Mechatronics II

Final report:

iControl: electro-oculographic scheme for eye movement-based control

Michał Kożuch
Biomedical Engineering, WEAIiIB, AGH UST

Reykjavik, 2016

Table of Contents

Overview

The aim of the project was to develop a way to facilitate controlling a physical device using eye movement. For this purpose designed was electro-oculogrpahic signal amplifier and software to process the signal. Testing proved that the device fulfilled its purpose, however the usability was limited because of signal acquisition method requiring application of uncomfortable electrode pads.

Introduction

Electrooculography is a diagnostic method based on measuring electrical potential on the skin surface near human's eye. Based on the spatial distribution of the potential it is possible to calculate eye position. The potential difference across the eye is a result of an eyeball being an electrical dipole in which the cornea has a positive charge and retina, thanks to accumulation of photopigments, negative charge. [1]

The electrooculagraphic examination is usually conducted by placing pairs of electrodes on each side of the eye in both horizontal and vertical direction. This way eye movement in two axes can be detected.

Electrooculography is used in clinical practice to assess the function of pigment epithelium but also found its way in other fields such as neuromarketing, brain-computer interfaces and assistive devices for disabled people.

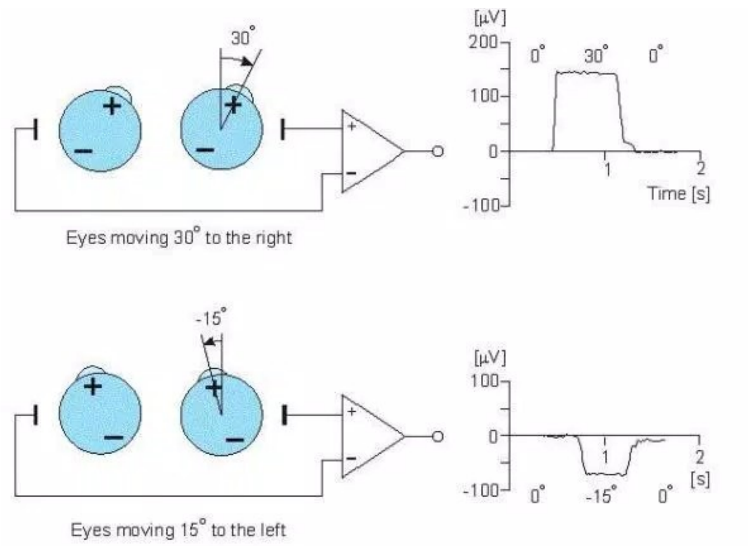

Illustration 1: Schematic view of electroculographic examination [2]

Aim of the project

The aim of this project is to develop a system for acquisition and processing of electric signal connected with human eyeball movement for the purpose of controlling electrical devices. Based on those goals the following business requirements have been formulated:

1. Te device shall be able to measure eyeball position in horizontal axis using EOG signal measurement
2. The device shall provide feedback to the user by indicating registered events
3. The device shall be able to drive a mechanical actuator in order to take control on physical object based on measured eye position
4. The device shall use Arduino Uno as controller
5. The device shall have the standard Arduino Uno shield form factor

Following the above, functional requirements have been defined as follows:

1. The input of the system will be single channel, horizontal axis electro-oculographic signal.
2. The input signal will be subjected to bandpass filtering and amplification
3. Controlling software will calculate eye horizontal position based on the acquired signal
4. The controller will control servomechanism in such a way that its position corresponds to eye position
5. The controller will drive a set of diodes indicating registered eye position and additional events

Project design

The system consists of the following parts: analog front-end, microcontroller unit, visual feedback device and mechanical actuator.

