocol. It records analogue voltages of up to 8 electrodes with up to 250 samples per second.

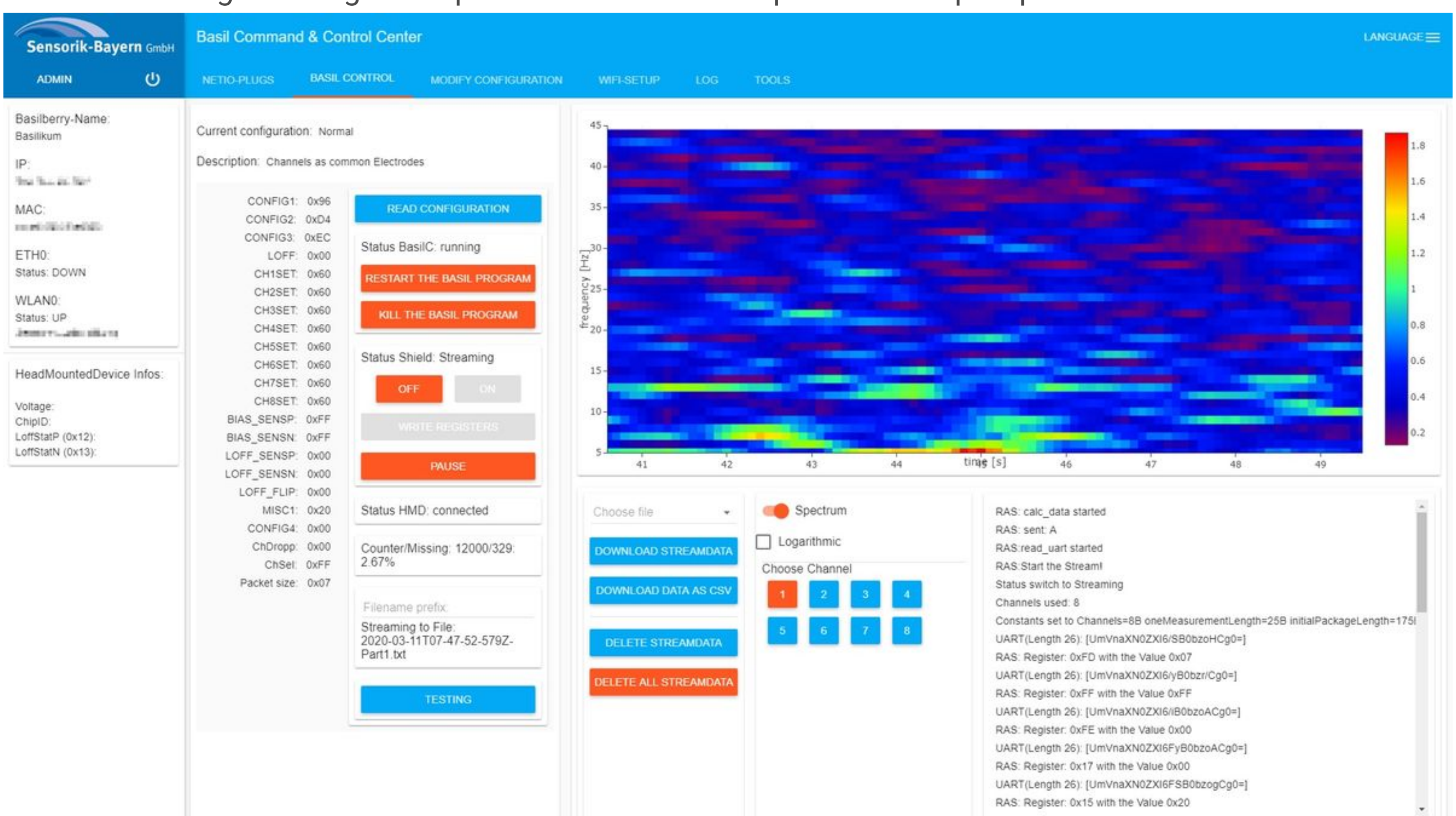

Figure 5

Web-Interface deployed on the base station. All necessary settings for the base station and head-mounted device, as well as communication between these two devices, can be easily changed.

