Dwell-Free Typing Using an EOG Based Virtual Keyboard

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Abstract. This work presents the development of an asynchronous dwell-free virtual keyboard application which can be operated using electrooculographic (EOG) data. Unlike other EOG based eye typing applications, the developed system avoids the use of dwell-times and relieves the user from the need to perform repetitive and unnatural eye movements to move a cursor towards the desired letter or the need to perform voluntary blinks to interact with the application. Instead, the proposed application requires the user to simply glance through the vicinity of the desired letters, as one would swipe through letters when typing on a touchscreen device, after which a set of word predictions are displayed for the user to select. The proposed application obtained a top five rate of $76.00 \pm 12.61\%$ using EOG data which is comparable to the top five rate of $79.00 \pm 13.37\%$ obtained when operating the application using a vision-based eye gaze tracker.

Keywords: Electrooculography · Eye typing · Virtual keyboard

1 Introduction

Gaze controlled virtual keyboards offer individuals with mobility impairments an alternative mode of communication through which one can edit documents, send emails, and participate in online chat rooms. In recent years, such human-computer interface (HCI) typing systems have been developed using videooculography (VOG) based techniques which operate through a vision-based eye gaze tracker that estimates the pixel coordinates of the point of gaze (POG) of the user on a computer screen. Although VOG based systems offer good resolution, they can be an economically unviable option for certain individuals and their performance is affected by different lighting conditions [1]. On the other hand, EOG can offer an alternative solution to human eye gaze tracking. It is based on the human eye behaving as an electrical dipole between the cornea and the retina which respectively maintain a positive and negative potential. This corneo-retinal potential (CRP) is oriented with the line of sight of the user and ranges from 0.4 to 1.0 mV [1]. This electrical activity is monitored through the use of non-invasive surface electrodes which are placed in close proximity to the human eye.

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In the literature, most EOG based eye typing applications are cursor-based implementations which operate directly on the saccadic activity of the user to move a cursor towards a desired letter in a step-wise manner [2–4] or perform eye movements originating from the center of the keyboard towards the periphery of the application [5]. Such implementations support four-directional or eight-directional cursor locomotion whereby cursor movement is based on the direction and amplitude of the user's saccades recorded in the electrooculogram. Finally, key selection is often executed through a voluntary blink [2–4].

On the other hand, the EOG based implementation of Barbara et al. [6] supports a dwell-based mechanism and permits the user to operate the application in an asynchronous manner. While operating this application, the user is required to fixate on each key for a stipulated period of time known as the dwell time. For example, in order to type in the word *'the'*, the user would need to dwell on three separate individual letters and fixate upon each letter until the set dwell time is elapsed for each letter. In such systems, the dwell-time simulates the standard click used in conventional systems however heavily limits the typing speed users can achieve.

Reducing the set dwell-time can have a positive impact on the user's text entry rate however it makes the user's input heavily susceptible to the Midas Touch problem where the user's gaze is simultaneously used for vision and to actuate a command, hence leading to more mis-selections. Alternatively, dwell-free systems employ a different technique whereby the user does not need to fixate on each letter for a stipulated period of time. Instead, such systems operate on the eye gesture of the user traversing through the desired keys without requiring the user to interface with each individual key for a stipulated period of time. Such systems offer a natural mode of interaction however, they have only been developed using VOG as an eye movement recording technique.

To this effect, the main contributions of this work include an analysis on the manifestation of EOG data recorded while typing in a dwell-free manner, the implementation of the LCSMapping algorithm [7], which is a state-of-the-art approach for dwell-free typing and its fine tuning to operate with EOG-based POG estimates, and the development of a real-time eye controlled virtual keyboard application that can be operated through EOG data in a dwell-free manner. The performance achieved using the data collected from ten participants will be compared to a VOG based alternative.

The rest of this paper is organized as follows. Section 2 describes the hardware framework used for data collection and the adopted experimental protocol. Section 3 outlines the manifestation of eye movements while typing in a dwell-free manner whilst Sect. 4 provides an overview of the adopted dwell-free typing mechanism to operate using EOG data. Finally, Sect. 5 concludes this paper.

