Eye-Tracking Capabilities of Low-Cost EOG System

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***Abstract*— This paper presents the design and implementation of a low-cost eye tracking system that allows measuring the rotational angle of the eye and gaze direction in healthy individuals. The system consists of an EOG circuit with simple components that acquire both horizontal and vertical eye movement through regular all-purpose contact electrodes. Then the data are analyzed and translated into corresponding angle values representing the eye rotation angle in both orientations. Results show that horizontal angle measurements are much more accurate than vertical measurements. A discussion regarding the performance and possible improvements is presented.**

I. INTRODUCTION

Eye-tracking systems are used in many applications, such as gaze tracking studies [1], PC interaction for people with disabilities [2], [3], [4], controlling a wheelchair [5], [6], entertainment and games, operators interfaces, etc. Currently, there are different methods to track gaze direction, with varying difficulty and cost. The best alternative to this date is video-based tracking, that can achieve high accuracy, but at a very high price, over US$30,000 for a single device. A different alternative is an eye-tracking system based on Electrooculography (EOG). This technique is very convenient because it involves medium complexity, low cost and requires common electrical components.

II. OCULAR ACTIVITY AND EOG

The eyeball creates a natural dipole whose potential can be measured through electrodes placed on the skin, next to the eye socket. When the eyes turn towards one electrode, a positive voltage potential can be measured relative to the opposite electrode. In the neutral position, when the eyes are looking forward, the relative potential is zero. The EOG measurement can be translated to a rotation angle of the eyes in either the horizontal or vertical directions. Due to the distance from the electrodes to the eye, the skin impedance and other factors, the recorded voltage is attenuated and EOG signal varies between 250 and 1000 microvolts [7]. The frequency range of the EOG signal is 0 Hz to 30 Hz [8]. However, this study considers a lower frequency range, from 0 Hz to 15 Hz, with most of the components between 3 Hz and 8 Hz. Many implementations remove the DC component of the EOG signal because it simplifies the acquisition, but without this component it is not possible to determine if the individual has his gaze focused into a point, losing the ability to translate EOG voltage into a direction.

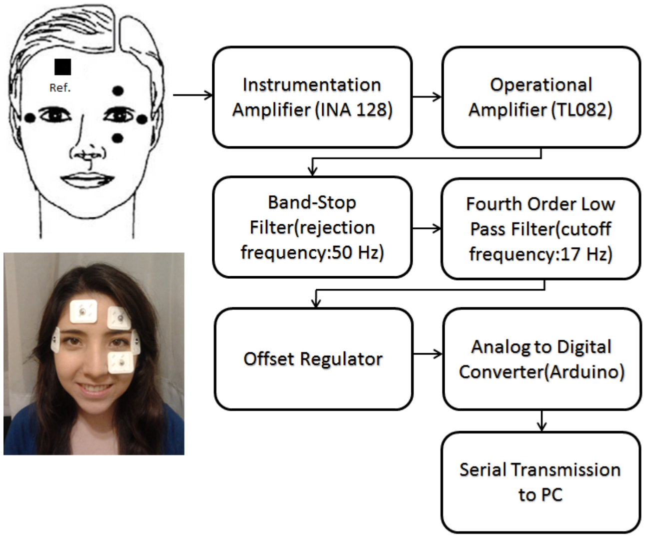

Fig. 1. Position of electrodes contacting the skin and the stages of the signal acquisition.

III. SIGNAL ACQUISITION

The acquisition system uses regular skin electrodes to measure EOG. The system has 2 channels for simultaneous horizontal (EOGH) and vertical (EOGV) recordings.

Fig. 1 shows the overall scheme of the designed system. It uses 5 electrodes attached to the subject's face, to register electrical activity of the eye movement. Two electrodes are placed on the outer sides of both eyes to capture the horizontal signal. The other two electrodes are placed above and below one eye for vertical movement evaluation. The fifth electrode is the reference electrode, and is usually placed on the forehead. The two signals obtained, one for EOGH and one for EOGV are then processed through a series of stages before being recorded on a notebook for further analysis.

The amplification was done in two phases. In the first phase, an INA128 instrumentation amplifier is used, mainly because of its high Common Mode Rejection Ratio (CMRR) and high gain. A gain of 714 was used for this stage. The second phase uses a TL082 operational amplifier to amplify the signal by three.

