

An Open-Source System for Biosignal- and Camera-Mouse Applications submission for the Young Researchers Consortium of the ICCHP 2006, Linz

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Introduction

In this paper, an open-source based approach to a universal Human-Computer-Interface will be presented. The system consists of a biosignal-aquisition hardware (EEG-amplifier), a data-analysis software with feedback functions (BrainBay), a PC (laptop or desktop) and a standard webcam. Using these components, a wide range of biosignals like EMG, EKG, EOG or EEG can be analysed and sensors for temperature, breathing or body movements can be processed. These signals can be used not only for monitoring, rehabilitation and feedback purposes but also to gain control over simple user-interface functions. Using image-processing functions and the webcam, severe disabled persons can be provided with a Camera-Mouse interface, which allows using the computer mouse by head-movements and performing left- and right-clicks by chin-movements.

Recent Developments in the Area of biosignal-based Interaction Systems

There have been several efforts to create Human Computer Interfaces by using body parameters as muscle tension (EMG) or eye movements (EOG) measured by skin electrodes. EMG signals can give a reliable control signal for a binary switch, thus opening a gate to different kinds of scanning-software that enable writing, control of system functions or home appliances.

A successful system working with EOG signals for a computer mouse substitution is *Eagle Eyes*, developed at Boston College by DiMattia and Gips [15]. Mouse-clicks can be performed via a selectable dwell time. *Eagle Eyes* provides several software applications for education and entertainment, and thus gives support to young people with severe disabilities. A common problem to all biosignal-based interfaces is that the application of electrodes is difficult to establish and inconvenient to use. An EOG based system shown by Wiebe [16], tries to ease the mounting problems of electrodes by incorporating them into eye-glasses. Additionally, an accelerometer was mounted on the glasses, so that the system can combine EOG- and acceleration signals to calculate head movements and gaze direction. Present problems with this approach are the need of extra-hardware and the still uncomfortable glasses.

A lot of academic research has been done to utilize EEG signals for direct Brain-Computer Interaction (BCI, Brain Computer Interface). Successful experiments were shown by Niels Birbaumer in the late 1990ties, who developed a writing-interface for a locked-in ALS patient using the CNV of the EEG (Contingent Negative Variation, a slow brain potential) [8]. These first steps could constantly be improved, and the works by Jonathan Wolpaw, [7] or Gert Pfurtscheller, [9] and their teams show two-dimensional cursor control by movement imagination using only a few EEG-electrodes. With the *BCI2000* framework [13], Gerwin Schalk introduced a modular and widely configurable software system for various BCI-tasks like P300 spellers, ERD-based cursor-control (event related desynchronisation of the mu-Rhythm caused by movement imagination) or VEP-systems (visually evoked potentials).

These applications can support completely locked-in patients, who are not able to voluntarily control any muscles. Because of the high Signal-to-Noise ratio (SNR) of EEG-based HCI-systems, data processing is an uneasy task and the achievable bit-rates are very low. Nonetheless, the performance could be improved constantly, enabling non-intrusive EEG-based 2-dimensional cursor control for well trained subjects.

Recent Developments in the Area of Camera-Interfaces

As the processing power of today's computer equipment increased significantly, camera-based Human Computer Interfaces did also improve in a remarkable way. With an up-to-date desktop system, it is possible to perform all image-processing that is necessary to do correct face- and eye-detection with a speed of 30 frames per second (which can be delivered by a standard webcam). This is a very promising development for disabled users who wait for a convenient tool to interact with their computers without contact. In the recent years, gaze-estimation systems have been built which are able to determine the users's gaze direction well enough to be used as a pointing device. An example is shown in the work of Leimberg and Vester-Christiansen [4], how built a gaze estimation system with respect to head movement based on Active Appearance Models and Deformable Template Matching. To that day, such systems use special hardware like DV-cameras and frame-grabber-cards for the PC-system to gain a high resolution and image quality. There has been other interesting work by Margrit Betke [1,2,3] how showed several different approaches for a camera-based user interaction using standard webcams. The Camera-Mouse System [3] can track selectable body features like the thumb, the nose-tip, the lip or an eye and uses this information for mouse control. Left-, right- and double-clicks can be performed using dwell-timing. In the Camera-Mouse, template matching is used to detect the position of the selected feature in the next image frame. Real time performance can be achieved with about 30 frames per second. A possible two-computer-setup maintains the full processing-power of the user's system. In the *Eye-Keys* – System [2], Betke and her team tried to use a standard webcam for gaze-estimation, and succeeded in providing a robust left/right distinction that can be used for switch-controlled spelling software or interaction-tools.

A mouse-interface, allowing free 2-dimensional movement and control of the clicking functions with standard computer components and a webcam has been presented by Gorodnichy [12]. His *Nouse*-System uses the convex-shape nose feature to track the nose position. A calibration procedure (nose-selection) is needed to initialize the system. Double blinking of the eyes can be detected and is used to switch the mouse-support on or off. Gorodnichy states that more extensible use of blinking like click-control is possible, but these functionalities are not part of the current software release.

The Cogain project emphasizes developments in the area of vision-based Human – Computer-Interfaces and gives an overview of existing products. To this date, some alternatives for a camera-based computer mouse do exist on the market, but the high prices or limited usability of these systems remain a problem for many disabled persons. A fully supported vision based Mouse-Interface providing X/Y control and clicking functions at a reasonable price is neither available at the present software market nor at the public domain scene. Considering all these circumstances, the development of an OpenSource-based universal Human-Computer Interface that can manage biosignal- and camera- inputs seems both justified and doable.

