Research Paper
Journal of Smart Systems Research (JOINSSR) 5(2),66-75,2024
Received: 11-June-2023 Accepted: 1-September-2024
DOI: 10.58769/joinssr.1499482

SAKARYA UNIVERSITY OF APPLIED SCIENCES

Electrooculography Signal Acquisition and Processing for Real-Time Virtual Keyboard

Leila BAROUR[1], Ayse Nur AY GUL[2*]

[1]Biomedical Engineering, Graduate Education Institute, Sakarya University of Applied Sciences, Türkiye, barour.leila.03@gmail.com

[2*]Biomedical Technologies Application and Research Center, Sakarya University of Applied Sciences, Türkiye, ay@subu.edu.tr

ABSTRACT

In cases of disease or trauma, individuals may lose the ability to communicate through conventional means such as speech or typing. Eye movements often remain one of the few active muscle capabilities for people with neurodegenerative disorders, such as amyotrophic lateral sclerosis (ALS), or those experiencing paralysis. Additionally, eye movement-based systems can be beneficial for privacy, security, or convenience when hands-free communication is necessary. This study aims to control a virtual keyboard using EOG signals, derived from the cornea-retinal standing potential between the front and back of the eye. Electrodes placed around the eye capture these signals, enabling text input based on eye movements. The system successfully recorded messages by detecting the desired letters during periods of sustained gaze. Further improvements could be achieved by incorporating blinking detection algorithms to refine letter selection and enhance system accuracy.

Keywords: EOG, ALS, Virtual Keyboard, Recorded Message.

1. Introduction

The eye is an organ that performs visual functions in humans. The eye movements are examined by using small-amplitude biological signals that occur during the movement of the eyes [1]. The signals mentioned are called electrooculogram (EOG) which are obtained by recording the potential difference between the eyes in two separate channels: horizontal and vertical [2]. EOG signals have a frequency range of 0.1 - 20 Hz and low amplitude values such as 100 - 3500 microvolts in amplitude [1]. Many studies are using EOG signals. For example, there are studies about the processing of signals received with electrodes placed around the eye, understanding the state of the eye, and studies in different areas such as sleep examination with the help of EOG signals, EOG-based eye movement detection and gaze estimation for an asynchronous virtual keyboard [3]. EOG-based computer control systems have been developed, such as a novel efficient human-computer interface and an EOG-based virtual keyboard [4]. Other advancements include adaptive virtual keyboards that minimize keystrokes for EOG-based control [5], continuous eye-writing recognition systems for assistive communication [6], directional eye

* Corresponding Author's email: ay@subu.edu.tr

movement detection systems for virtual keyboard controllers [7], and further eye movement detection algorithms [8]. Additionally, wearable forehead EOG measurement systems have been developed for practical applications [9].

This study aimed to develop a communication method for individuals with Amyotrophic Lateral Sclerosis (ALS) and paralysis, as well as for security purposes, using electrooculogram (EOG) signals to create an EOG-based virtual keyboard. The system operates by employing a typing method that utilizes specific directions and timings to select individual letters based on the keyboard design. EOG signals are captured through electrodes placed around the eyes, detecting the electrical activity generated by eye movements. These signals are then processed and translated into cursor movements on the virtual keyboard. Users can type by moving their eyes in specific directions, allowing them to select characters without needing physical input. This innovation not only provides a valuable tool for individuals with severe motor impairments but also offers potential applications in secure communication systems where traditional input methods might be compromised.

2. Material And Methods

2.1. Experimental Procedure

In this study the signals were acquired using electrodes placed around the eyes, after that a Measurement System was used which is KL-730 Biomedical Measurement Training System (Figure 1). It provides a platform for students to learn how to extract various body signals using bioelectronics sensors [10].

Figure 1: Biomedical Measurement Training System KL-75003 [10].

Measurements were performed in the Biomedical Technologies Research and Application Center (BIYOTAM) at Sakarya University of Applied Sciences. Figure 2 shows the whole process of the experiment starting from the capturing EOG signals to the treatment of the signals in the machine, to the wave form and data and the virtual keyboard till the result which is the recorded message.