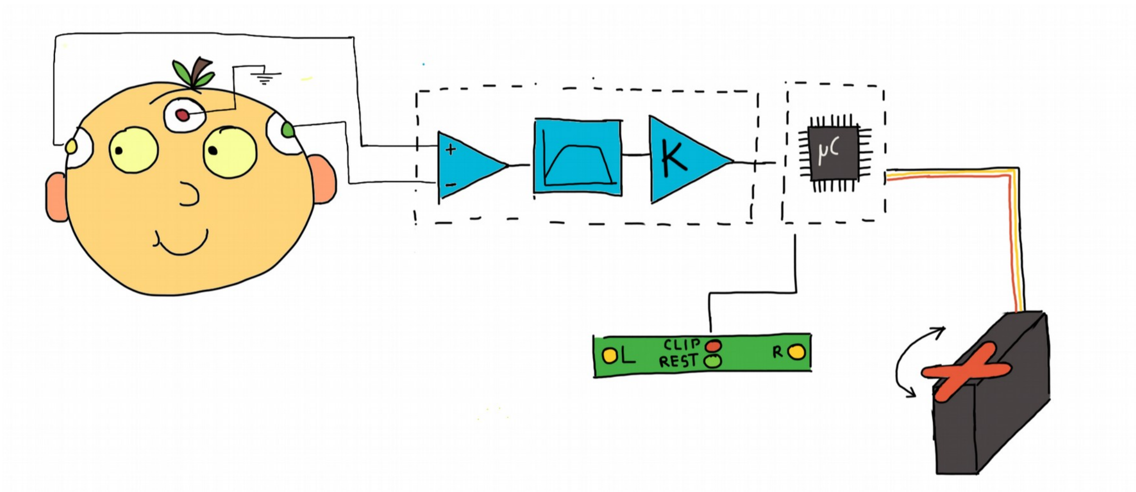

Illustration 2: Schematic diagram of the system

Analog front-end

The purpose of analog part is to acquire electrical signal, amplify it and filter out unwanted frequencies. The usual amplitude of raw EOG signal is between 15 and 200µV and usable frequencies are from 0 to 38 Hz [07095398]. However biosignals' amplitude may vary drastically based on skin resistance. Which depends on such factors as: moisturisation, fat layer thickness, sebum excretion and so on.

The front-end was designed in such a way that total gain is around 12,8 kV/V. This value was determined experimentally and provides output signal swing of around 4V. The bandwidth is limited to range between 0,1 and 16 Hz. Bottom frequency was adjusted in such a way to reject low frequency noise which is result of electrode-skin contact effect. Top frequency has been set to a value that allows enough attenuation at 50Hz but preserving maximum energy in usable band. In retrospect this value should be higher and the order of the low-pass filter should be higher in order to provide

Additionally the circuit is biased at 2,5V in order to allow the circuit to be powered from single 5V supply and match the signal level to input range of analog-to-digital converter.

The circuit consists of three parts:

1. Input instrumentation amplifier
2. High-pass second-order unity-gain Sallen-Key filter
3. Third-order low-pass Sallen-Key filter.

Sallen-Key architecture for both low-pass and high-pass filters has been chosen as it is relatively easy to calculate values of components for desired cutoff frequency and frequency response. This architecture was preferred over multiple feedback topology as it is more resilient to components' tolerances at low gains. Also, the architecture was limited because of the decision that, for the simplicity of the design, there would be only one quad package op-amp in the circuit.