The amplified signal is then filtered to remove the noise coming from the 50 Hz mains, using a notch filter. Then, a fourth-order low-pass filter is used, using a Sallen-Key configuration with a cutoff frequency of 17 Hz. After the signal is amplified and filtered, an offset is added to prepare it to be digitized. To this end, the Analog to Digital Converter

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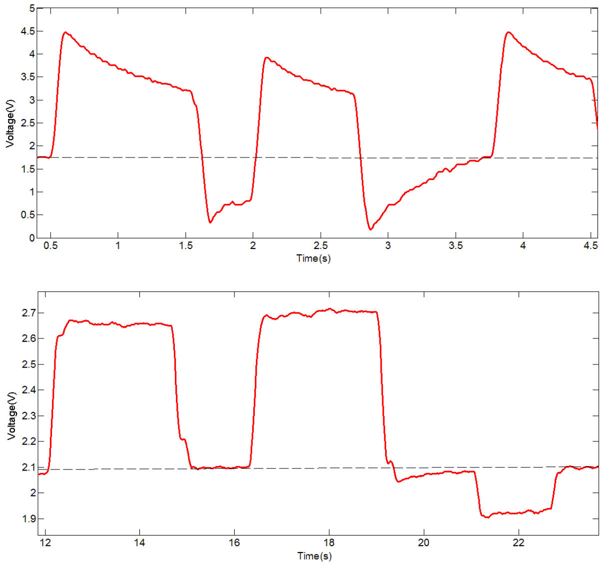

Fig. 2. Difference between an EOG signal without DC component (top) and with DC component (bottom). Note that if the gaze is kept in the system with DC filtering, the value will decay to zero, which corresponds to the value when the gaze is straight ahead (zero degree angle).

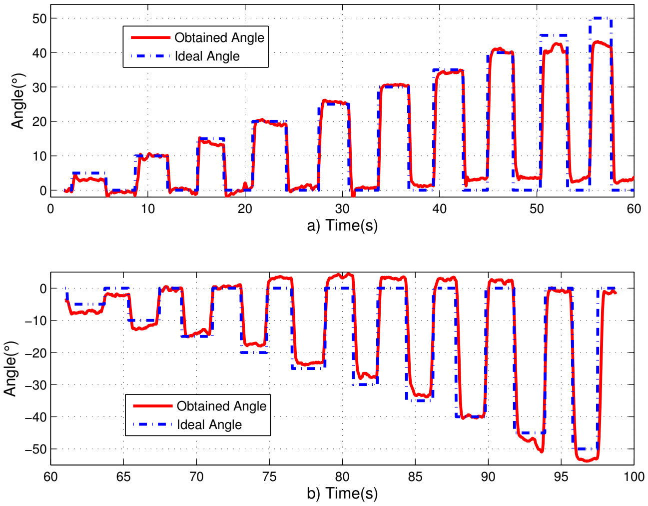

Fig. 3. Sample EOGH recorded in a subject. Top: Positive angles. Bottom: Negative angles. Angles greater than 40° in any direction present more errors compared to the expected result.

TABLE I

SUMMARY OF SIGNAL MEASUREMENT RESULTS IN 5 VOLUNTEERS.

Variable	EOGH	EOGV
Maximum Averaged Angles	44.2°	33.5°
Minimum Averaged Angles	-43.4°	-31.9°
Physiological limits [10]	±45°	±30°

(ADC) port in the Arduino Uno microcontroller is used. The sampling frequency is 100 Hz. Finally, the converted data are sent through serial communication to the notebook for recording.

As mentioned before, in this application the DC component of the signal is very important to obtain reliable information. When the DC component is removed with a high-pass filter (usually a cutoff frequency of 0.5 Hz or less), it is impossible to know if the subject is keeping the gaze at a specific location. In Fig. 2, it is possible to appreciate the difference between both approaches. When the signal has the DC component removed due to a high pass filter, if a person maintains an eye orientation, the signal slowly returns to zero.

IV. RESULTS

To validate the data obtained from the EOG, a test subject sits at a distance of 50 cm from a calibration guide. The calibration guide consists of a series of points that correspond to different angles at which gaze will be directed when staring at them. The angle ranges from -50° to 50° for the EOGH and -30° to 30° for EOGV, with a step of 5°. The distances between points in both directions are obtained from the trigonometric relationship to the distance of 50 cms.