2 Hardware Framework and Data Acquisition

Ten subjects (mean age 23.8 ± 2.32 years) participated in this study which was approved by the University Research Ethics Committee (UREC) at the University of Malta. Subjects were positioned at a distance of approximately 50 cm away from a 24-inch LCD computer screen which displayed the virtual keyboard application. Subjects' EOG data was recorded using the g.tec g.USBamp biosignal amplifier in conjunction with the conventional electrode setup as shown in Fig. 1. The latter consists of six surface electrodes connected in close proximity to the user's eyes. Specifically, the electrodes labelled '1' and '2' are placed above and below the human eye and record EOG data attributed to the vertical EOG channel, whereas electrodes '3' and '4' are connected to the outer canthi of the user's eyes and record data attributed to the horizontal EOG channel. Finally, a reference electrode 'R' is positioned behind the ear whilst a ground electrode labelled 'G' is placed at the top of the user's forehead. These electrodes detect changes in the electrical potential on the user's skin surface which shed light on the size and direction of the user's eye movements. On the other hand, VOG data was recorded using the SMI RED500 vision-based eye gaze tracker from SensoMotoric Instruments. This eye gaze tracker directly provided the estimated pixel coordinates of the user's POG on the screen. During data collection, subjects were instructed to perform different dwell-free eye gestures using the virtual keyboard design developed for this study. Subjects were instructed to input a total of twenty words in a dwell-free manner using each eye movement recording modality. These words were randomly selected from the Corpus of Contemporary American English (COCA) [8].

The virtual keyboard designed for this study is shown in Fig. 2. This consists of a writing bar together with five-word prediction sections in the second row which are designed to operate in tandem with the dwell-free typing mechanism explored in this work. Due to its widespread use, the keys were designed to support a QWERTY layout with which users are familiar, allowing them to locate the desired keys with ease and ensuring an optimal user experience. While operating the virtual keyboard, visual feedback was provided, by momentarily highlighting the closest key to the user's POG. This mechanism enabled user interaction and also mitigates the Midas touch problem since the user can avoid selecting undesired keys. Throughout the data collection procedure, participants were instructed to dwell upon the first letter for a short period of time until this is highlighted in red, traverse through the remaining desired letters in a dwell free manner and finally dwell on the last letter until this is selected. This interaction enables the user to demarcate the start and end of a dwell-free eye gesture and was used to filter the lexicon when retrieving the potential word candidates.

The vision-based eye gaze tracker used in this study provides the estimated pixel coordinates of the user's POG on the computer screen. In turn, this data was directly used to operate the virtual keyboard application and accordingly highlight the closest key to the user's POG. On the other hand, the EOG electrodes registered the change in potential while performing the eye gesture to type a word, which in turn had to be processed to estimate the gaze angles corresponding to the user's POG. In order to carry out the latter, this study adopted the work of Barbara et al. [9] which estimates the horizontal gaze angle θ_h and vertical gaze angle θ_v of the user's POG. Based on the resolution of the screen being used and the distance of the user from the screen, the gaze angles were converted to the pixel coordinates of the user's POG on the screen using a trigonometric model.

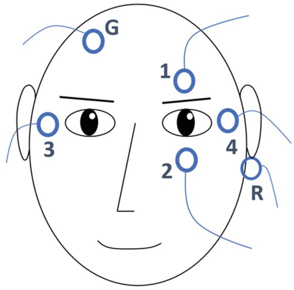

Fig. 1. EOG electrode configuration used.

3 Manifestation of Eye Movements While Dwell-Free Typing

The goal of this section is to show the nature of the EOG data while dwell-free typing, where the user is not required to fixate upon each key for a stipulated period of time but glance through the vicinity of each key in a rapid sequence instead. As the user is performing this eye gesture, he/she momentarily fixates upon the desired keys, generating what are known as quasi-fixations. These quasi-fixation periods occur naturally, as they are situated between the end of one saccade as the user's POG approaches the desired key and the start of another saccade as the user directs his/her POG towards the next key. These quasi-fixations shed light on the user's typing intent since more sample points are collected in the vicinity of the 'intended letter' candidates [7]. Figure 2 demonstrates such instances, where the intended letters have an abundance of POG estimates located within their respective key area.

When typing in a dwell-free manner, the user is also likely to select the neighboring key of the desired target thus registering a neighbour letter error [7]. There are various reasons why this happens, one of which depends on the POG estimation framework which may, in time, degrade in accuracy due to the accumulation of errors resulting from the continuous drift typical in EOG signals [6]. Moreover, neighbour letter errors also manifest themselves in the occurrence of saccadic overshoots and undershoots whereby the user's POG misses the desired target and thus falls on a neighboring key. In most cases, neighbour letter errors are followed by a corrective saccade through which the user directs his/her POG back to the desired letter. For example, while travelling from the letter 'U' (labelled as '6') towards the letter 'S' (labelled as '7') in Fig. 2, the user's POG landed on the letter *'D'* after which a corrective saccade was performed. Finally, while the user is traversing from one letter to the next, some POG estimates fall on letters in between the two desired keys. These are referred to as extra letter errors. Such instances can be noted in Fig. 2 where POG estimates on the letters *'Y'* and *'U'* were collected as the user's POG was travelling from the letter '*R*' (labelled as '3') towards the letter *'I'* (labelled as '4'). These extra letter errors occur with a low occurrence rate as they are situated within a saccadic region where the user is not maintaining a relatively fixed POG.