Commercially available Biosignal Hardware

In recent years, a new generation of Biosignal- and EEG-amplifiers has emerged, trying to reach not only the professional and medical market, but also home-users. This leads to cheap prices and a great availability of the products. Examples are the *Brainmaster*, *Waverider*, or *Roshi* – products. These amplifiers of course cannot compete with a modern biosignal system like the *g.USBamp* (Guger Technologies) or the *Neurotrace* hardware, which are devices with medical admission and have prices about 10-50 times higher. Fortunately, current low-cost hardware is sufficient to provide appropriate measurement for many biofeedback- or HCI-applications. A remaining problem is the lack of cheap and universal software solutions, which allow dynamic configurations for the various purposes and feature intuitive user-interface functions. A positive example is the *Bio-Explorer* application by Cyberevolution, which features a rich set of transformation functions and output capabilities for biofeedback. Unfortunately, no HCI-support is provided here, and the cost for the product is relatively high (about 500 US\$).

Hardware – Methods : The OpenEEG-project

The *OpenEEG* project started in 2001 with the aim of providing a low-cost and high-quality EEG amplifier to the public and to motivate developments on the software side. Naturally, an EEG-Amplifier can be used for processing as well other biosignals like EOG, EKG or EMG or sensor outputs like acceleration or skin conductance, when the right gain settings are provided.

Until 2006, three hardware concepts could be realized by the group and various applications were implemented, leading from wavelet-based viewers to experimental BCI-applications. In the following, two of the hardware-solutions are briefly described:

1.) The ModularEEG

The *ModularEEG* was created by Jörg Hansmann [5] in 2001. It is a 2 – 6 channel EEG amplifier with one digital and one to three analog boards. Each analog board provides two EEG-channels. The amplification is done in three stages (x12, x40, x16). Between the first and the second stage, a high-pass filter removes DC-voltage offsets. The amplification of the second stage can be adjusted from 10 to 100 using a trimmer. In the last stage a 3rd order low-pass filter at 59 Hz is implemented. To achieve a high common mode rejection, a right-leg driver (DRL) is used (see Fig 1).

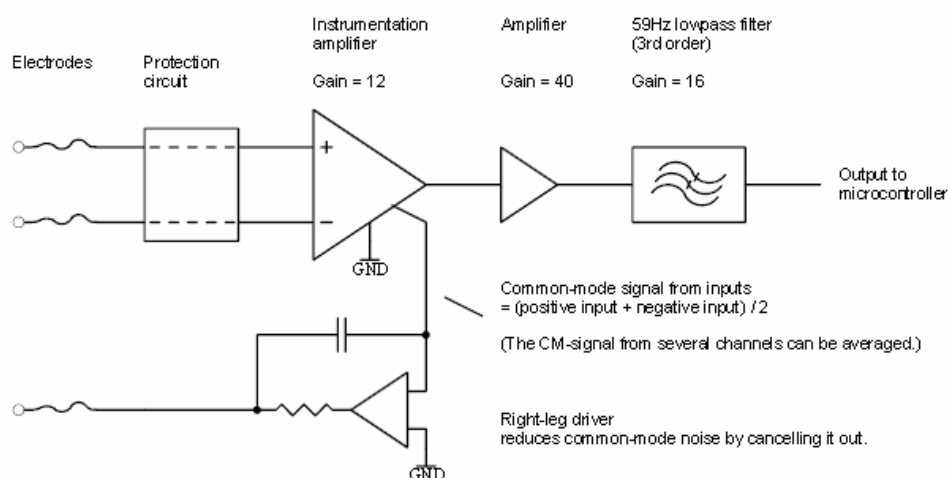


Fig1: simplified block diagram of the ModularEEG amplifier stages

The A/D-conversion is done by the internal converters of the Atmel AVR ATmega8 microcontroller. The firmware can be transferred to the chips EEPROM using a standard STK200 interface to the PC's parallel port or a STK500 serial interface. During system operation, the digitized channel-values are transmitted to the host-PC or PDA via RS232 using one of three possible transmission-protocols. The circuit is ESD protected and features a user-protection via a DC-DC converter and optocouplers as show in Fig 2:

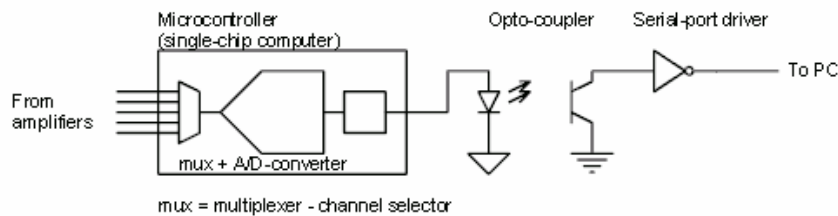


Fig2: simplified block diagram of the RS232 interfacing to the host computer

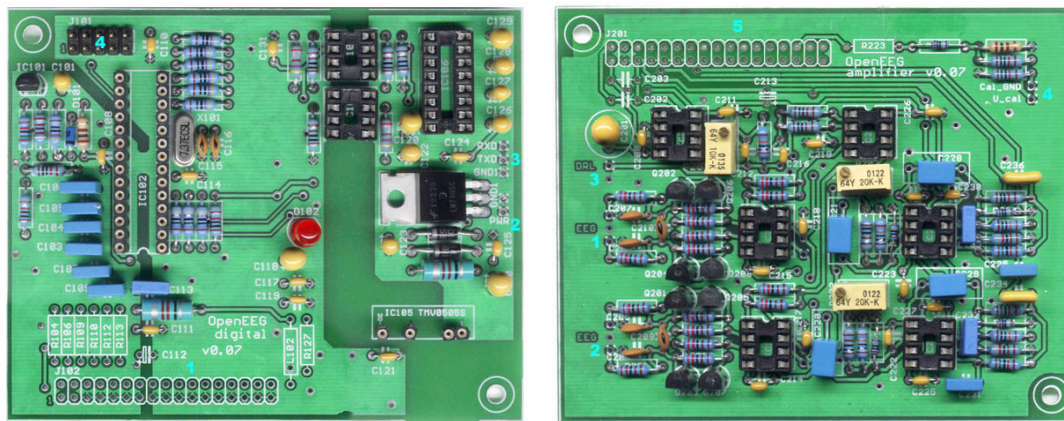


Fig 3,4: digital (left) and analog (right) PCB's of the *ModularEEG* amplifier, size: 10 x 8cm

Number of channels	2 - 6 (only 2 tested)
Resolution	four 10 bits, two 8 bits
Input Voltage Resolution	0.5 μ V
Input Voltage Full Scale	+/-256 μ V
Wideband noise	\sim 1 μ Vp-p
Supply Current (5V or 9 - 12V supply)	70 mA (2 channels)
Isolation voltage (<i>note 2, 3</i>)	2500V (1 minute)
Continuous isolation voltage (<i>note 2, 3</i>)	480V

Table 1: *ModularEEG* technical specifications

The *ModularEEG* is not certified as a medical device, because its isolation voltage is below 15kV. The device has to be used at the user's own risk. Electrode Cables and Device should be shielded to prevent mains hum.

2.) The MonolithEEG

The *MonolithEEG* is a small and lightweight 2-channel EEG amplifier created by Reiner Münch [6] in 2005. The design is based upon the *ModularEEG* and the amplification characteristics are similar to the above table. Using a smaller SMD-manufacturing process and sharper input filters, the need of isolated electrode cabled could be overcome with this design. The *MonolithEEG* allows sampling in 10bit quality up to a rate of 1kHz. The device is USB-powered and does not need an external voltage supply. A Bluetooth-Adapter is in development. When being used with a battery-powered laptop computer or with Bluetooth – radio link to a desktop system, there are not potential dangers of an electric shock to the user (this is also true for the *ModularEEG* system).



Fig 5: the *MonolithEEG*

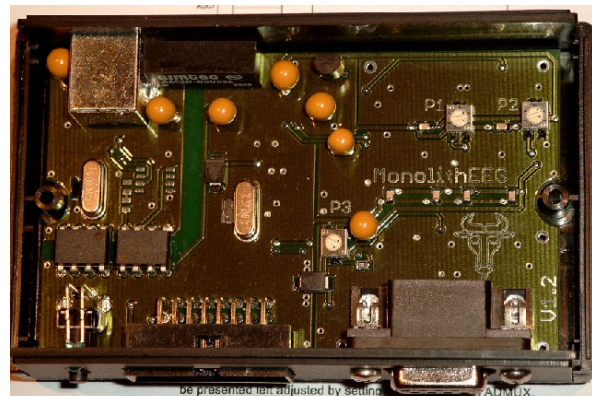
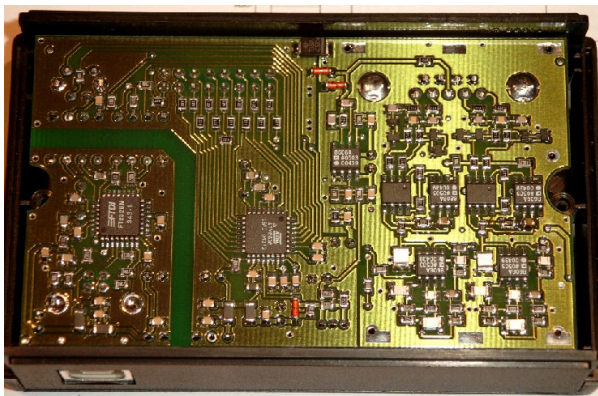


Fig 6,7: the *MonolithEEG* PCB, bottom view (left) and top view (right), size: 9 x 5,5cm

Number of channels	2
Resolution	10 bits (9 bits effective)
Input Voltage Resolution	0.5 μ V
Input Voltage Full Scale	\pm 250 μ V
Wideband noise	\sim 1 μ Vp-p
Maximale Offsetspannung bei 100nA	\pm 140mV
CMRR (VGND)	8uVpp/-72dB
CMRR (DRL)	<1uVpp/-93db
Supply Current (5V)	75 mA
Isolation voltage (note 2, 3)	2500V (1 minute)
Continuous isolation voltage (note 2, 3)	480V

Table 2: *MonolithEEG* technical specifications

Software - Methods : *BrainBay*

BrainBay is a Windows-based software application written in C++, which provides a flexible and easy-to-use user interface for biosignal processing comparable to the *Matlab/Simulink* graphical design window. This allows an intuitive creation of specific designs, dynamic linking of the processing elements and easy adjustment of the system properties. An important design-issue was the openness of the system to future extensions like new output functions for device control or interfaces to other assistive technologies. This extensibility is based upon an object-oriented software framework that provides classes for signal processing elements.