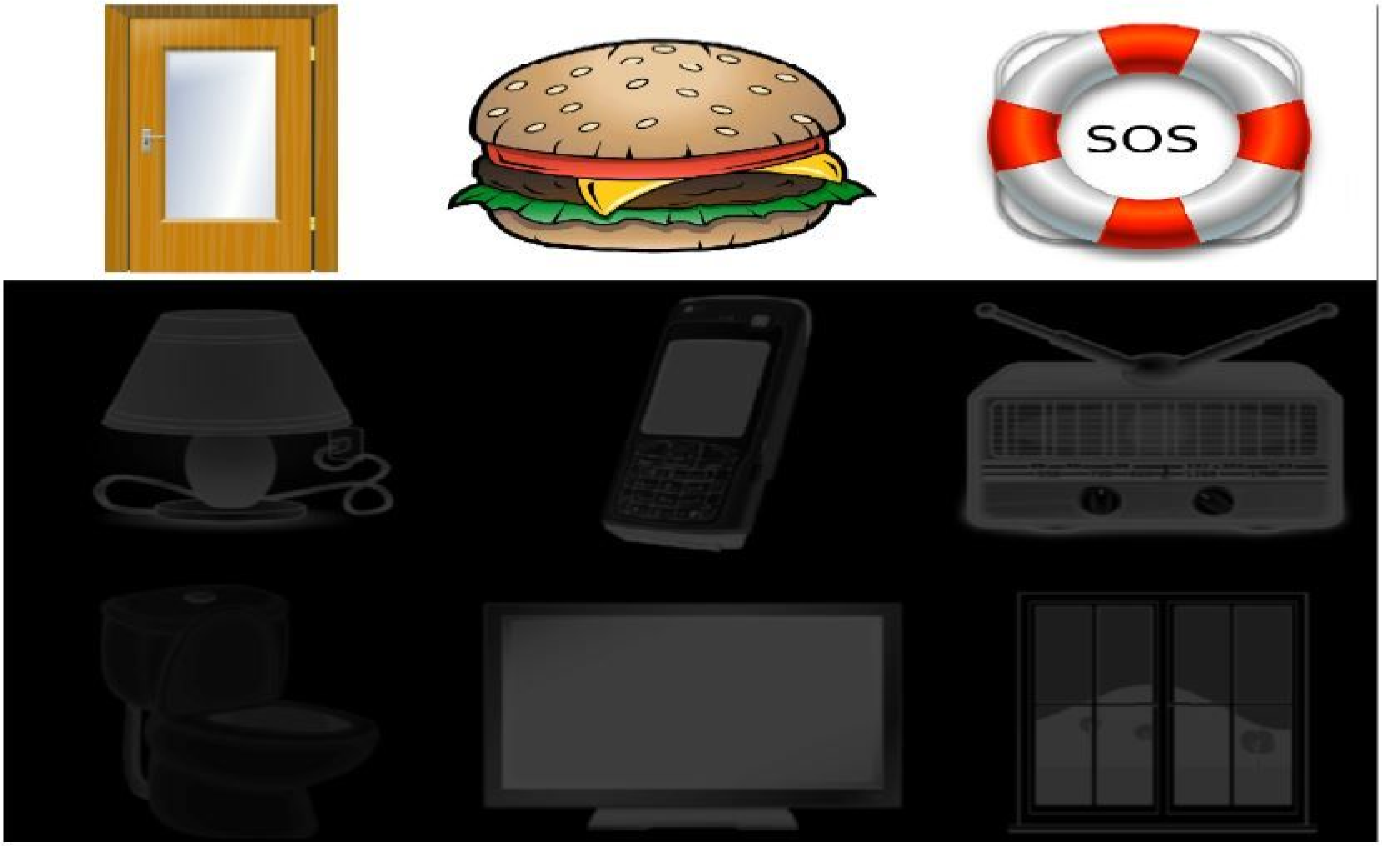

Figure 6

P300 stimulation protocol. The user focuses on one of nine stimuli within matrix representing his/her possible activities and needs; it means he/she focuses on the row or column containing the selected symbol when this row or column is highlighted.

Figure 7

SSVEP stimulation protocol. Each of the three objects flashed with a different frequency depicted in green.