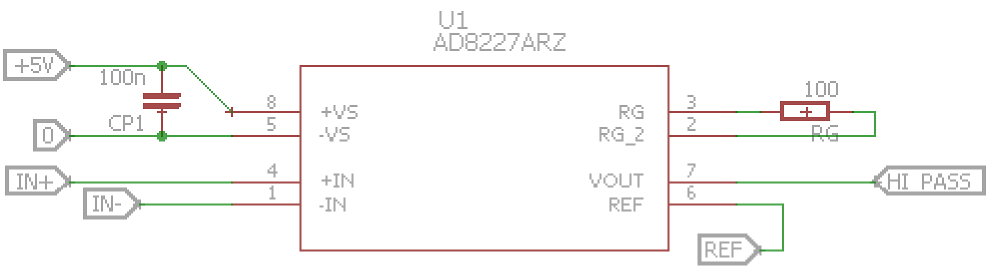

Illustration 3: Input instrumentation amplifier schematic diagram

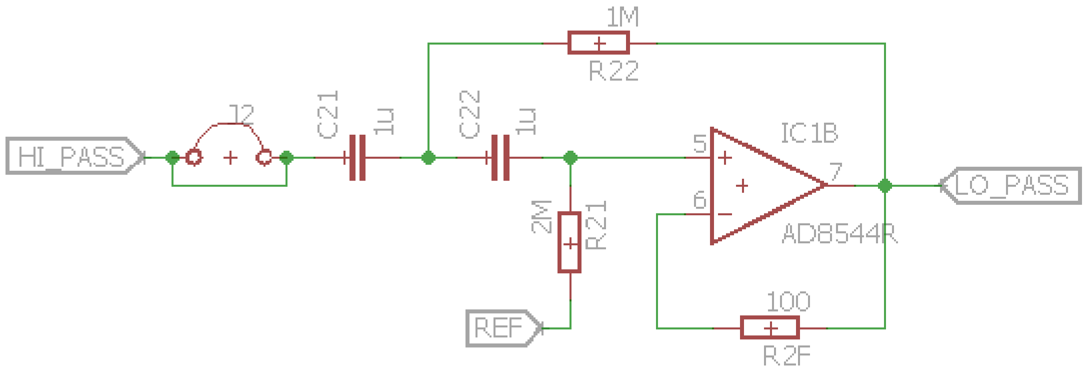

Illustration 4: High-pass filter schematic diagram

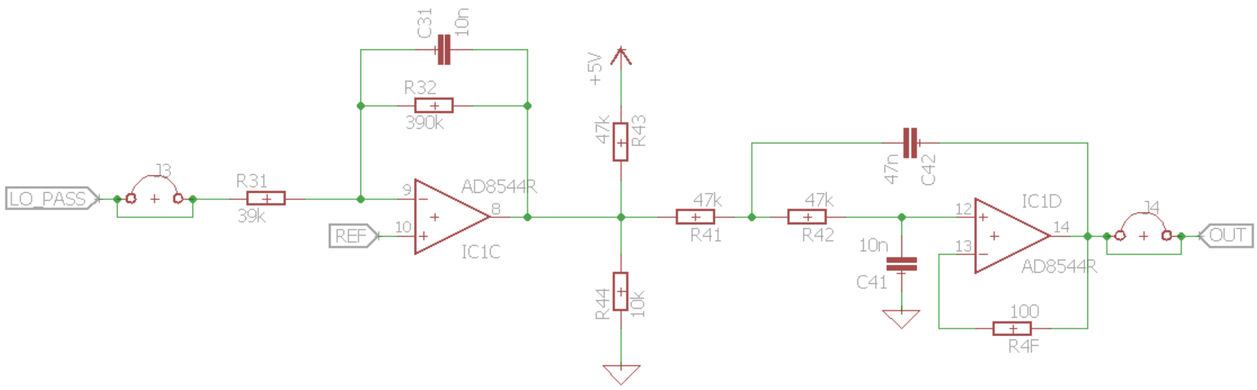

Illustration 5: Low-pass filter schematic diagram

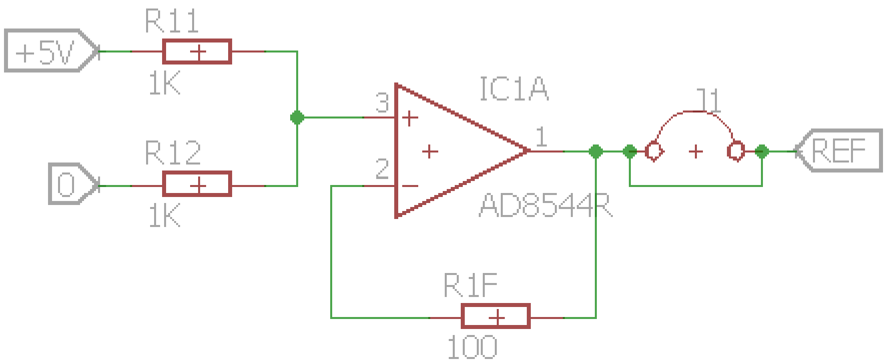

Illustration 6: Reference voltage driver schematic diagram

Component selection was based on Analog Devices inc. catalog as this particular company provides free samples of their products to students.

For input amplifier selected was amplifier AD8227 because of its high common mode rejection ratio (around 140dB at G= 800 and f < 50Hz) and ability to be powered from single rail and rail-to-rail output. [3]

Active filters and reference voltage driver have been realized using quad op amp AD8544, it was selected mainly because of its rail-to-rail input and output, single supply operation additional feature is no inverting effect. [4]

Advantage of both ICs is relatively low cost and high availability via big electronics suppliers.

Circuit has been designed using EAGLE CAD and simulations have been conducted using TINA: SPICE-based simulation program.

Elements J1 through J4 are jumpers whose purpose is to both simplify PCB layout and provide convenient test points to hook oscilloscope probe.