Once the test individual has the electrodes connected, the procedure is to change the gaze direction from 0° to each one of the dots in the positive angles, in order, always returning to the 0° position. Once that has been done with the positive part of the guide, this procedure is repeated for negative values.

To obtain the relationship or scaling factor between the signal and the rotation angle of the eyes, the voltage corresponding to a 60° rotation is used as reference. This is because the eye movement model is linear from -30° to +30° [9]. The last value while fixating the gaze at -30° is subtracted from the first value after changing the gaze to the +30° mark, thus registering a 60° movement. The reciprocal is then obtained and multiplied by 60°, resulting in the normalization factor of the voltage values. This factor is used to scale the entire signal and obtain the corresponding angles. The result of multiplying the EOGH signal with the calculated factor is shown in Fig. 3, alongside the reference or 'ideal' gaze angle. The differences between both of them becomes noticeable for angles values greater than 40°.

To obtain EOGV angles, the same procedure described above is repeated. However the results are worse than for the horizontal experiment. For EOGV it is difficult to make a correct estimation within 5°. The results for EOGV can be seen in Fig. 4.

In order to assess repeatability, a second test was conducted with 5 volunteers: 3 men and 2 women, ranging from 20 to 55 years old. Table I shows the average maximum and minimum angle values obtained among the volunteers. Note that the values obtained for both EOGH and EOGV are comparable to the physiological limits of eye movement. Fig. 5 and Fig. 6 show the individual records to assess the mapping capability and dispersion between volunteers, both in the horizontal and vertical axes.

Results have similar magnitudes among all individuals when positive and negative parts of the signals are compared. EOGH signal presents lower dispersion compared to EOGV signal values. Table II show that the standard deviation for all

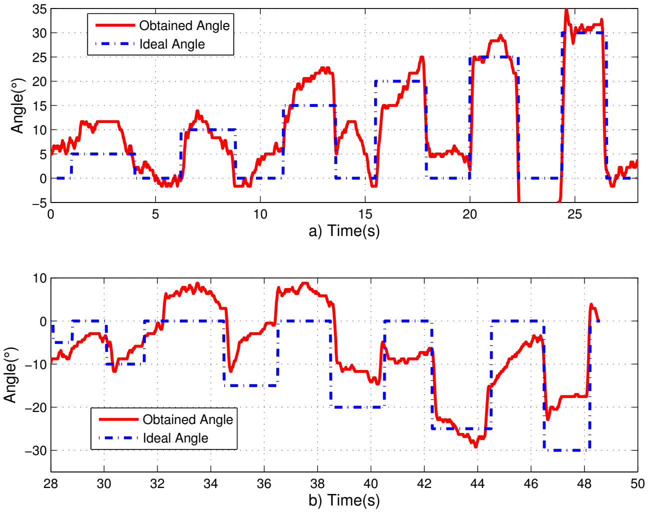

Fig. 4. Sample EOGV recorded in a subject. Top: Positive angles. Bottom: Negative angles. In EOGV, the error between the measured and the ideal angle value is evident throughout the test.

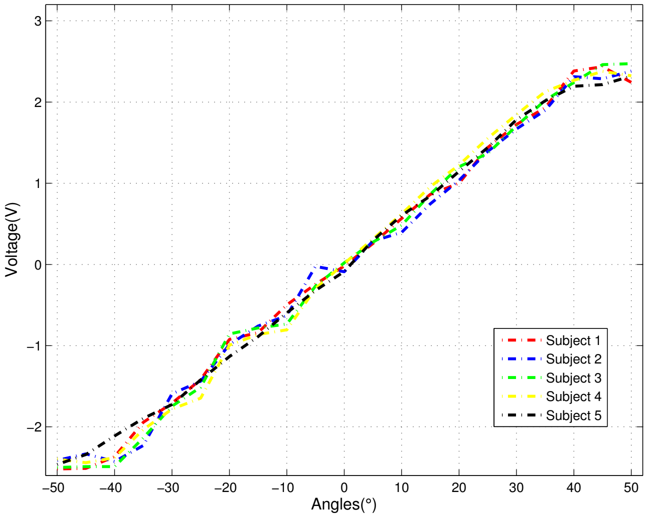

Fig. 5. EOGH values. Among different indivuals, EOGH present similar values.

angles tested in EOGH is under 2.3°. Furthermore, EOGH angles and voltages can be mapped almost one-to-one, while EOGV results for different angles are mapped to the same voltage, which will produce errors in the angle estimation. Table III also support this observation. The standard deviation in vertical angles larger than 30° or smaller than -30° is higher than the 5° step used.