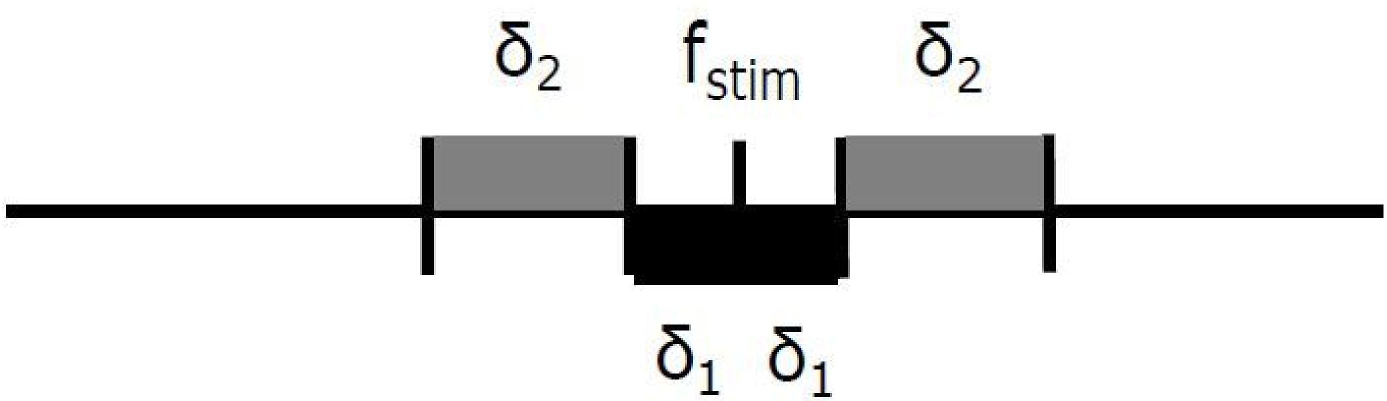

Figure 8

Spectral difference method. Energy of the close neighborhood (depicted in black): E1 =Pfstim+�1 n=fstim��1 x[n]2 is divided by the energy of the broader neighborhood (depicted in gray): E2 = Pfstim+(�1+�2) n=fstim�(�1+�2) x[n]2 � E1. The stimulation frequency with the highest proportion is the winner.

