

VERE

VERE: Virtual Embodiment and Robotic Re-Embodiment

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WorkPackage WP3: *Intention Recognition*

Deliverable D3.2 **First BBCI Prototype**

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EXECUTIVE SUMMARY

This document describes the brain and body computer interface developed in workpackage WP3. It lists the different parts of the first prototype and provides the description of the EEG based steady state visual evoked potential (SSVEP) and P300 brain computer interface paradigms used to recognize the high-level intentions of the user. For the detection of erroneous selections of actions either by the user or the BBCI system the Error Potential generated by the human brain in these cases will be exploited. First steps of identifying such error-related potentials from EEG signals are reported.

While high-level intentions decide on the what should be executed (transformed into a sequence of actions by WP4), low-level intentions aim at modifying how these actions are executed (quality of actions) by taking into account the actual user mental state. First steps into recognizing low-level intentions from EEG and physiological signals have been undertaken by recording an emotional database.

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Abstract (for dissemination)	The first BBCI prototype was successfully developed and installed at several VERE partner institutions. First studies are already successfully running.	
Keywords	BCI, physiological monitoring system, P300, SSVEP, error potentials	

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1 INTRODUCTION

The goal of workpackage 3 is to develop a system for identifying the intentions of the user and to extract their different components and aspects. There exist different levels of intentions. High level intentions include all goal oriented intentional actions and plans such as grabbing a glass or walking to the cinema, whereas low level intentions represent all actions and behavior which is not directed towards a specific goal. They typically define how a high level intention, a goal oriented action, is performed, the level of commitment to it, by considering e.g. different emotional states. The Body Brain and Body Computer Interface System (BBCI) records biosignals like the EEG, ECG, the respiration or the galvanic skin response of the user's body. It extracts the physiological parameters and features thereof and uses them to generate measures which represent both types of user's intentions.

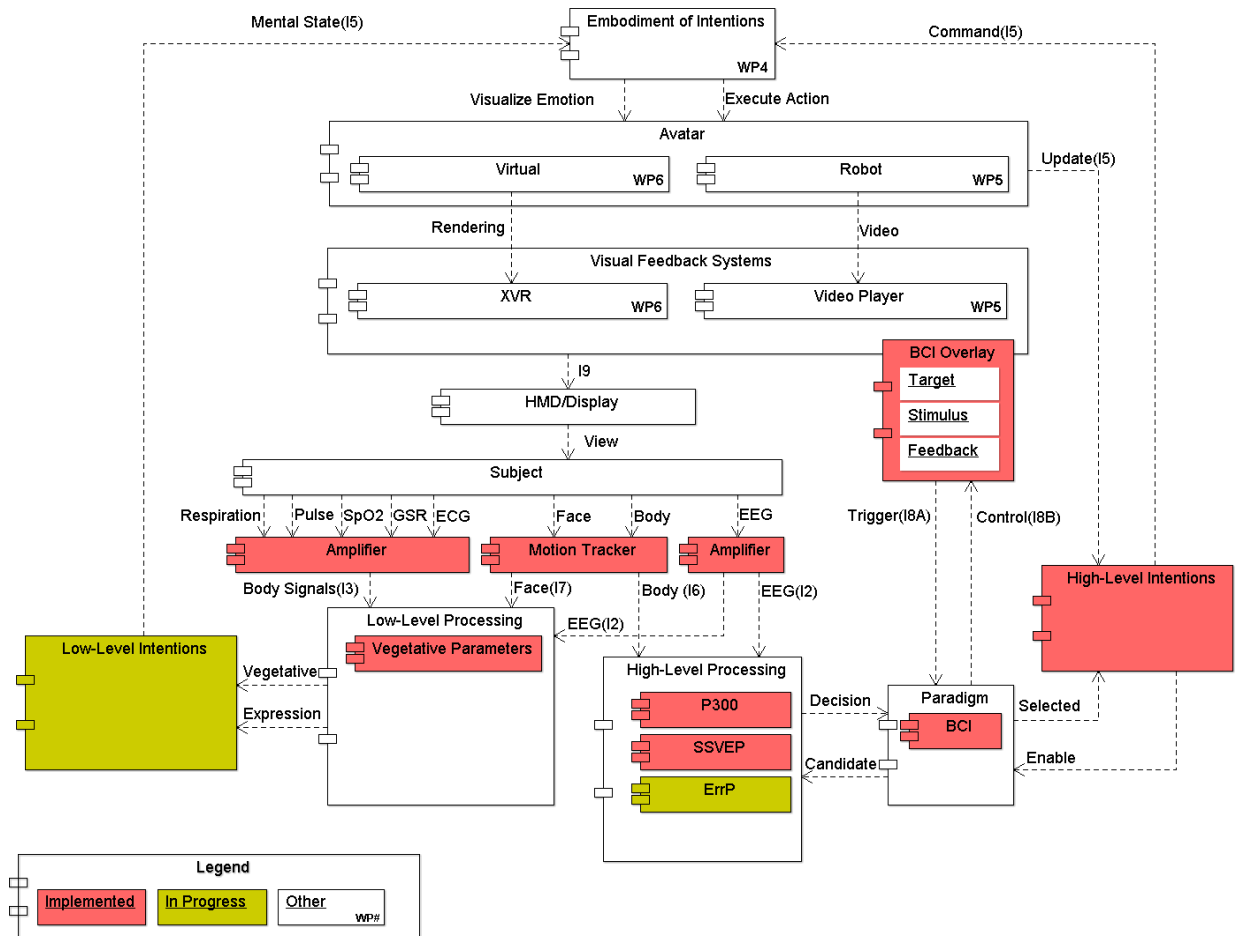
The first prototype of the BBCI uses the EEG signal for selecting discrete commands which are passed to the robotic and virtual avatar controller system. The remaining biosignals such as ECG, galvanic skin response, etc. and related physiological parameters like heart rate or respiration rate are recorded and mapped to different qualities of robot actions in WP4.