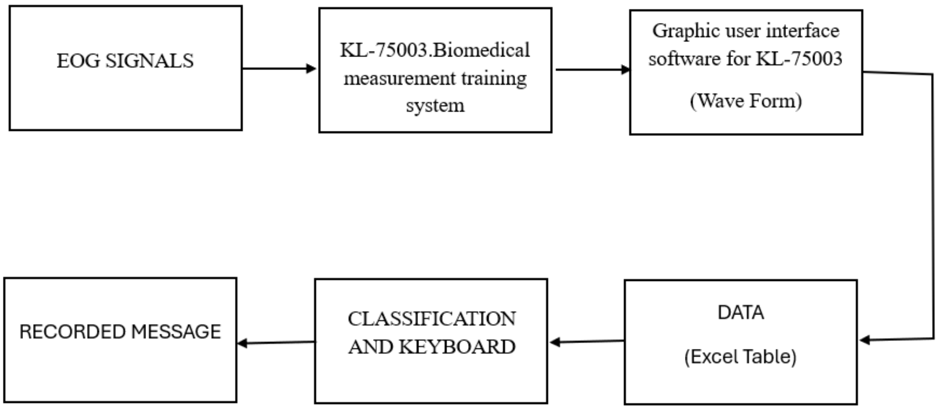

Figure 2: Block Diagram for an EOG Based Keyboard.

Both horizontal and vertical EOGs are measured as voltages using electrodes. For horizontal EOG measurements, electrodes are placed as close as possible to the canthus of each eye. For vertical EOG measurements, electrodes are placed just above and below the eye. The reference electrode is placed on the forehead [11]. For this preliminary measurement, the EOG data was recorded once from a single volunteer student. Figure 3 shows electrode placements and figure 4 displays disposable electrodes for the measurements.

Figure 3: Placement of Electrodes for EOG Recording.

Figure 4: 50mm-Round-Medical-Disposable-Electrode.

2.2. Acquisition and Processing

Raw signal was acquired and merged with noises coming from various sources, power-line interference, cables, skin resistance. It also had a very low amplitude (in the range of microvolts), making it too difficult to detect the change in the signal. For treating this signal KL- 75003 Electrooculogram module was used which is seen in Figure 5.

Figure 5: KL-75003 Electrooculogram (EOG) Module.

The Specifications for Electrooculogram EOG Module is a surface electrode and gain with range of 5~3000. Adding an isolation circuit and a band-pass filter with from 0.05~30Hz. Also 2 outputs one for horizontal signal and one for vertical signal [10]. GUI for KL-75003 is displayed in Figure 6.

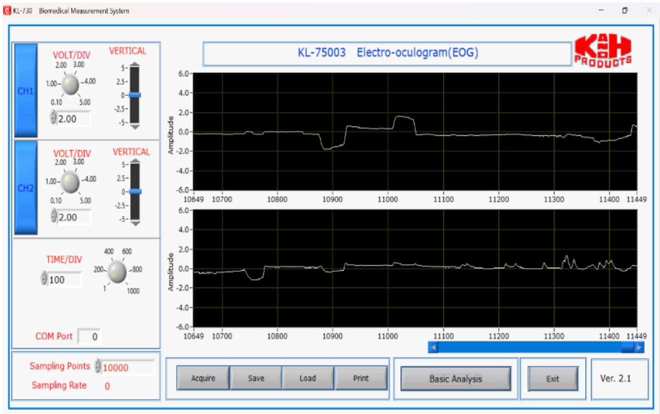

Figure 6: Graphic User Interface Software for KL-75003.

The EOG data was then stored in an Excel file with two columns for horizontal and vertical EOG signals, with a total of 1501 data points captured. Thirteen rows from our captured data are shown in Table 1.