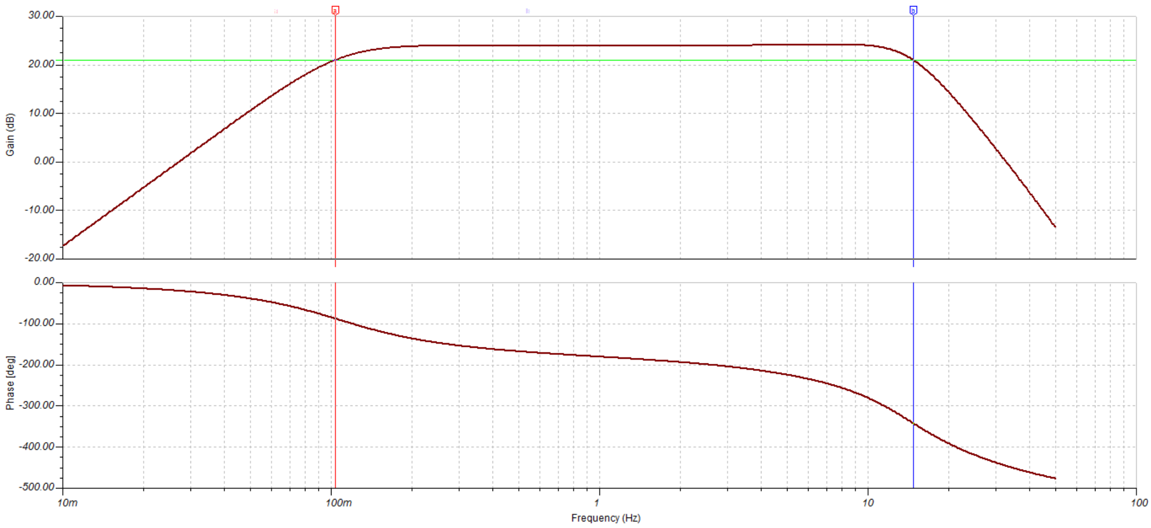

Illustration 7: Frequency response of simulated filtering stage

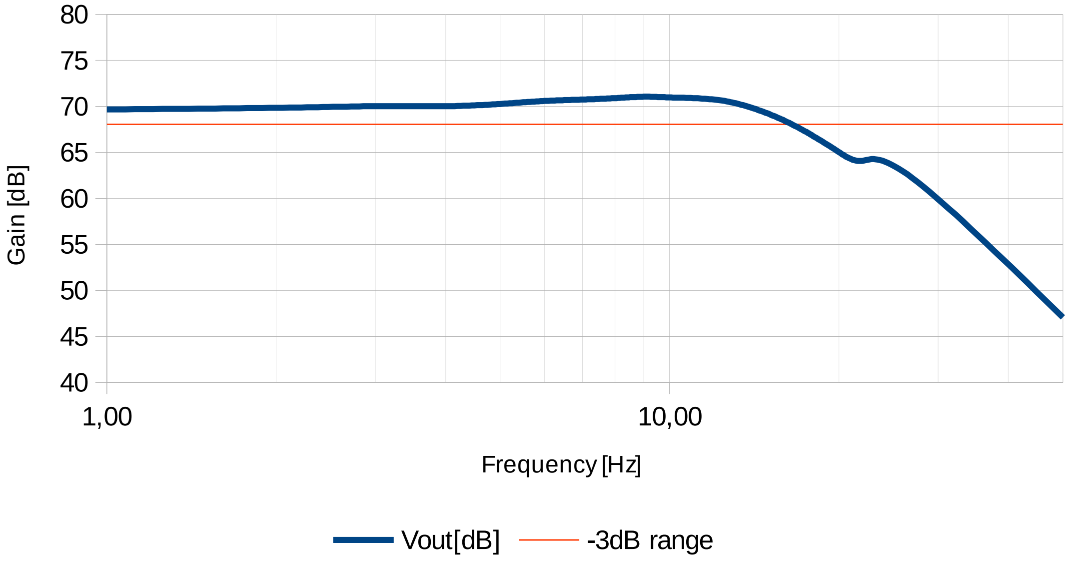

Illustration 8: Frequency response the analog front-end circuitry

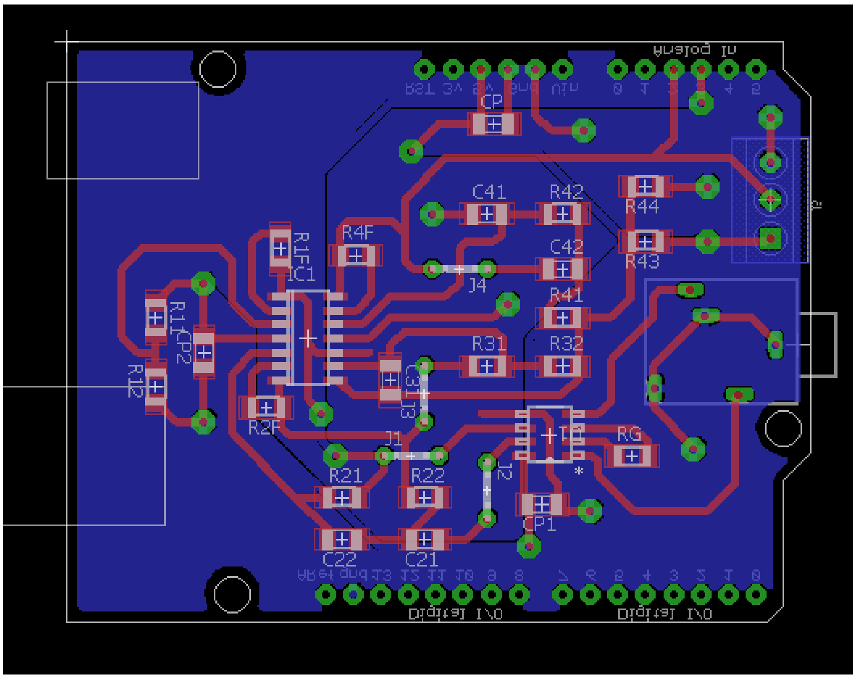

Illustration 9: PCB layout for analog circuitry

Microcontroller unit

Microcontroller unit's purpose is to sample the signal and process it in such a way that the position of the eye is calculated and proper control signal is outputted. Microcontroller used for this project is be Atmega328p as the element of Arduino Uno platform. This particular controller has been selected mainly because the author already owns one. Selected microcontroller is fitted with 10-bit SAR ADC with 6 multiplexed inputs.