In the following section 2 the components of the first BBCI prototype and the interfaces between them are shown. The block diagram helps to clarify the description and to visualize all required interactions between the BBCI components.

2 BLOCK DIAGRAM

A block diagram of the main hardware devices and software components of the BBCI system is shown in Figure 1. The dashed lines represent the interfaces between them and the arrows indicate the direction along with the data and information are passed onwards to the next component. The arrow labels indicate the data to be exchanged between the different components. The interfaces **I2, I3, I5, I6, I7, I8** and **I9** interconnect the BBCI prototype system with the components of the VERE prototype developed within other workpackages. These interfaces have been defined and described in detail in deliverable D3.1.

Basically, two types of intentions are recognized by the BBCI system, i.e. high-level and low-level intentions. The high-level commands recognized via the active BCI paradigm (e.g P300 or SSVEP) are passed on to the next system blocks for the embodiment of the intentions on the robot (WP4,5) or the the virtual avatar (WP4,6). Herein, it is decided how these commands are interpreted and it is decided how they are executed on the virtual or robotic avatar in succeeding work packages. The low-level intentions are processed in parallel to the high-level intentions. While high-level intentions are mapped in WP4 into a sequence of robot actions, the low-level intentions determine the quality of how these single actions are implemented.



- I2** Active EEG electrodes and biosignal amplifier including g.USBamp driver and MATLAB/Simulink API
- I3** Biosignal sensors for ECG, respiration, galvanic skin response, SpO₂, pulse and biosignal amplifier including g.USBamp driver API
- I5A/B/C** XML interface between multimodal intention recognition system and avatar, either virtual or robotic
- I6** Body motion recording interface
- I7** Facial motion recording interface
- I8A** BCI control interface of the head mounted displays
- I8B** HMD trigger interface using digital IO or direct network connection to the BCI processing system
- I9** binocular image display interface of the head mounted displays

I1 is the interface to the fMRI system which is not included in the first prototype. I4 is the knowledge base which will be integrated into the Low-Level Intentions in the next prototype.

Figure 1: Block diagram of the first BCCI prototype including the connections and interfaces to components developed within the workpackages 2, 4, 5 and 6.

3 HIGH LEVEL INTENTION PROCESSING AND DETERMINATION

Different BCI paradigms will be used to record the high-level intentions of the user. The BBCI prototype implements the stimulus based P300 (section 3.1) and SSVEP (section 3.2) paradigms. Both paradigms are able to recognize a target stimulus e.g. a single character or icon, to which a user is attending out of many other non target stimuli. The interface translates mental response of the users to the target stimulus to predefined xml strings which closely correlate to the high-level intentions the user most likely has within a specific situation.