V. DISCUSSION

As shown, a simple EOG device, constructed for less than U$50 in components, can attain good results as an Eye Tracking device, with some limitations.

Working with EOG signals with DC component, as is required by an Eye Tracking application, introduces some problems to the data acquisition, such as the oscillation in the baseline. This oscillation is most evident in the EOGV signal, but can also occur in the EOGH signal.

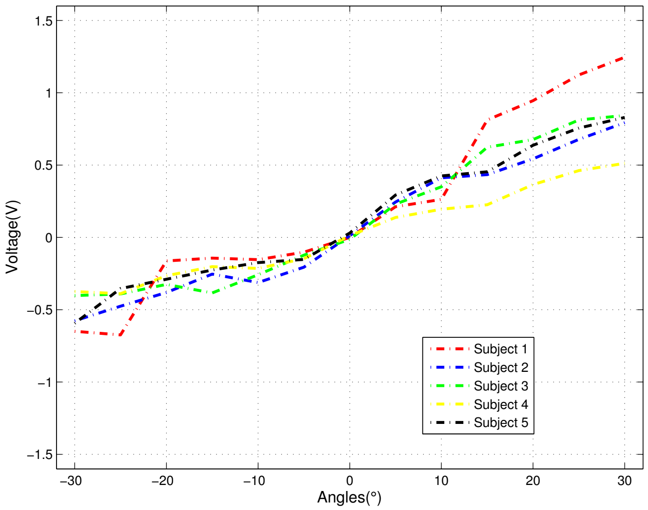

Fig. 6. EOGV values. Among different indivuals, EOGV has more dispersion.

TABLE II

SUMMARY OF RESULTS FOR EOGH.

Corresponding Angles [°]	EOGH mean angle [°]	EOGH standard deviation [°]
-50	-50.02	1.07
-45	-45.04	1.55
-40	-40.10	2.29
-35	-35.12	2.32
-30	-30.04	1.30
-25	-25.08	1.54
-20	-20.17	2.07
-15	-15.05	1.07
-10	-10.28	1.94
-5	-5.06	0.60
0	0.18	0.15
5	5.02	0.38
10	10.29	2.04
15	15.10	1.36
20	20.07	1.35
25	25.05	1.21
30	30.04	1.17
35	35.06	1.57
40	40.04	1.46
45	45.01	0.62
50	50.01	0.74

EOGH results show a good performance using the proposed system. The recorded potential can be translated into a gaze angle, with satisfactory results, being possible to make fine distinctions between angles. EOGH signal also presented the expected behavior of at least 30° linearity.

Evidently, EOGV signal has not the same satisfactory behavior as EOGH signal. It is very difficult to make a correct distinction in angles values from measured voltages. Also, the results showed more dispersion in EOGV signal, presenting a behavior with more variations than the corresponding EOGH signal. The problem with EOGV signal may

TABLE III

SUMMARY OF RESULTS FOR EOGV.

Corresponding Angles [°]	EOGV mean angle [°]	EOGV standard deviation [°]
-30	-28.94	8.05
-25	-24.03	6.05
-20	-19.16	7.78
-15	-13.65	5.82
-10	-7.98	2.98
-5	-2.70	1.35
0	0.12	0.04
5	5.32	1.64
10	10.90	3.84
15	17.99	9.47
20	22.01	7.94
25	27.14	8.99
30	32.48	10.56

be due to the position of the electrode above the eyebrow, being far from the eye dipole. Besides, the eyebrow and the cheek have more underlying gesture muscles, which affect the signal. Eye blinking also was more visible in EOGV than EOGH.

The proposed system can be used for low-cost Eye-Tracking systems, for simple evaluations or pre-screening in rural or isolated locations. Even if its ability to detect detailed characteristics such as saccades is limited, it can be used as an assistive device, in reading evaluations or to train selective sustained attention. Its low-cost would allow to opt for a simple and quick replacement in case of failure.

There are many directions for future work. First, it is necessary to improve the acquisition system to be able to avoid unwanted offsets or oscillations in the baseline. Also, smaller electrodes should be considered, which can be positioned more proximal to the eye, especially to improve the EOGV signal. Lastly, it would be interesting to try different electrode orientations. A diagonal orientation may balance the good performance horizontally with the poor performance vertically and maybe better results can be obtained.

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