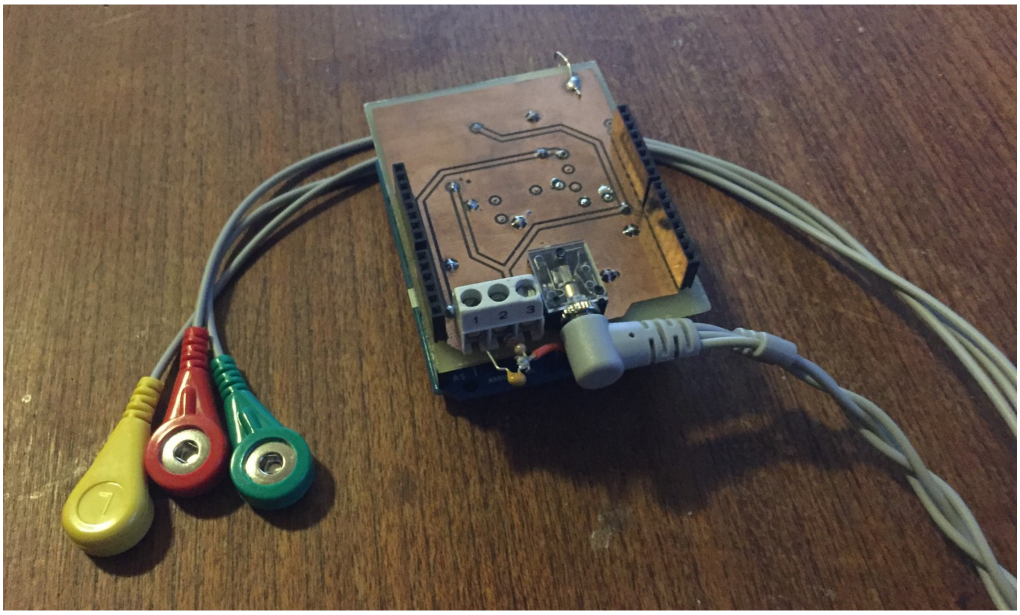

Illustration 10: Finished prototype together with leads

Sampling rate, as Whittaker–Nyquist–Kotelnikov–Shannon theorem sates, must be at least twice as high as the highest frequency present in the signal. The sampling frequency has been set to 100Hz in order to easily design digital filter whose purpose is to further attenuate 50Hz hum. ADC resolution is reduced to 8 bits in order to speed up computations.

Software architecture

Because analog filtering stage introduces differentiation to the signal it proved to be very difficult to correlate signal level to eye position. This is the reason that the decision as been made to differentiate between three states (LEFT, RIGHT, REST) based not on eye absolute position but rather its relative changes. Also, contrary to initial assumption, blinking did not introduce much noise this is the reason that initial BLINKING state has been changed to CLIPPING which occurs when signal exceeds ADC range which is the case when the electrodes are not placed correctly. Illustration 10 shows raw signal acquired by the device and visualized using Python script, green waveform illustrates signal subjected to moving average operation with window of length 32 samples.