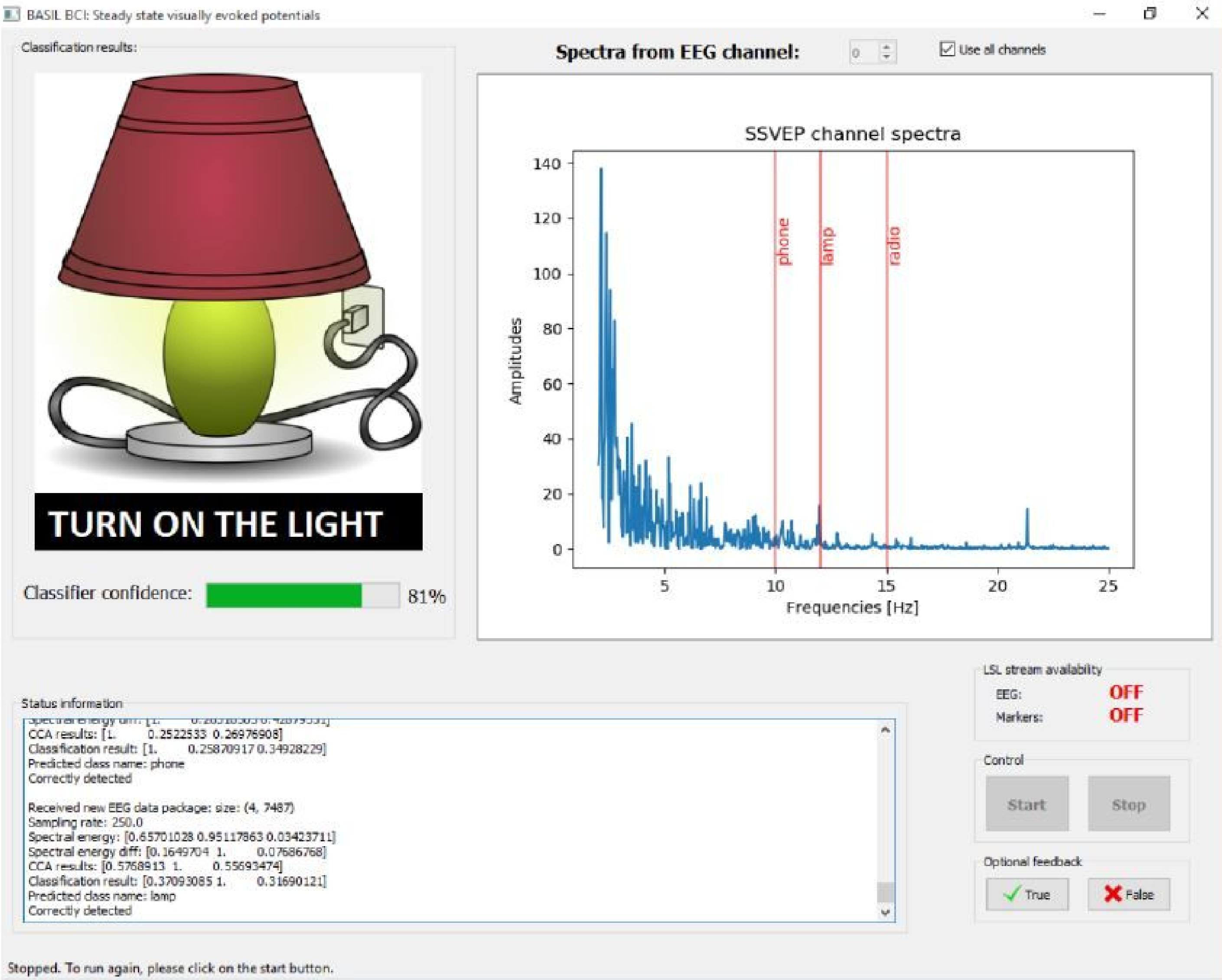

Figure 9

SSVEP on-line classification. The application for SSVEP on-line classification. The figure on the left depicts the predicted classification results. The plots on the right show power spectral density allowing the user to check spectral peaks corresponding to classification images manually.

