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UTRECHT NEUROPROSTHESIS: FROM BRAIN SIGNAL TO INDEPENDENT CONTROL

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ABSTRACT: Recently a locked-in ALS patient was equipped with the Utrecht NeuroProsthesis (UNP), a fully implantable electrocorticography (ECoG)-based BCI system. The UNP system translates the neuronal activity from this patient to a control signal that is used to make selections within a graphical user interface (GUI) and speller application. This paper describes the current architecture of the UNP system from brain signal to GUI and speller control.

INTRODUCTION

Due to severe paralysis, patients with Locked-In Syndrome (LIS) are no longer able to communicate with the outside world independently. Although their cognition is still intact, LIS patients do not have the ability to move or speak anymore. Using assistive technology, LIS patients may use eye movements to control (communication) devices. As an alternative, BCI solutions are occasionally used to employ brain activity for control. Our BCI system is the first fully implanted ECoG-based system, where electrode strips are placed - subdurally - directly on the cortical surface and connected to a transmitter device inside the chest. Because the electrodes are permanently implanted, caretaker assistance for using the system only involves placing an antenna over the implanted transmitter and connecting it to the computer. In addition, brain potentials are measured directly from the cortex so we can record brain activity with a high spatial and high temporal resolution. Over the past 1.5 years we have developed a signal processing pipeline and GUI to allow the patient to control the UNP independently. By means of this pipeline and GUI, the patient is now able to alert her caregiver, spell sentences and practice tasks to improve control [1]. The UNP-system employs brain driven ‘clicks’ as the primary input to the GUI. Input by means of brain clicks was chosen since this would provide the most robust control for the patient. The aim of this paper is to describe the features and architecture of the UNP system that the patient currently uses.

MATERIALS AND METHODS

The UNP system was implanted in a 58-year-old locked-in patient who suffers from late stage Amyotrophic Lateral Sclerosis (ALS). A subdural four-electrode strip (Resume®, Medtronic, 4mm electrode diameter, 1cm inter-electrode distance) was placed over the hand region of the left motor cortex, which activates on attempted hand movements [2]. The electrode strip is connected to a left infraclavicular, subcutaneously placed amplifier and transmitter device (Activa® PC+S, Medtronic). The Activa® device can process and amplify signals from each bipolar electrode pair on a single strip. We selected the electrode pair showing the strongest responses in high frequency band power (HFB, 65-95 Hz) during attempted hand movement. For the UNP, we configured the Activa® S to transmit power in two frequency bands: Beta power (center frequency 20Hz) and Gamma power (center frequency 80Hz) from the selected electrode pair at a rate of 5Hz. During use of the system, an antenna is placed on the chest over the device to receive the amplified and converted signal. The received signal is forwarded to a signal decoding computer (Microsoft Surface Pro 4 Tablet), which runs both a signal processing pipeline and GUI implemented on the BCI2000 platform [3]. The tablet running the pipeline and GUI is placed in front of the patient. She currently uses attempted hand movements to control the UNP-system.

RESULTS

The signal processing pipeline consists of six consecutive filters: Time smoothing, Z-transformation, Linear classification, Escape sequence, Threshold classification and Click translation (see Fig. 1). Each filter takes one or more input channels, manipulates or interprets the channels and sends output to the next filter or to the application. At the beginning of the pipeline, each of the two frequency bands is received on a separate channel, the Beta power on one channel and the Gamma power on another.

Time Smoothing: The incoming power signal from each channel is smoothed over time by taking the average over the current and previous 5 samples (a smoothing window of 1.2 seconds). Time smoothing is applied to deal with the noisy and spiky characteristics of ECoG measured brain signals.

Z-Transformation: The smoothed signal from each channel is taken from the previous step and normalized by subtracting the mean and division by the standard

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deviation of that channel. This normalization step stabilizes slow amplitude trends in the signal (i.e. different days or parts of the day). Initially, the mean and standard deviation were based on a 30 second pre-run calibration. However, since the amplitude and deviation of the signal proved to be stable over a longer period of time, a fixed mean and standard deviation are currently used.

Linear Classification: The normalized (z-scored) Beta and Gamma signals from the previous step are combined into a single control signal by subtracting the low frequency (Beta) channel from the high frequency (Gamma) channel.

Escape Sequence: The incoming signal proceeds through this filter without modification. This filter specifically detects long periods of sustained activity produced by the user, and, if detected, it outputs an 'escape' trigger directly to the GUI. The duration is currently set to 5.6 seconds of sustained activity.

Threshold Classification: The control signal from the linear classification is converted to a binary signal based on a threshold value. For every incoming sample the filter will output a '1' if the control signal is above the threshold, or a '0' if below the threshold.

Click Translation: The incoming binary signal is converted to clicks. This filter buffers the incoming samples and sends out a single click if a pre-defined number of consecutive '1'-samples is received from the previous filter (currently set to 5 samples). After sending out a click, the filter sets a refractory period of 3.6 seconds where no clicks can be made.