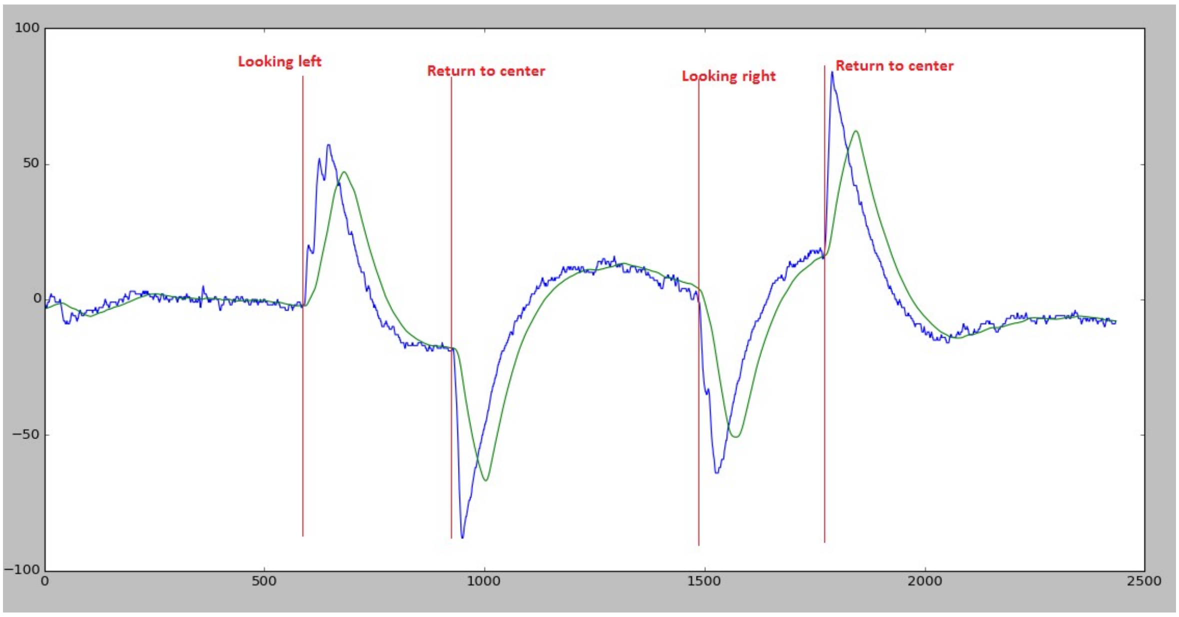

Illustration 11: Registered waveform. Blue line: raw signal, Green line: signal subjected to moving average operation

Software for this project has been written in C and compiled using AVR-GCC compiler with Cmake as build manager.

Sampling is timed by timer1 at 10ms intervals. ISR at ADC Conversion Complete reads sample from ADC buffer and puts it in 64-element long buffer, then calculates its average value. Based on this value, and previous value of variable ECSignal global flag ECSignal is set to one of possible values: REST, LEFT, RIGHT or CLIPPING.

Main loop is executed once every 10ms and is timed by software delays. In every iteration state of variable ECSignal is checked and based on its value proper diode is lit. Also, every 30 iterations if state detected is other than REST, servomechanism is rotated one step left or right. That means that as long as LEFT or RIGHT signal is held, every 0,3s servo will turn left or right one step respectively. Servo is stopped by setting REST state. If CLIPPING state is detected servo returns to its neutral position. Servo pulse length is controlled by interrupt at timer2.

Visual feedback/debugging device

Visual feedback device consists of colorful LED diodes that inform user about device operation. There are four diodes labeled: 'Left', 'Right', 'Rest' and 'Clipping'. Each diode represents one of states that are be recognized by software. Also the device is used for simple debugging while developing software.

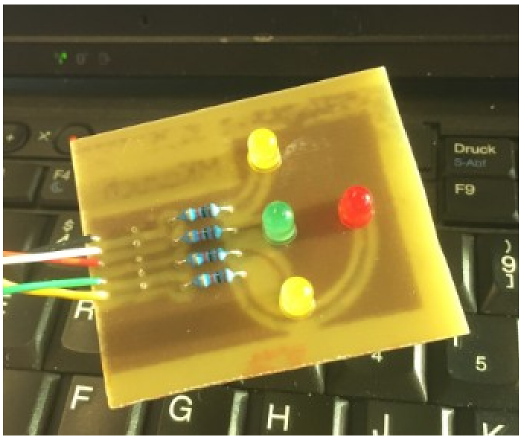

Illustration 12: Prototype indicator device

Actuator

The electro-oculographic control system allows for controlling a standard servomotor by outputting control signal on Arduino pin 11. Every 30ms state is checked, if LEFT or RIGHT state is detected, servo turns one step in the proper direction. At REST state no action is taken. When it reaches either end position it stops.