Table 1: *Table for EOG Data*

Vertical	Horizontal
1.2	-10.72
1.28	-10.72
1.28	-10.72
1.28	-10.8
1.28	-10.72
1.28	-10.72
1.2	-10.72

1.28	-10.72
1.2	-10.72
1.2	-10.72
1.2	-10.8
1.28	-10.72

During the measurements, analog filtering was utilized with the device. EOG signal information is mainly contained in low frequencies. For this reason, a band-pass filter, which combines both high-pass and low-pass filtering, allowing only a specific range of frequencies between 0.1 and 30 Hz to pass through, was applied to isolate the frequency band where the EOG signal is most prominent, with a sample rate of 128 Hz. Then, an average filter was applied to remove some noise components [12]. The original and filtered EOG signals are displayed in Figure 7.

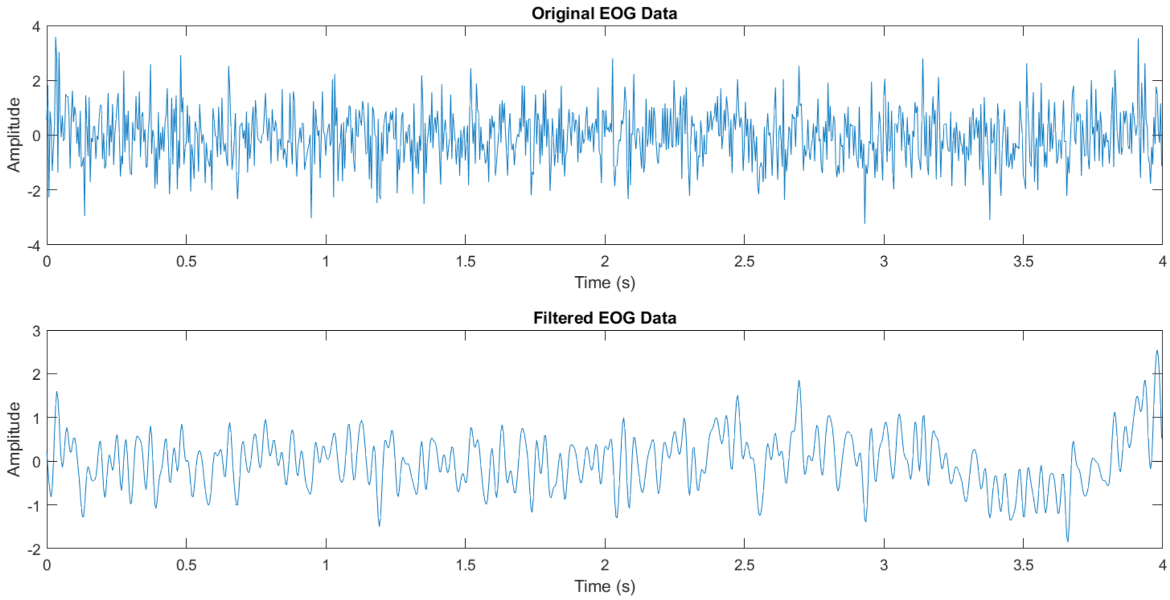

Figure 7: Original EOG Data with Filtered EOG Data.

2.3. Assistive Keyboard Design

The virtual keyboard is a 5x5 grid. Cursor movement is determined by comparing EOG signal deviations against set thresholds: exceeding positive or negative thresholds for horizontal signals shifts the cursor right or left, while vertical signal thresholds move the cursor up or down. An initial stabilization period minimizes transient noise by allowing the EOG signals to settle. Real-time position updates are displayed on the graphical user interface (GUI). When the EOG signals stabilize within a narrow range, indicating a steady gaze, the character at the current cursor position is selected and added to the output message. This method ensures reliable text entry by interpreting only significant and deliberate eye movements, demonstrating the effectiveness of EOG-based input systems. Designed virtual keyboard is displayed in Figure 8.

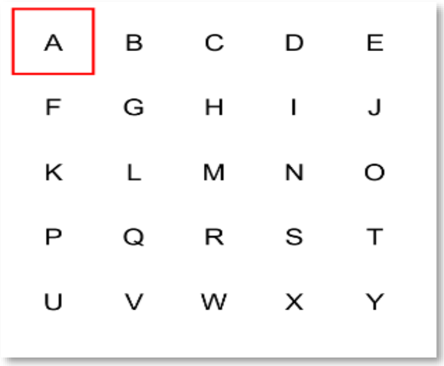

Figure 8: Virtual Keyboard Designed in MATLAB.