Currently Error-related Potentials (ErrPs) are being explored in parallel to recognize user's cognitive error states. For instance, the interaction ErrPs indicate user awareness of errors done by the interface or that he had selected the wrongly selected target symbols. We try to simulate this case by erroneous keyboard interactions, where users try to push a ball into a hole (both laying on the same horizontal line on the screen) using keyboard left and right arrows. User input is translated by the interface into the wrong direction with a probability of error, P . The current implementation of the ErrP detection paradigm is described in detail in section 3.3. It is planned to extend the recognition of ErrPs to BCI paradigms, like P300 and SSVEP, to obtain an instantaneous verification and validation of the identified intention. Ignoring user interactions, which are followed by ErrPs, leads to higher information transfer rates [3-5].

3.1 P300 Paradigm

Whenever an unlikely event which is awaited by the user occurs randomly between other events a so called P300 evoked potential is elicited. It manifests itself in a positive deflection in the amplitude of the EEG signal around 300 ms after a visual stimulus onset.

For a P300 spelling device commonly a 6x6 matrix of different characters and symbols is presented on a computer screen [2]. In single-character mode all characters are flashed in a random order but only one character after each other as shown in Figure 2a. In row-column mode a whole row or a whole column flashes at a time as shown in Figure 2b. The subject has to concentrate on a specific letter he or she wants to write. The flashing of exactly this character or the corresponding row or column is a relative unlikely event which induces a P300 component in the EEG signal reaching its maximum amplitude around 300 ms after the onset of the flash. For all other characters, rows or columns no such P300 component is elicited because they are not relevant to the subject currently.

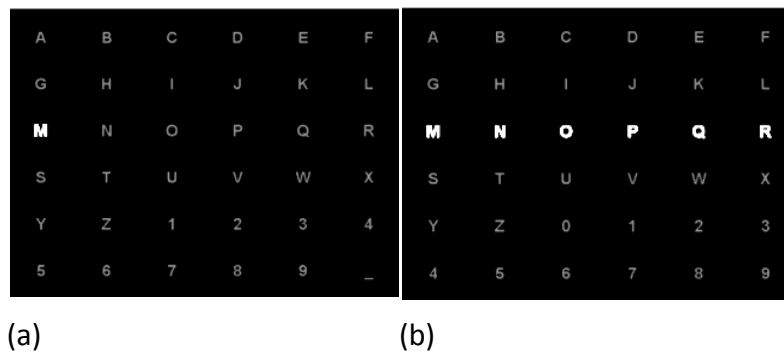


Figure 2: Screen layout of a 36 character speller. Either a single character is highlighted (a) at a certain time or a whole row or column (b).

To measure the P300 component acquisition of EEG signals from 8 electrode positions mostly over occipital and parietal regions is sufficient [1]. To train the BCI system an arbitrary word like LUCAS is announced to the system to be aware of which characters the subject is supposed to concentrate on (targets) and which not (non-targets). Each of these letters respectively each row and column flashes several times e.g. for 100 ms per flash. The subject focuses on each of these letters, one after the other and increments a mentally running count whenever the letter flashes the subject is currently concentrating on. EEG data of a specific time interval around each flash is then sent to a LDA classifier to learn to distinguish the typical EEG signal form of the target characters from the typical signal form of all other non-targets.

The EEG data were recorded with a biosignal amplification unit (g.tec medical engineering GmbH, Austria) at 256 Hz sample rate and transferred to the computer. A notch filter (50 Hz or 60 Hz) and a band pass filter were applied to the signals in order to eliminate possible artifacts before they were down-sampled to 64 Hz. Data from 100 ms before each flash onset to 700 ms afterwards were filtered and down-sampled again to get 12 feature values (i.e. samples) per channel and flash. These data chunks were sent to the LDA to determine if a target character flashed or not. A MATLAB/Simulink model controls the interface masks, processes the received data via a specific device driver and dispatches the targeted commands via the described UDP XML message passing interface. The subjects were sitting in front of a computer screen and were instructed to relax as much as possible.