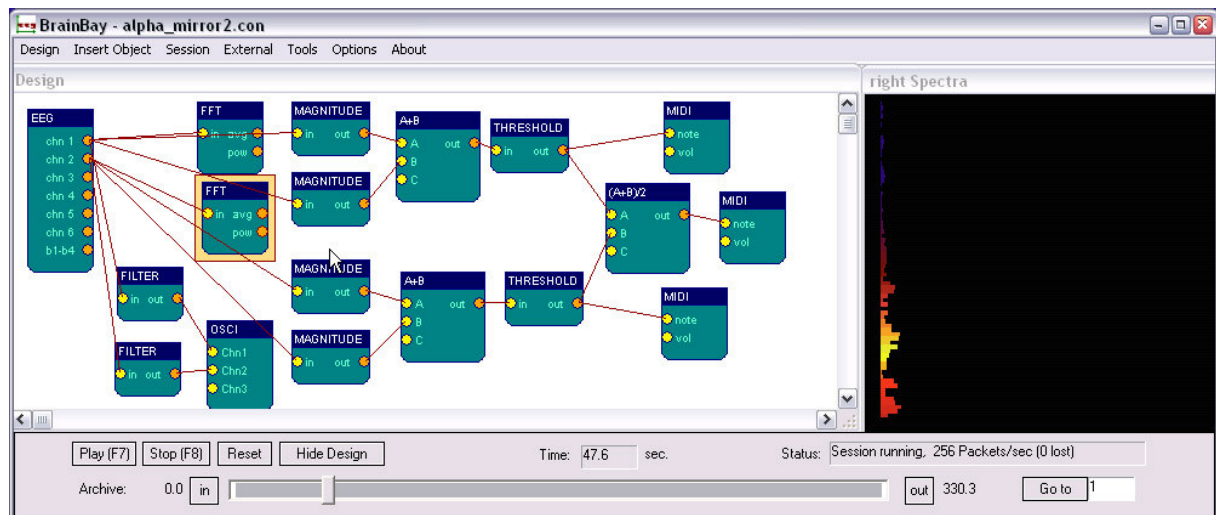


Fig 8: *BrainBay* Configuration Design Window

There are three types of signal processing elements:

1. Signal Sources:

The signal sources have one or more output ports. A signal source could be a sine-generator, a file reader, an EEG-amplifier or a webcam.

2. Mathematical Operations:

Mathematical operations have at least one input and one output port. These elements allow processing and transformation of the data. Important examples are: digital filters, correlation / coherence, average, threshold-level, expression-evaluator, logical operators, integrator, sample-and-hold, or the FFT-transformation.

3. Signal targets:

These elements have one or more input ports. Currently available signal targets include Midi- and Wave-elements for sound-output, graphical outputs like oscilloscope or movie-player and HCI-functions like the mouse-control-element.

Every element has a dialog window for properties which is displayed when clicking the element. The elements parameters can be adjusted using this window. This is also possible during system operation, the effects of parameter changes can be seen in real-time.

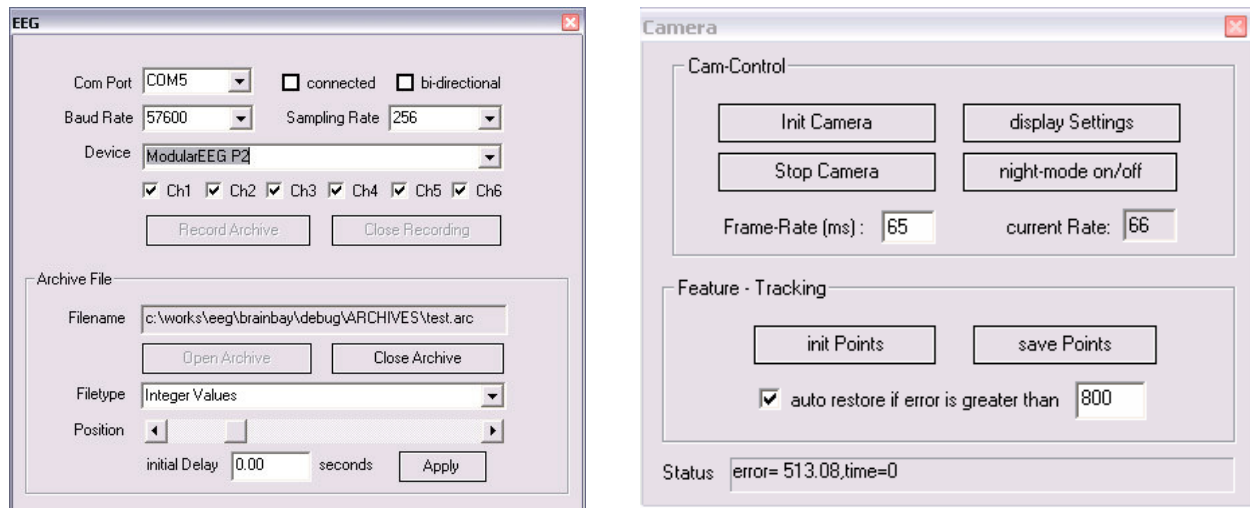


Fig 9,10. The properties of the EEG signal source (left) and the Camera signal-source (right)