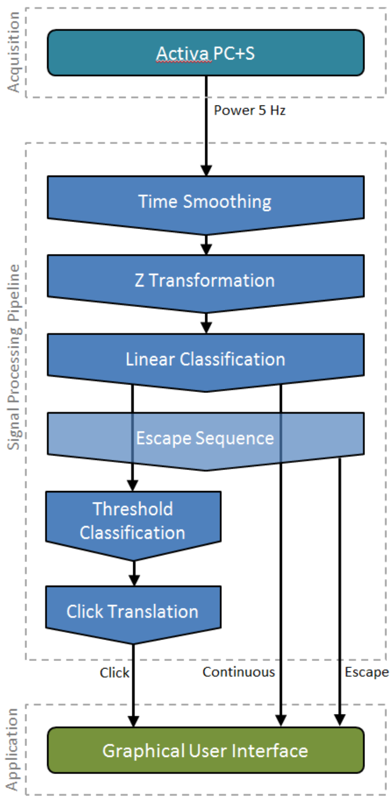

Figure 1: Overview of the processing pipeline. When click-control is required to control the GUI, the signal will pass through all six filters. If continuous-control is required then only the first four are enabled, skipping the Threshold Classification and Click translation steps.

The GUI connects at the end of the pipeline. By making (brain) clicks, the patient can navigate through the GUI menus (see Fig. 2).

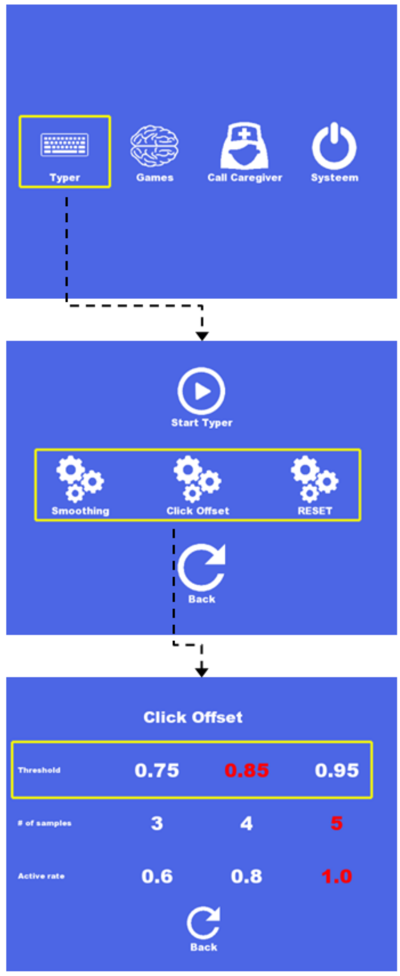

Figure 2: The GUI, showing the start menu, the speller menu and the speller click settings menu. Each menu in the GUI consists of icons organized in rows and columns. A selection rectangle will loop from top to bottom over each row. The patient can select a row by making a (brain-)click. When a row is selected a selection rectangle will loop from left to right within the row, allowing the patient to click an icon in the row. If no icon is clicked, the selection will revert back to row selection. If an icon is clicked, the selection rectangle will stay there for 3 seconds, requiring the patient to make another click within that time to confirm that option.

Over the past 1.5 years, several features were introduced into the pipeline and GUI to help the patient use the UNP.

Practice Games: A number of research tasks/games have been developed and are performed regularly in

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order to improve control over the (spelling) system. These tasks allowed us to find the optimal parameters for control and allow her to gain control over her brain activity. Normally these tasks are started by the researcher during home visits. However, since these tasks provided a good mean of practice for signal control, we included them in the GUI, allowing her to practice independently.

Spelling: The patient is able to start spelling software by choosing the 'Typer' icon in the GUI. When the patient chooses to start spelling in the menu, Tobii Dynavox Communicator 5 is started and takes focus on the tablet. The Tobii software is set to work in a similar way as the GUI, but instead shows a letter matrix for spelling and only single clicks have to be made. Clicks coming from the pipeline are relayed by the GUI to clicks in the Tobii application, allowing her to spell and pronunciate letter, words and sentences.

Optimizing pipeline parameters: As soon as the tablet is switched on, the pipeline is booted automatically with standard parameter values (e.g. a smoothing window of five samples). The standard parameter values were calculated from research task data. However, in certain circumstances, the user may wish to change these settings, for example to make clicking easier. In order to facilitate such changes, the UNP allows the patient to set some of the parameters values herself through the GUI (see Fig 2). For the speller (Tobii) and practice tasks she is able to set the smoothing window and various click parameters.

Escape: The escape sequence accommodates the need for the patient to stop what she is doing in the GUI and/or call for care. As soon as the escape sequence is made (keeping the control signal high for 5.6 seconds), the GUI shows a popup menu asking her if she wants to call the caregiver using audio, stop what she is doing or continue what she was doing. This feature allows her to always signal her caregiver, and from any place within the GUI and speller.

Continuous control: The UNP system has two control modes, a click control mode and a continuous control mode. The mode for click control involves all six filters. The patient uses this mode to navigate the menus, practice click-based tasks and use the spelling software. The mode for continuous control only uses the first four filters and is currently used in only one of the practice games. In this mode the amplitude of the signal controls the vertical position of a ball on the screen. The GUI can automatically switch modes in the pipeline depending on the tasks or program she is using.

DISCUSSION AND CONCLUSION

The UNP-system allows the patient to communicate using speller software and brain-clicks. In addition to spelling, the pipeline and GUI allow the patient to alert the caregiver, practice tasks to improve control signal regulation and fine-tune parameter settings independently. The patient has reported good user satisfaction with the implantable BCI system [1], and uses it on a regular basis without help from the research team. Although the system provides in a number of needs, improvements can be made. For example, the spelling speed could be improved by allowing her to experiment with the click refractory period and the number of consecutive above-threshold samples required for a click. In the coming period, we will work on further fine-tuning the system. The input of the participant is invaluable in this process, since only a system that fully meets the wishes and needs of the end-users will be interesting for further development and commercialization and eventually become available for the people who need it.

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