3.2 SSVEP Paradigm

The steady state visually evoked potential (SSVEP) is elicited, if a subject is exposed to a visual stimulus which is repeated with a frequency of at least 6 Hz. For example, a flickering LED can be used as stimulating device. If the LED flickers with a frequency of 14 Hz, the response of a subject paying attention to the LED is increased to 14 Hz. A spectral analysis of the captured EEG data shows a clear peak at 14 Hz. If several LEDs flicker at different frequencies and the user pays selective attention to one of the LEDs, the captured SSVEP can be used as input method for a BCI.

3.3 Error-related Potentials

Interaction Error-related potentials (ErrPs) are special features that can be detected in the EEG, after a wrong action selection by the BCI system or the user. After the onset of the feedback indicating the selected action, these features can be distinguished by first, a

sharp negative peak after 250 ms followed by a positive peak after 320 ms and a second broader negative peak after 450 ms [4].

In a first experiment similar to the one described in [4], we try to explore interaction ErrPs in the case of erroneous keyboard interactions. Thereby the user tries to push a ball into a hole which is located on the same horizontal line as the ball using keyboard left and right arrow keys only. The user input is translated by the interface into movements of the ball, thereby it moves the ball into the wrong direction with a probability of error P as shown in Figure 3. The recognition of the ErrPs is challenging due to the low signal-to-noise ratio (SNR) inherent in single trials, as opposed to averaging number of trials in case of P300. The combined usage of the interaction ErrP paradigm with SSVEP and P300 is part of our future work.

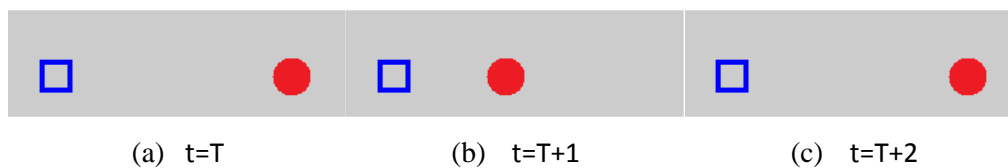


Figure 3: Experimental setup for interaction ErrPs. Using left and right arrow keys, the user should bring the ball (red circle) into the hole (blue rectangle). As an example, the initial positions of the ball and the hole, are shown in (a). The user hits the left arrow button to move the ball closer to the hole, and the result is shown in (b). Interaction ErrPs are evoked when the user hits the left arrow button and the ball goes to the right as shown in (c). Erroneous interactions reduce the information transfer rate ITR, e.g. $ITR=0$ for this example.

3.4 System Layout

All types of BCI systems are embedded within the rapid prototyping environment (RPE) described in deliverable D3.1. Figure 4a shows the basic structure of the P300 system. The EEG data is recorded through the biosignal amplifier from g.tec, bandpass filtered and down sampled to 64Hz. The signal processing block evaluates the P300 responses and computes the ID of the selected symbol. The paradigm block displays the control mask (Figure 4b) and drives the flashing of each single symbol in single character mode and each row and column in RC mode in random order. After each character or row and column has flashed the configured times, indicated by the stop signal of the Processing block the Paradigm block sends the ID of the selected control to the Interface Unit block. The later sends the command string configured along with the displayed symbol to the intention embodiment system of the VERE prototype (Deliverable D4.1) for interpretation and execution.