Critical design issues for a HCI-application are accuracy and good run-time-performance. *BrainBay* is written in *VisualC++*, using the native Windows API. System-critical tasks like the hardware-interfacing with a COM-Port or the communication with the webcam are implemented in separate threads. System timing is maintained by interrupt-driven routines querying the High Performance Counter, which is the most accurate timing instance in a windows system. Depending on the kind of design and the number of processing elements, sampling rates up to 1kHz can be processed by a *BrainBay* application running in background and consuming about 10% of the CPU-power of a 1,6Ghz Pentium IV Laptop. This performance is sufficient for a real-time feedback of the body parameters. Thus, *BrainBay* can act as biofeedback software with multimedia capabilities. It can be used for the treatment of indicated diseases like ADHD, post-traumatic stress syndrome, tension headache, cardiac arrhythmia and as well as aid for rehabilitation training of deficit muscular functions or posture faults. When the webcam-element and the Mouse-control element are utilized with appropriate signal transformations, a functional camera-mouse system with support for left and right-clicking can be configured.

BrainBay is released under the GNU license for open source software, and a programmer's guide to the creation of elements shall be added to the software documentation to encourage system-extensions.

***BrainBay's* Cam interface**

The camera-element makes use of *Intel's OpenCV* - library for Computer Vision [17], which allows an easy implementation of images processing and face-detection functions. The camera element provides four output ports that deliver biometric data of a user's face detected in the camera's field of view: the X/Y – coordinates of the the nose and the X/Y coordinates of the chin. This functionality is provided by two tasks:

1. Initialization-Phase: A Haar-Classifer Cascade [17] that was trained with frontal faces is used for face-detection. When a face could be detected, the positions of the nose and of the chin are estimated. Other features like the lip, eye or eyebrow could be used by adjusting the relative coordinates of the feature points. The standard configuration uses the nose, because this location can be detected well and gives the user a good feeling for cursor control as pointed out by others [3,12]. The chin is a good location for measuring voluntary movements that can be used for click controls.

The initialisation phase is finished when the coordinates for nose and chin remain in selectable thresholds

2. Motion-Detection of the ROIs: The initial locations for nose and chin are used as input-points for a Lukas-Kanade Optical Flow algorithm [17]. This algorithm is a fast method for calculating the movement of points in two consecutive image frames. The new positions for nose and chin are checked for threshold-levels, and a re-initialisation of the face position is done if the levels are exceeded. The current positions of nose and chin are presented to the Camera-Object's output ports and can be processed in the signal path as any other signal.

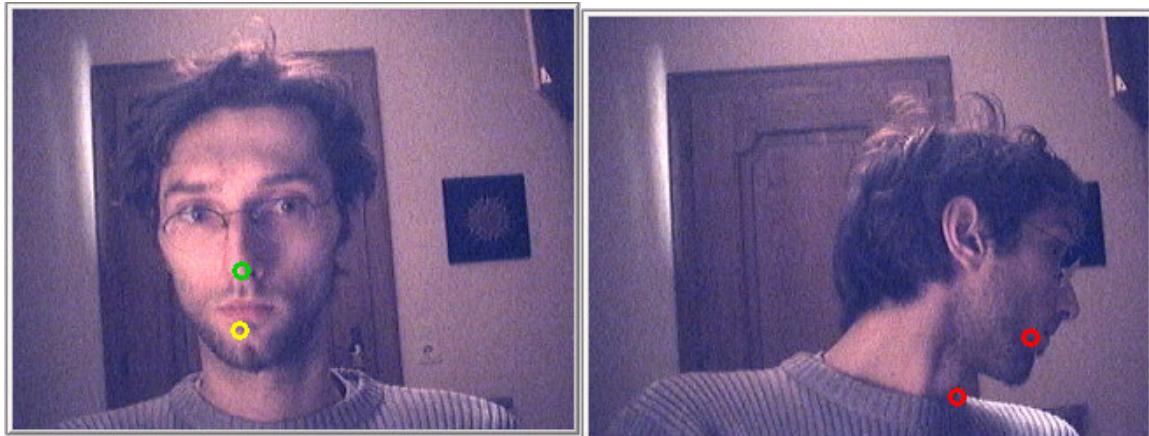
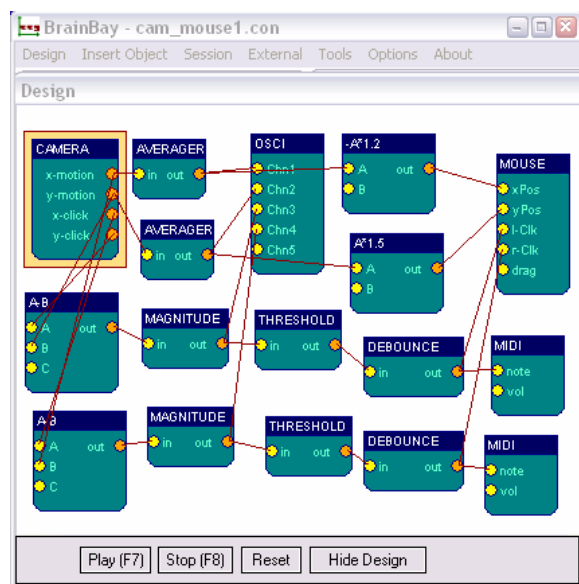


Fig. 11,12: tracking of nose and chin positions (left), re-initialisation (right)



A simple strategy for the clicking-interface is to use high-pass-filters on the normalized chin-position: The chin-position is subtracted from nose-position to get the relative chin-movement. Then a high-pass filter is used on the vertical and horizontal components to detect a rapid movement. The magnitude of these signals can be used as control parameters for the left- and right- clicking operations.