Where there another keyboard example that is different starting from the matrix to choosing letters by double blinking and the red rectangle highlight is created to show the currently selected key [13]. This variation provides another efficient method for selecting characters using eye movements.

3. Results

The captured EOG data was successfully translated into text messages, demonstrating the system's capability to control the virtual keyboard through eye movements. The virtual keyboard responded to the EOG signals by navigating according to the detected directions, with letters being selected when the gaze remained fixed longer on specific letters (e.g., U, Y, E, A). This approach was employed to evaluate the system's effectiveness in different scenarios. Notably, the letter 'X' was initially missed but subsequently recorded, which may be attributed to transient or uncontrolled eye movement steps.

As a result of the measurement, a message was successfully recorded based on the selected directions and the letters on the virtual keyboard model, as depicted in Figure 9.

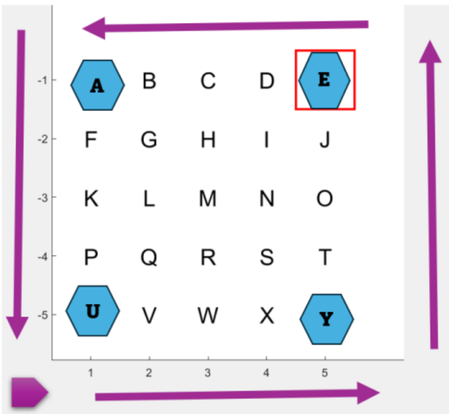

Figure 9: Virtual Keyboard with the Chosen Directions.

Due to the inherent difficulty in capturing each letter in precise order, some unintended letters appeared in the message. For instance, the letter 'X' was initially skipped but subsequently included, likely due to uncontrolled eye movement during the process. This observation highlights the challenges in achieving exact letter selection and suggests areas for improving system accuracy. Sample recorded message is shown in Figure 10.

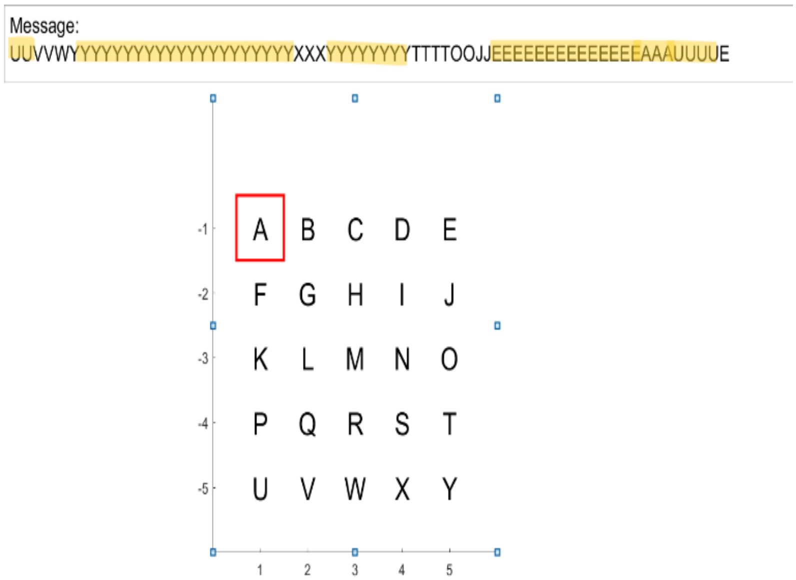

Figure 10: A Message Recorded by EOG Showing the Wanted Letters Followed by the Chosen Directions.

4. Discussion

The EOG signals captured during this study demonstrated good quality post-filtration, as illustrated in Figure 7 and summarized in Table 1. The initial results, based on data from a single participant, underscore the system's potential. However, greater efficacy can be achieved through training in a specific keyboard layout. This contrasts with the study by Keskinoglu and Aydın, where repeated trials by the volunteer led to improved control and accuracy in recording specific messages [1].