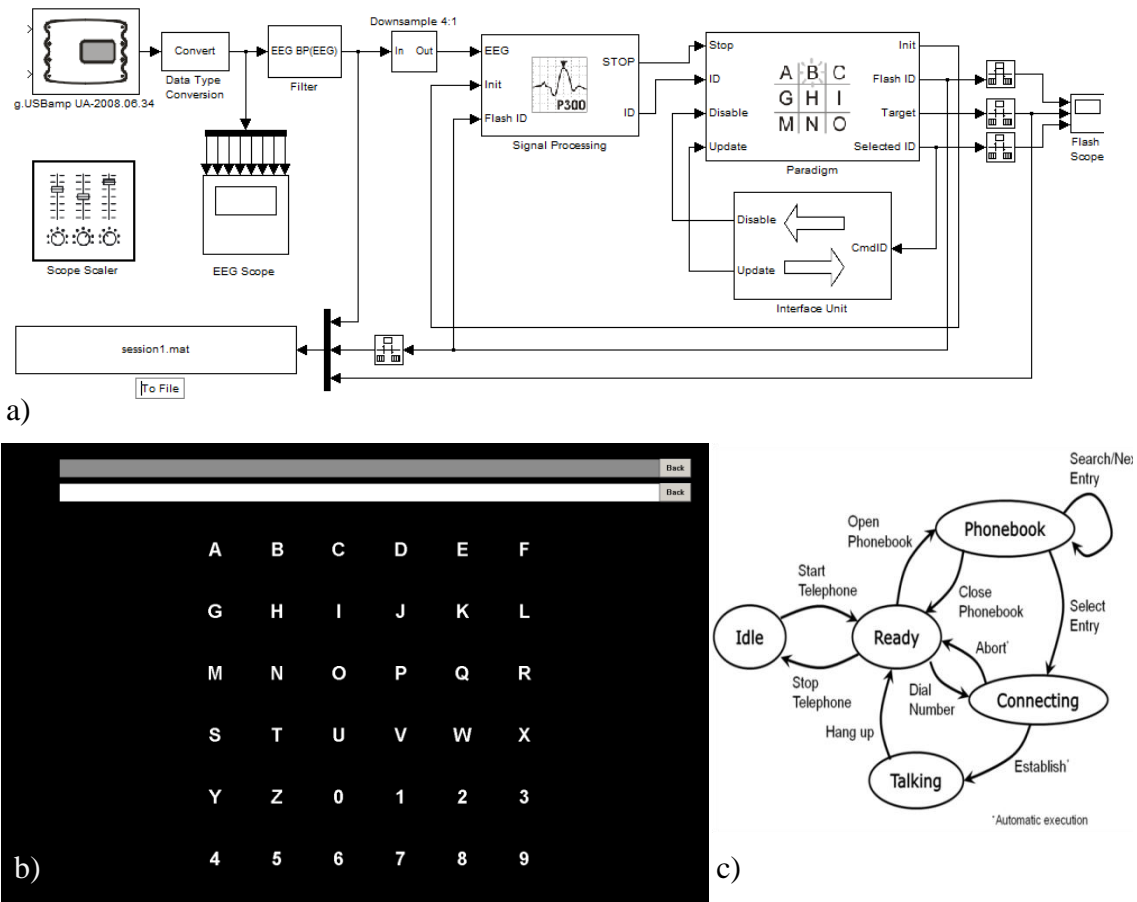


Figure 4: a) Brain Computer interface system implemented in Matlab/Simulink. It is based on the P300 paradigm. The Interface Unit block implements the interfaces I5B and I5C which interconnects the BCI unit of the high level intention recognition systems with the components developed within the other workpackages (WP4, WP5 and WP6) b) Spelling mask for writing texts or chatting. c) State diagram for defining the commands available when using for example a phone through the BCI.

The whole system can be adapted to the intended application through an XML formatted configuration file. This file contains the size of the control mask, the address of the components developed by the other workpackages (WP4, WP5 and WP6) which shall receive the command strings associated with each single symbol. The system even allows defining multiple levels of masks. It is advisable to generate for each target system a so called state diagram as shown in Figure 4c. It describes the states of the client system which shall be accessible though the BCI system and all possible transitions between these states and their direction. The arrows representing these transitions are labelled with the names of the commands which shall initiate the transition. If necessary these labels may include additional parameter values, in case one single command is able to trigger multiple related transitions. Details on how to configure the BCI system are available from the user manual distributed along with the system and from g.tec.

The structure of the SSVEP based system is shown in Figure 5. Four visual stimuli at frequencies of 7.5Hz, 8.5Hz, 10Hz and 12Hz are generated by the BCI Overlay module described in the following section 3.5. During the training mode a green frame indicates

to the user at which SSVEP stimulus he has to focus on. The ID number of each SSVEP element directly corresponds to the command which shall be executed by any of the attached components of the VERE prototype. As for the P300-based system the Paradigm block interrelates these IDs with the intended action which is transmitted via the Interface Unit block to the attached component of the VERE prototype.