Fig 13: A complete design setting for a Camera-Mouse Interface, providing X/Y cursor movement, and left-/ right-click operations with acoustic feedback

Although these image processing strategies are not novel, and other, more sophisticated approaches have been shown in recent work [1,2,4] the applied techniques give good results for an applicable mouse replacement for users that can voluntary move their head and chin as shown in the section "Evaluation of the Camera-Mouse setting".

Evaluation of the Muscle Rehabilitation Setting

As in all other test-sessions, a 1,6 Ghz Pentium IV (M) Laptop Computer with 256Mb Ram running Windows XP prof. was used as a hardware platform. The graphics-board supports OpenGL. Although the principal function of the system has been shown on more powerful desktop computers, the decision was made to evaluate the system with a computer that is 3 years old, because many of the people how could be interested in a low-cost system for biofeedback and communication purposes will not be able to spend 2000 Euros for a new hardware platform.

To evaluate the practical use of the system for muscle training and rehabilitation purposes, two training sessions were accomplished with a 70 years old female patient suffering multiple sclerosis. Due to a diabetic syndrome, an amputation of the right lower leg had to be performed about two years ago. Daily exercises are very important to maintain and improve the patient's physical and psychical condition. It was the first time for her to try a biofeedback system, and she was quite surprised when she realized the ability of producing sounds and/or visual changes of the displayed meter windows.

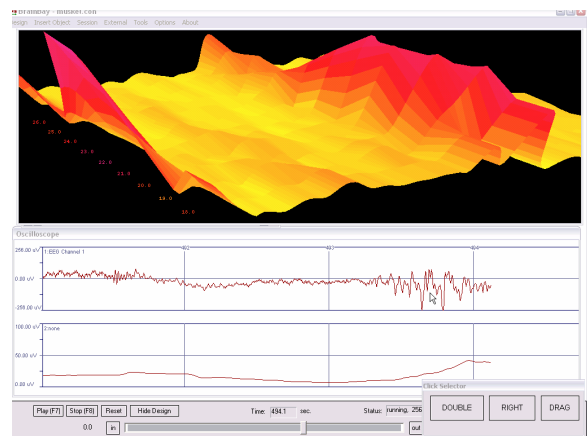
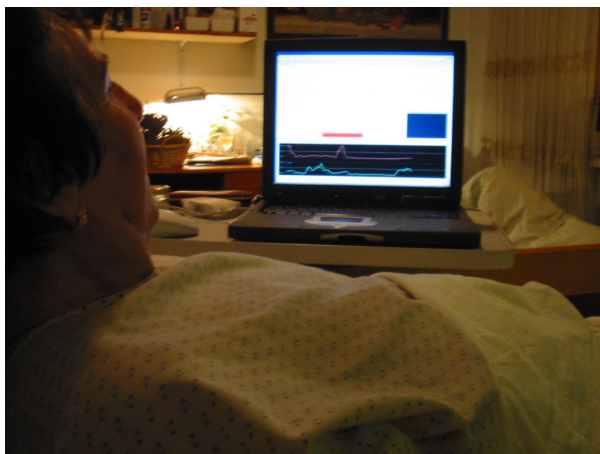
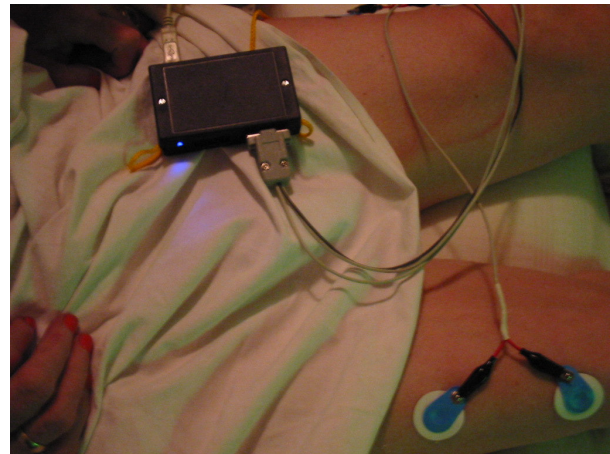


Fig. 14-16: the setting of the muscle training task

Fig17: 3d-spectra (FFT) of a muscle contraction

For measuring the muscle activity, standard BlueSensor EKG-electrodes were used. These electrodes have self-adhesive stripes and can be used a few times (although single use is recommended). In a one-channel setting, two electrodes were placed at the right thigh, to measure stretching and relaxation of the muscle. In a later, two channel setting, four electrodes were placed, two at each thigh. The DRL-electrode was placed at the left wrist.

The main components of the used design setting include the EEG signal source, filter-elements for the calculation of the magnitudes at the desired frequency-bands (here about 70 Hz), threshold-elements with meter displays and midi-elements for acoustic feedback.