While our 5x5 grid keyboard is straightforward, it requires enhancements to broaden its functionality, such as incorporating numbers. This is similar to the approach taken by Teja et al., who used a 5x6 grid with an additional column for control functions [14]. Other studies, like those by Barbara et al., employed standard QWERTY keyboard layouts, organizing various symbols into comprehensive menus, demonstrating diverse design possibilities for virtual keyboards [3]. Furthermore, integrating our keyboard with a computer system for varied applications could enhance its utility, as seen in the work by Donchin et al., where eye movements controlled computer operations [15]. Additional improvements can be made by focusing on increasing accuracy and speed. This aligns with findings from studies achieving near-perfect accuracy and typing speeds of up to 10 characters per minute [16]. For instance, Tangsuksant et al. reported an average typing speed of 129.35 seconds per word for the word "HELLO" [7].

Although our system could capture the letters by employing a method that follows specific directions and timings to select letters based on the keyboard design, it is evident that further refinements are needed. Future investigations should focus on optimizing the system for faster eye movements and more precise control over virtual environments, with the goal of achieving higher accuracy and greater typing speeds. This will involve additional experiments with multiple volunteers to validate and enhance the system's performance.

5. Conclusions

This study focused on developing novel techniques to facilitate communication through speech or typing by translating EOG signals into messages. The result was a message recorded by EOG, displaying the desired letters according to the chosen directions. These preliminary results indicate that with repeated measurements, especially for individuals diagnosed with eye diseases, the system could be significantly improved.

The success of this work opens new possibilities for enhancing the quality of life for people with disabilities and improving the robustness of security protocols. The EOG-based virtual keyboard system offers notable advantages, particularly in providing a non-invasive, cost-effective communication method for individuals with severe physical disabilities. It enables text input using eye movements, making it accessible and customizable to individual needs. The system is portable and provides real-time feedback, enhancing usability. However, the system has drawbacks, including susceptibility to signal noise and artefacts, which can lead to incorrect inputs. Additionally, the input speed is slower than traditional methods, and prolonged use may cause eye strain. Despite these challenges, refining the technology and training protocols can significantly enhance its effectiveness as a communication aid.

Future research could focus on further improving the accuracy and user-friendliness of the system, as well as exploring additional applications of EOG-based technology.

6. Declarations

6.1. Study Limitations

Data (preliminary results of the system, limited number of volunteer data).

6.2. Acknowledgements

The authors thank to BIYOTAM researchers and students for their contributions at Sakarya University of Applied Sciences.

6.3. Funding source

There is no Funding source.

6.4. Competing Interests

There is no conflict of interest in this study.

6.5. Authors' Contributions

All authors: developing ideas for the research, planning the materials and methods to reach the results, taking responsibility for the experiments, organizing and reporting the data, taking responsibility for the explanation and presentation of the results, taking responsibility for the literature review during the research, taking responsibility for the creation of the entire manuscript, reworking not only in terms of spelling and grammar but also intellectual content or other contributions.

All authors: developing ideas for the research, planning the materials and methods to reach the results, taking responsibility for the creation of the entire manuscript, reworking not only in terms of spelling and grammar but also intellectual content or other contributions.

References

[1] C. Keskinoğlu and A. Aydin, "EOG – Based Computer Control System for People with Mobility Limitations," *Europan Journal of Science and Technology*, Jun. 2021, doi: 10.31590/ejosat.948124.

[2] A. N. A. Gul, M. Sahin, T. Kandis, K. Kavrak and Z. Oner, "Robotic Arm Control Using Machine Learning-Based EOG Signal Classifier," *2023 Medical Technologies Congress (TIPTEKNO)*, Famagusta, Cyprus, 2023, pp. 1-4, doi: 10.1109/TIPTEKNO59875.2023.10359205.

[3] N. Barbara, T. A. Camilleri, and K. P. Camilleri, "EOG-based eye movement detection and gaze estimation for an asynchronous virtual keyboard," *Biomedical Signal Processing and Control*, vol. 47, pp. 159–167, Jan. 2019, doi: 10.1016/j.bspc.2018.07.005.