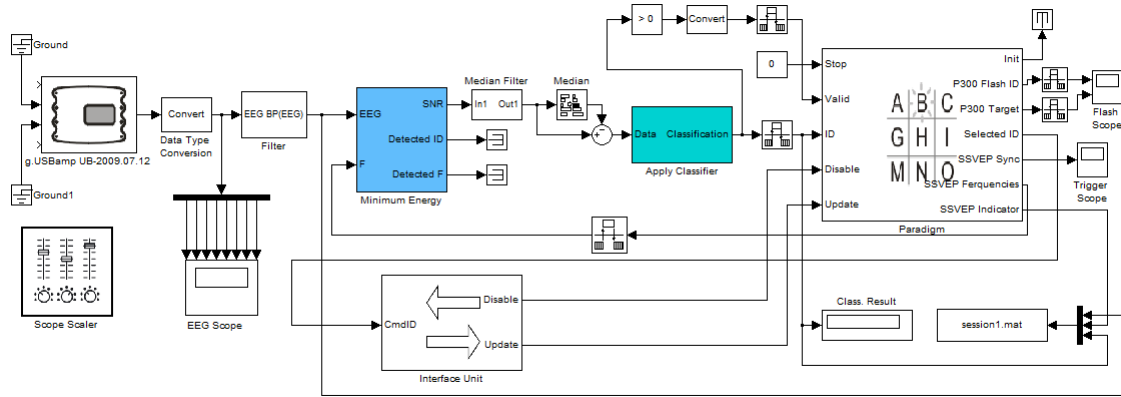


Figure 5: BCI based on the steady stated visual evoked potential paradigm.

3.5 Remote Stimulus Display

As users need to get the visual feedback of the environment from the perspective of the robot or their physical avatar, a stereo camera (two 2D cameras) is mounted on the robot and keeps transmitting the captured frames to users. With the help of Head-Mounted Displays, users are able to have the full 3D experience of the robot environment. The visual feedback system is developed within the workpackages WP2, WP5 and WP6.

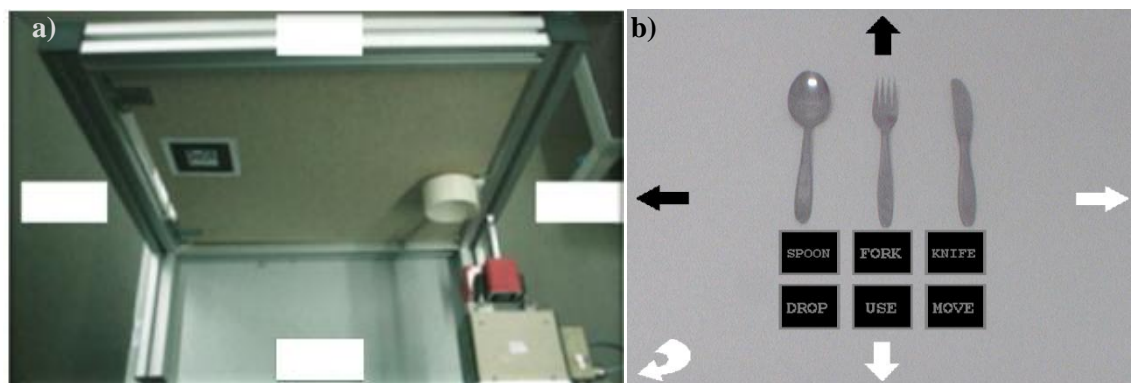


Figure 6: BCI controls displayed on top of a life video streams. a) User observes a robot opening a door and controls it via simple SSVEP controls. b) User is presented SSVEP controls for steering the camera and P300 controls for utilizing a knife, a fork and a spoon.

Through the interface **18** it is possible to merge the stimuli required by the BBCI system with the video stream from the cameras of the robot or the virtual scenery created by the modules developed in WP5 and WP6. The combination of video stream and BCI controls enables the user to observe the environment, the set of possible actions and the effects of their executed actions.

a) b)

Figure 6 shows examples of what users might see when wearing the HMD. In Figure 6a the SSVEP paradigm is overlaid on the video stream received from a robot while opening a door. The example in Figure 6b shows the combined display of SSVEP and P300 controls. In both examples the display for only one eye (left or right) is shown.

The BCI controls are generated by the BCIOverlay module DLL which the visual feedback system loads and initializes when needed during runtime. This DLL uses native OpenGL commands to draw the P300 and SSVEP stimuli and the different symbols and characters representing the different actions the user may execute through the attached avatar.