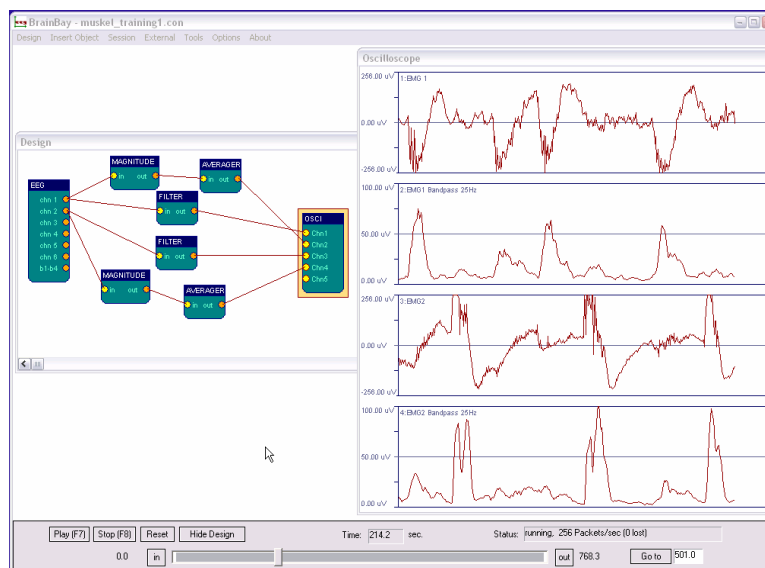


Fig 18: filtered signals and magnitudes of 2 channel EMG data

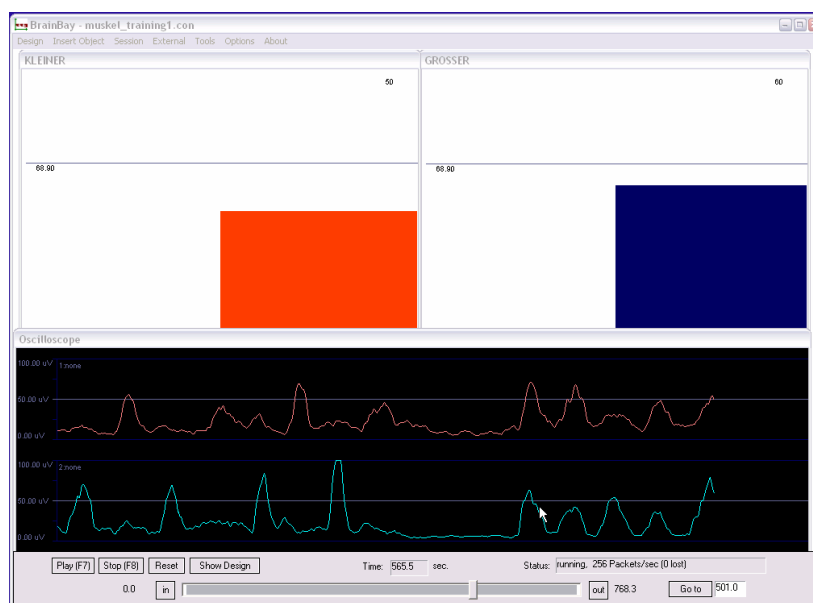


Fig 19: EMG-magnitudes and meter-windows presented to the user

Results / Reports

The patient accepted the new situation of biofeedback training very well and made ample use of the gained muscle control. As the sensitivity and threshold levels could be adjusted to her actual needs, even very light muscle contraction could be detected and displayed. The test subject interpreted the signal traces and meter-displays as direct measurement of her personal success, and got motivation to continue training. To gain this effect, it was important to keep the feedback-mechanism transparent and easy to understand. A further use as a training system was evaluated as reasonable, but did not take place because the patient does not have a computer by now.

Evaluation of the Camera-Mouse Setting

The Camera-Mouse setting was evaluated by two male persons, A. and C., in the age of 38 and 31 years. A is tetraplegic after an accident with a motorcycle 19 years ago. C is well trained to the camera-mouse system while A. had only about 10 minutes training time. A standard setting for mouse control as described in section “*Brainbay’s Cam-Interface*” was used to provide movement and click-control. The Webcam used was the *Logitech Quickcam 5000 pro*. Two application-environments were used to get an evaluation of the system performance:

1. Writing a letter with the Switch Access to Windows application (SAW)

Saw allows the creation of a flexible graphical selection system for alphanumeric characters and/or system functions and function-macros. The writing focus can be set to desired applications like word processing applications, email clients or web-browsers. Besides the selection via mouse-clicks, SAW allows other input-modalities like scanning of external switches or alternative input devices.



Fig 20: Using SAW with the camera-mouse function: a demo letter written into notepad

As the accuracy of cursor control proved to be sufficient for reaching the desired letter at a reasonable speed, the main point for getting a nice writing speed was the correct recognition of mouse clicks. A good strategy to make the click-control more sensitive was the selection of a low frequency-band for the chin-movement (a window with a width of 0,5 Hz, centered at 2 Hz) and to use a large amplification value for the magnitude in this passband. Thus, the reaction to chin-movements could be improved and the overall typing speed got faster while the interface was usable with less physical effort. This for sure resulted in a trade-of to false-positive predictions: As the interface is made very sensitive to movements, talking and rapid head-movements are producing mouse-clicks, too. Thus, the present system could be improved with a user-friendly selection of the sensitivity from for example five modes, which can be done in one click.

CAM-MOUSE – Typing (10 min)	Test Person C	Test Person A
Total Characters	337	250
false Characters	7	15
Missed Clicks	2	5
Characters per Minute	30	23,5

Table 3: Results for the typing task

2. Testing the accuracy of the System: a game of minesweeper

Minesweeper is a demanding test for a mouse-replacement system, because of the game's tiny selectable areas. Although A. did not have any training with the system, he performed surprisingly well in the first session. This may be due to his good coordination of head movements, which is trained by the use of other alternative interfaces like the mouth-stick he is using normally.