Servo has range of 180 degrees, in this case divided into 10 steps. Which means that accuracy is 18 degrees.

Project evaluation

In order to evaluate the solution some tests with the participation of volunteers have been conducted. Testing involved volunteers being asked to perform specific tasks connected with operation of the device. Their subjective opinions have been gathered as well as some objective quantities. Because of the major discomfort connected with placement and removal of electrodes only two volunteers have been tested.

Objective quantities

In order to gather measurable quantities the testing protocol has been devised. It consists of several tasks each repeated three times that volunteer is required to perform. Each task is graded from 0 to 3 depending on whether the device response was as expected. Before the test participants had a couple of minutes to familiarize themselves with the device operation. Three points indicate that in every trial the system behaved as expected.

	Participant 1	Participant 2
Look left then back to center	3	3
Look right then back to center	3	3
Keep looking left	3	3
Keep looking right	3	3
Switch from looking left to right	3	2
Switch from looking right to left	3	2
Looking up and down	3	2

This shows that, after a couple of minutes of getting to know the system, users had little trouble operating the device correctly. The only problem they had is understanding that the device can not transition from LEFT state to RIGHT directly, instead when switching from looking left to right and reverse there needs to be a certain time of looking straight otherwise the device does not work properly.

Volunteers' feedback

Volunteers claimed that this scheme of controlling is fun easy to use however the necessity of putting sticky electrodes and tangly wires lowers usability of the device significantly.

Conclusion

To sum up: it turned to be possible to measure electro-oculographic signal and use it for the purpose of controlling devices. However calculating absolute eye position based on the signal proved to be difficult and prone to errors. This is why another scheme was proposed based on relative eye position changes. The system turned out to be relatively easy to use and accurate however its usability was limited. Actual application of this scheme of control in which it would prove usable is yet to be determined. Similar solutions serve paralyzed people as one of the ways in which they can interact with their surrounding along with brainwave and tongue movement based systems. [5]

Future Work

Current design of the device leaves much room for improvements in order to increase accuracy and usability. Firstly, better way of mounting electrodes on the temple should be devised. For example in glasses frame. This would enable quick electrode placement and removal and improve cable management. Furthermore by using additional operational amplifiers in the circuit it would be possible to increase order of the filters providing steeper frequency response. This would allow to increase bandwidth of measured signal allowing faster response and more accurate signal analysis. Removing high-pass filters form the circuit would preserve DC component in the signal making calculation of absolute eye position easier however in this case low frequency electrode drift would have impact on the signal. Another improvement to the device would be adding additional channel to measure signal also in vertical axis thus adding one more freedom degree to the control system.

References

1: Augustyniak Piotr, Przetwarzanie sygnałów elektrodiagnostycznych, 2001
2: https://electrooculography.wordpress.com/project-proposal/
3: Analog Devices, AD8227 Datasheet, , http://www.analog.com/en/products/amplifiers/instrumentation-amplifiers/ad8227.html
4: Analog Devices , AD8544 Datasheet, , http://www.analog.com/en/products/amplifiers/operational-amplifiers/general-purpose-amplifiers/ad8544.html
5: Mike Szczys, The gaze-controlled wheelchair that won the Hackaday prize, 2015, http://hackaday.com/2015/11/17/the-gaze-controlled-wheelchair-that-won-the-hackaday-prize/

Bill of materials

No	Name	Amount	Cost [€]
1	ECG cable wires	1	10
2	ECG electrode pads	50	10
3	AD8227BRZ	1	3,75
4	AD8544ARZ	1	1,25
5	Arduino pin headers	4	1,75
6	Screw terminal	1	1
7	Arduino Uno	1	20