The module is controlled by and connected to the BCI paradigm block (Figure 4a and Figure 5a) through a bidirectional network socket connection using the UDP network protocol. Whenever a set of stimuli P300 or SSVEP are presented to the user the module indicates this by sending a trigger message indicating the highlighted controls to the BCI Paradigm block over the UDP socket. These trigger signals are then converted and distributed to the Simulink blocks for the P300 and SSVEP processing.

3.6 Electrodes and electrode cap

Figure 7a shows an image of the electrode cap (g.GAMMAcap) with active electrodes (Ag/AgCl ring electrodes g.LADYbird, see Figure 7b and Figure 7c for details) mounted. Each electrode is connected to the preamplifier autonomously, which means, that – if one electrode is faulty, it can be removed immediately. Furthermore, the position of each electrode and its electrical coupling to the scalp can be verified and corrected easily throughout the measurement.

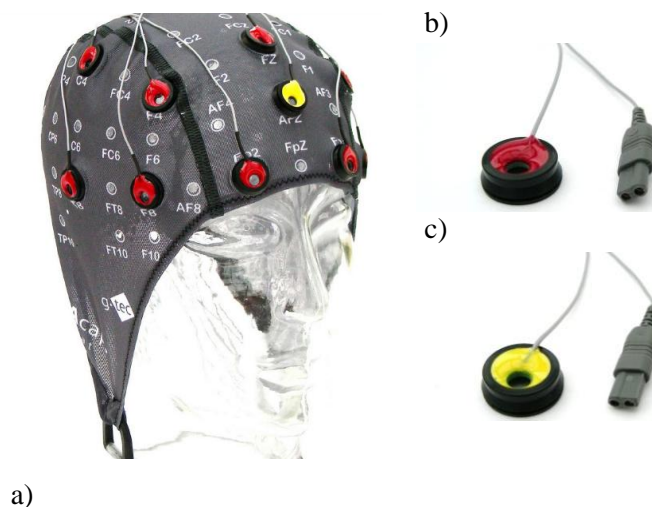


Figure 7: The g.GAMMAcap a) with mounted active electrodes b) and the ground electrode c).

The electrodes require a pre-amplifier (see Figure 8), which makes the electrodes less sensitive against environmental noise such as power line interference and cable movements. Compared to passive electrodes, active electrodes allow a higher skin impedance (exceeding 10 kOhm), which is crucial considering movements throughout measurement. The active electrodes have system connectors to supply the electronic components with power. The preamplifier shown in Figure 8 can directly be connected to the biosignal amplifier.



Figure 8: Preamplifier g.GAMMAbox for active electrodes

3.7 Biosignal amplifier: g.USBamp

For the VERE RPE multiple g.USBamp biosignal amplifiers are used (see Figure 9). They are required to amplify the received ECoG, EEG and physiology related signals, to decouple successive components via optical link from parts applied to the user, to digitize the signals and to transfer data to the processing unit via USB interfaces **I2** and **I3**.

The amplifier device has 16 input channels, which are connected over software controllable switches to the internal amplifier stages. Signals pass through an anti-aliasing filter stage before being digitized using sixteen 24 Bit ADCs. The device is equipped with digital to analog converters (DAC) enabling the generation of different signals like sinusoidal waves, which can be sent to the inputs of the amplifiers for system testing and calibration. All these components are part of the “applied part” of the device, as a subject or patient is in contact to these components via the electrodes.



Figure 9: 16 channel amplifier g.USBamp with USB connection

4 RECOGNITION OF LOW-LEVEL INTENTIONS

In order to investigate the recognition of the user's mental state by means of EEG and physiological data an emotional dataset containing signals of 13 subjects has been recorded. The setup of the different sensors is shown in Figure 10. Five emotions (happy, curious, angry, sad and quiet) were induced using pictures from the IAPS database [5]. We recorded a 64-channel EEG together with physiological signals (GSR, respiration, ECG, and SpO2) and facial markers. Currently, the data is being validated.