[4] A. B. Usakli and S. Gurkan, "Design of a novel efficient Human–Computer interface: an electrooculagram based virtual keyboard," *IEEE Transactions on Instrumentation and Measurement*, vol. 59, no. 8, pp. 2099–2108, Aug. 2010, doi: 10.1109/tim.2009.2030923.

[5] A. Anandika, P. D. Laksono, M. S. A. B. Suhaimi, J. Muguro, and M. I. Rusydi, "Enhancing interface efficiency: Adaptive virtual keyboard minimizing keystrokes in Electrooculography-Based control," *Jurnal Nasional Teknik Elektro*, pp. 64–72, Dec. 2023, doi: 10.25077/jnte.v12n3.1160.2023.

[6] F. Fang and T. Shinozaki, "Electrooculography-based continuous eye-writing recognition system for efficient assistive communication systems," *PLoS ONE*, vol. 13, no. 2, p. e0192684, Feb. 2018, doi: 10.1371/journal.pone.0192684.

[7] W. Tangsuksant, C. Aekmunkhongpaisal, P. Cambua, T. Charoenpong, and T. Chanwimalueang, "Directional eye movement detection system for virtual keyboard controller," 2012. https://www.semanticscholar.org/paper/Directional-eye-movement-detection-system-for-Tangsuksant-Aekmunkhongpaisal/3bc91bde3c0d8101a2745a17de2f518c7927f2f5

[8] Z. Lv, X.-P. Wu, M. Li, and D. Zhang, "A novel eye movement detection algorithm for EOG driven human computer interface," *Pattern Recognition Letters*, vol. 31, no. 9, pp. 1041–1047, Jul. 2010, doi: 10.1016/j.patrec.2009.12.017.

[9] J. Heo, H. Yoon, and K. Park, "A novel wearable forehead EOG measurement system for human computer interfaces," *Sensors*, vol. 17, no. 7, p. 1485, Jun. 2017, doi: 10.3390/s17071485.

[10] International Engineering, "KL-730_10603," *Scribd*.

[11] M. Trikha, A. Bhandari and T. Gandhi, "Automatic Electrooculogram Classification for Microcontroller Based Interface Design," *2007 IEEE Systems and Information Engineering Design Symposium*, Charlottesville, VA, USA, 2007, pp. 1-6, doi: 10.1109/SIEDS.2007.4373994.

[12] M. Merino, O. Rivera, I. Gómez, A. Molina and E. Dorronzoro, "A Method of EOG Signal Processing to Detect the Direction of Eye Movements," *2010 First International Conference on Sensor Device Technologies and Applications*, Venice, Italy, 2010, pp. 100-105, doi: 10.1109/SENSORDEVICES.2010.25.

[13] H. S. Dhillon, R. Singla, N. S. Rekhi and R. Jha, "EOG and EMG based virtual keyboard: A brain-computer interface," *2009 2nd IEEE International Conference on Computer Science and Information Technology*, Beijing, China, 2009, pp. 259-262, doi: 10.1109/ICCSIT.2009.5234951.

[14] S. S. S. Teja, S. S. Embrandiri, N. Chandrachoodan and Ramasubba Reddy M., "EOG based virtual keyboard," *2015 41st Annual Northeast Biomedical Engineering Conference (NEBEC)*, Troy, NY, USA, 2015, pp. 1-2, doi: 10.1109/NEBEC.2015.7117201.

[15] E. Donchin, K. M. Spencer and R. Wijesinghe, "The mental prosthesis: assessing the speed of a P300-based brain-computer interface," in IEEE Transactions on Rehabilitation Engineering, vol. 8, no. 2, pp. 174-179, June 2000, doi: 10.1109/86.847808.

[16] Anjaliagarwal, "GitHub - anjaliagarwal8/EOG-Keyboard: EOG(Electrooculogram) based virtual keyboard can assist people with motor neuron disease to communicate effectively.," *GitHub*.