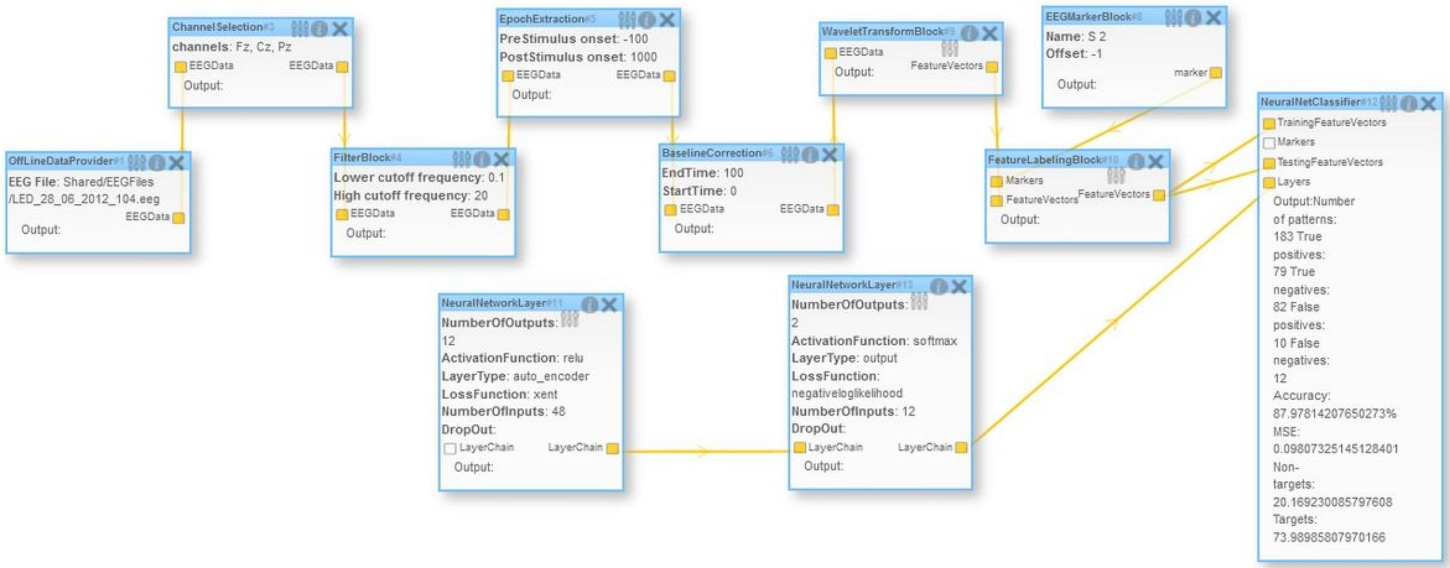

Figure 10

Workflow designer. An example of a simple single-trial classification workflow that forms the central part of a P300 BCI system. This work flow consists of several steps ensuring signal pre-processing (e.g. channel selection, band-pass filtering, and epoch extraction), feature extraction (discrete wavelet transform) and classification (neural network). In this work flow, for simplicity, the same data were used both for training and for testing. The results of the classification are depicted in the NeuralNetClassifier block.

Figure 11

Machine Learning Hardware Setup. LED arrays on the sides of the monitor ash on four different frequencies (7.5 Hz, 10 Hz, 13 Hz, and 15 Hz). SSVEPs elicited by flashing LED diodes are processed by machine learning libraries TensorFlow 2 and Keras.

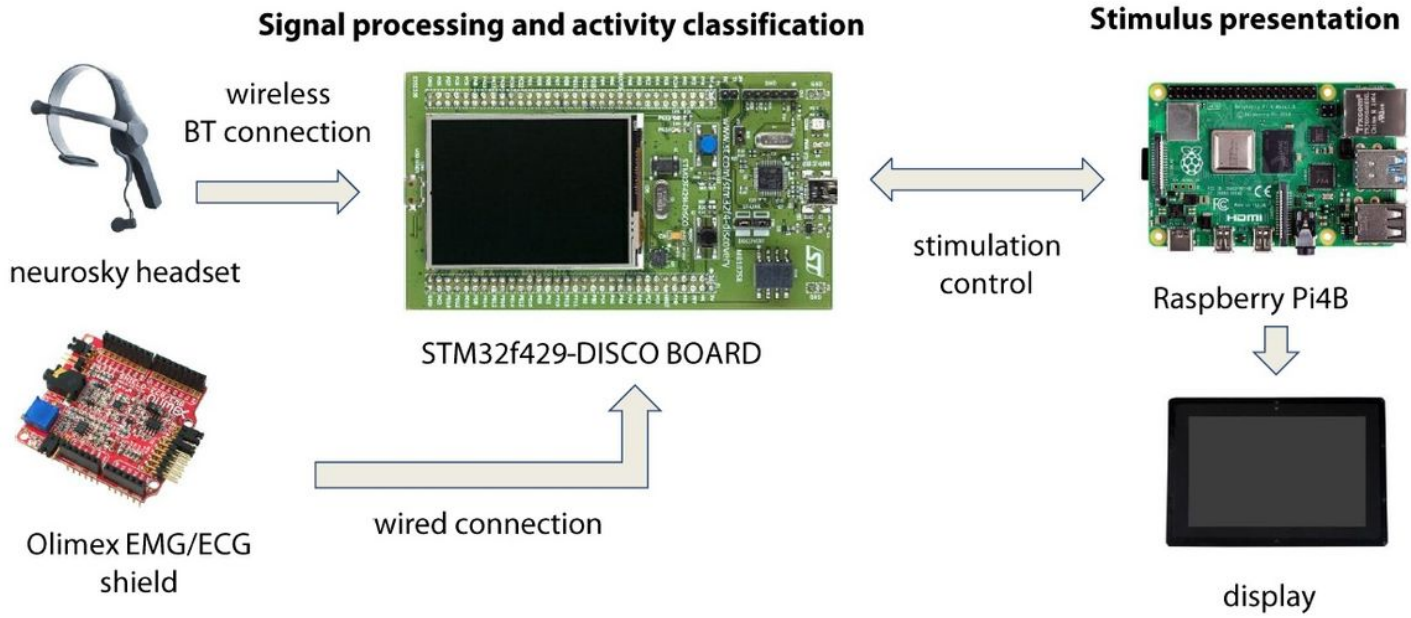

Figure 12

Use of muscle activity - block diagram. A block diagram of a system that implements an alternative protocol for confirming the selected activity. The EMG shield is connected to the A/D converter of the micro-controller, and the EEG headset communicates with the micro-controller via the Bluetooth module connected to the serial port of the micro-controller. GPIO pins of both devices (the micro-controller and single-board computer presenting stimuli) are used for synchronization and stimulation control.