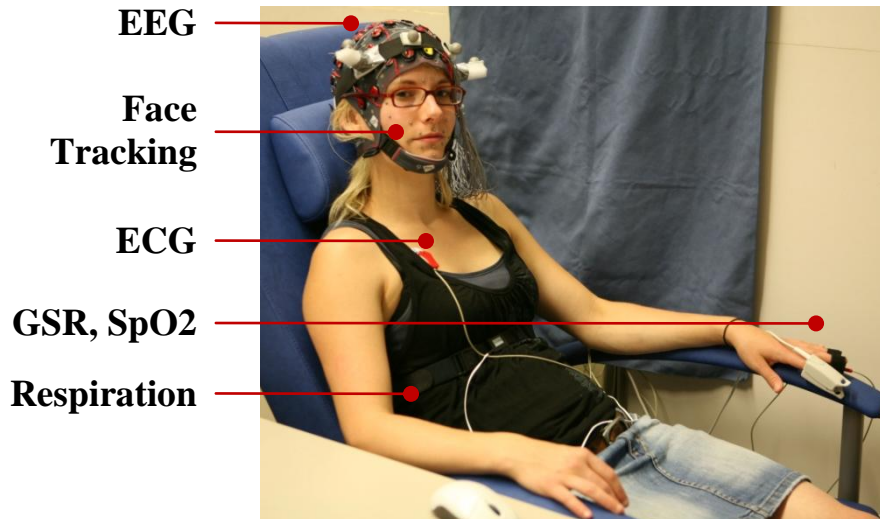


Figure 10: Recording of emotional database.

This dataset will be used to investigate machine learning algorithms to detect the mental state of a user given these signals. This knowledge can then be used to determine how an action (e.g. a high-level command from the BBCI) is executed on the virtual or robotic avatar.

This dataset will be used to investigate machine learning algorithms to detect the mental state of a user given these signals. This knowledge can then be used to determine the quality of an action (e.g. a high-level command from the BBCI) to be executed on the virtual or robotic avatar.

4.1 Physiological Monitoring

The first BBCI prototype will be able to extract physiological features like heart rate, the rate of changes in the skin resistance or the respiration rate. These parameters are provided by the PhysioModul software which is able to extract physiological parameters in real-time and transmits the results via UDP to other applications. The software works with g.tec biosignal amplifiers g.USBamp or g.MOBILab+ and g.tec sensors. The Physio Module is remotely controlled from client applications via UDP. For further details on the interface **I13** which is used by the Physiology Processing system to receive commands and to transmit the extracted feature values are described in the deliverable D3.1.

The following table states the signals to be recorded and the features to be extracted thereof. If requested in the configuration file they will be transmitted via UDP whenever

an updated value of the feature is available. If an update is available for several features at the same time one UDP message containing all changes will be transmitted.

- ECG:
 - Heart-rate (HR): mean heart rate in beats per minute computed for the past N seconds.
 - Heart-rate variability (HRV): Heart-rate variability over the past N seconds
 - Ratio of normalized HR and normalized HRV: Both HR and RMSSD will be normalized to their maximum signal range observed during the reference segment at the beginning of the session.
 - RMSSD: Root Mean Square of duration variations of adjacent RR intervals for the past N seconds
 - HR/RMSSD: Ratio between normalized HR and normalized RMSSD. Both HR und RMSSD will be normalized to their maximum signal range observed during the reference segment at the beginning of the session.
 - pNN50: Percentage of adjacent RR intervals differing by more than 50 ms within the past N seconds.
 - HR/pNN50: Ratio between normalized HR and normalized pNN50. Both values HR and pNN50 are normalized to their maximum signal range observed during the reference segment at the beginning of the session.
- GSR:
 - ERD: Normalized relative Means (in percent) for the past N seconds.
- TaskActive: Indicates if a task is currently active and running, or not.
- Respiration:
 - Respiration Rate
 - Duration of inspiration and expiration intervals
 - Depth of inspiration and expiration
 - Pauses during inspiration and expiration.
- EEG: The feature signals required for the recognition of low level intentions are still under investigation and thus not yet defined

5 BCI SYSTEM INSTALLATIONS

Currently the following partners have running BCI systems

IDC – 16 channel BCI system

EPFL – 48 channel BCI system

UCL – 16 channel BCI system

FSL – 16 channel BCI system

TUM – 32 channel BCI system

CNRS – 16 channel BCI system

g.tec – 16 channel BCI system

UB – 8 channel BCI system

IDIBAPS – 16 channel BCI system

PERCO – 16 channel BCI system

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