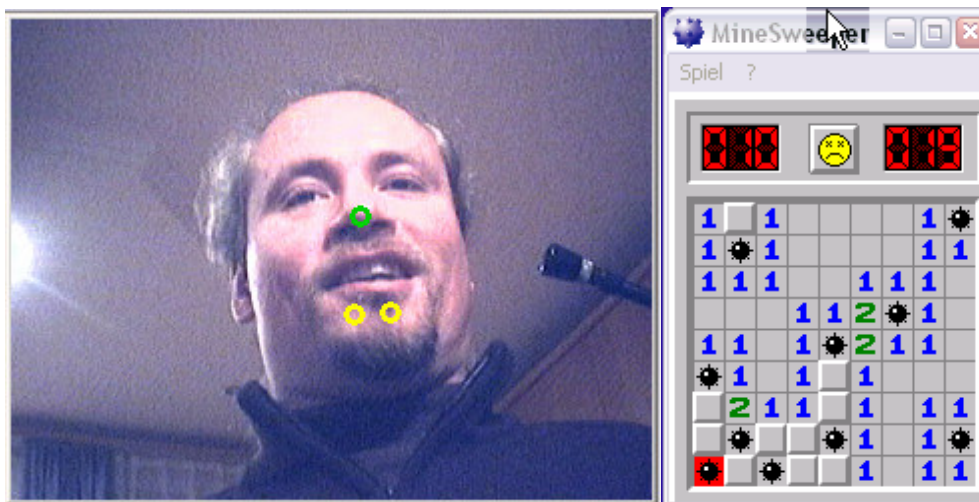


Fig 20: A game of Minesweeper, played with the camera-mouse function

As the mouse control has to be very precise to achieve a good performance in the minesweeper-game, the drifting and jittering caused by camera-noise and poor performance of the Lukas-Kanade tracking became a noticeable problem. Possible strategies to get a better spatial resolution were to decrease the gain-settings for X/Y control or to reduce the sampling rate of the processing. Both strategies resulted in a slower X/Y – acceleration / speed so that the cursor could be controlled to tiny spots more easily. Again, the need for a user-friendly selection of the sensitivity came into focus. As in the writing task, overall system performance proved to be sufficient for cursor control. The system adapts well to changing lighting conditions, because a camera with good lighting characteristics was used and the Lukas-Kanade-Tracking adjusts the templates every frame. Thus, even under conditions of just one artificial light near the desktop, the mouse control could be maintained.

CAM-MOUSE - Game (Minesweeper)	Test Person C	Test Person A
Overall clicks	125	100
Overall time	5 min	5 min
Missed Clicks	10	17
Correct hits	92 %	87%

Table 4: Results for the Minesweeper game

Discussion

A functional test of the system was successful. All hardware and software components are open source and can be downloaded from the given websites [5, 6, 18]. Using these components, a very flexible system for biosignal acquisition and processing is available for less than 200 Euros. The system provides sufficient functions for signal processing and user interaction to be used for muscle-feedback rehabilitation training and other biofeedback-based therapy.

The webcam - mouse control shows some principal advantages against other approaches where physical markers or electrodes need to be attached. The usability-tests of the camera-mouse system as a complete or partly mouse-replacement revealed that the system already gives some improvements to tetraplegic users. Nonetheless, in certain situations like after rapid head movements or due to occlusion of parts of the face, misinterpretations of the head-position can happen, and an improvement of the image-processing techniques is needed to make the camera-mouse functions more stable.

Current limitations / Future Work

As the BrainBay-Software is in beta-stage, there are many issues that could be improved to make the system more powerful and to extend the variety of possible usage. From the runtime point-of-view, the propagation of samples between the objects could be made more flexible: now, one floating-point value is transferred via each signal path at sampling frequency. A buffering has to be done in each specific object. Possible improvements could include a more flexible data-type for propagation (a matrix), varying sampling rates for signal-paths and signal loops. Another problem is the need for a wide range of signal processing methods. It was clear at the beginning of the work, that it would be a trade-off between the openness and flexibility of a new development against the usability of existing solutions like the vast signal processing capabilities of software like Matlab. With the implementation of communication standards like the EDF (European data format for biosignal processing) and real-time transmission of the data via TCP/IP sockets, some of these restrictions could be overcome.

The camera-functions have also a rich potential for improvements: As a Lukas Kanade Optical flow algorithm is used, drifting of the feature-points can occur and strategies for error correction have to be provided. Currently, simple methods like the Euclidean distance and threshold-values come to use, leading to some possible misinterpretations. Novel image processing algorithms like the Active Appearance Model or other techniques [1,2,3,4] build a better basis for a smart camera-mouse system. An extension of the present software design to the AAP is possible and could lead to a better stability of the cursor control.

From the user's point-of-view, grouping of design-elements could lead to a better structured interface. Another improvement would be a new element that provides user-interface functions like buttons, numeric and alphanumeric input-fields or sliders for the runtime system. Thus, one "control-window" could present all important settings for a specific design to the user.

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Note to the reviewers: During presentation, real-time-capabilities of the system can be demonstrated either by using pre-recorded biosignal-archives or by doing a live acquisition of data (depending on time available and on actual light situation.)

For further information please visit <http://openeeg.sf.net> , <http://brainbay.lo-res.org>