The next step would be to implement an algorithm which can exploit the information in the recorded eye gesture to determine the desired word that the user wanted to type, while also handling the resulting neighbour and extra letter errors. For this aim, the LCSMapping algorithm [7] will be used which will also be fine-tuned to handle EOG-based POG estimates as discussed in the next section.

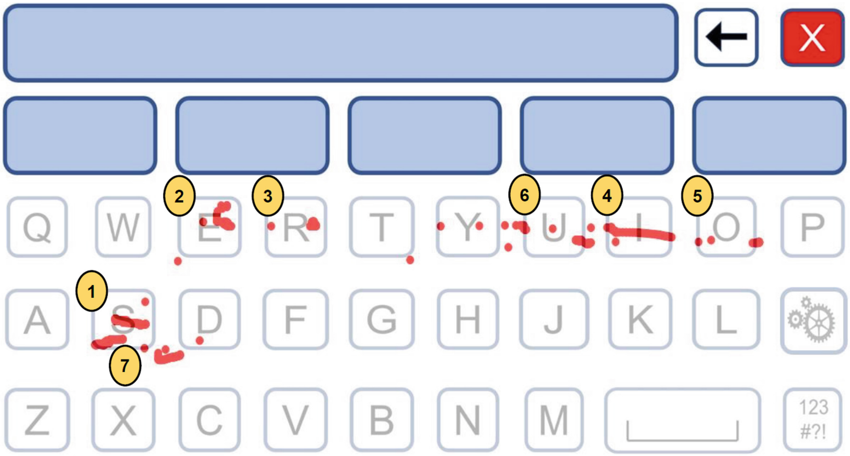

Fig. 2. Graphical illustration of the user's POG while dwell-free typing the word 'SERIOUS' on the designed virtual keyboard.

4 Adaptation of the LCSMapping Algorithm

The LCSMapping algorithm is a robust dwell-free typing algorithm developed by Liu et al. [7] which uses eye gaze tracking data obtained through a VOG based eye gaze tracker to identify the intended letter typed by the user. This algorithm regards the user's input as an '*observable transition*' which is constituted by the different letters ('*observable states*') selected by the user's eye gesture. This observable transition is then compared to each potential word in the lexicon in order to determine their resemblance. The latter is carried out by constructing a 2-D table where the first row corresponds to the observable transition whilst the first column corresponds to the considered potential transition from the dictionary [7]. The latter are then compared, and each corresponding cell is populated based on the following three conditions:

I. Same letter condition: If the states being compared between the observable and potential transition are identical, the corresponding matrix cell is populated with the occurrence rate value of that particular state.
II. Neighbour letter condition: If the states being compared between the observable and potential transition are neighbouring letters, the corresponding matrix cell is populated with the occurrence rate value of that particular state multiplied by a neighbour weight w.

III. Extra letter condition: If the states being compared do not satisfy the neighbour letter or same letter condition, the cell is populated with a value of zero.

These three conditions show how the LCSMapping algorithm handles neighbouring or extra letter errors by employing the weight w or assigning a zero respectively. In this work, the goal is to use the LCSMapping algorithm using eye gaze tracking data as captured through EOG instead of VOG. Given the stream of EOG-based POG estimates, the sequence of selected letters could be determined and was translated into <*l, t*> tuples where '*l*' corresponds to the selected letter whilst '*t*' corresponds to the occurrence rate of that particular letter. After running the LCSMapping algorithm on this data, its performance is measured through the top five rate which corresponds to the percentage of the desired words which were ranked in the top five recommended candidates by the algorithm.

4.1 Optimal Weight Estimation

Since in this work, the LCSMapping algorithm was made to operate using EOG-based POG estimates, an optimal neighbour weight parameter w had to be identified. The latter was determined by considering the data collected from the ten participants and running the LCSMapping algorithm to determine the top five rate for different neighbor weights w ranging from 0 to 0.9 in steps of 0.1. The results shown in Fig. 3 identify the optimal neighbour weight w to be equal to 0.1. A similar procedure was carried out using the VOG data of the same subjects, in which case the optimal weight was found to be 0.2 as implemented in [7].

4.2 Results

The performance of the LCSMapping algorithm using both EOG and VOG data from the ten participants was calculated and compared. The results are tabulated in Table 1. It can be noted that the LCSMapping algorithm achieved an average top five rate of 79.00 ± 13.37% and 76.00 ± 12.61% when operated using VOG data and EOG data respectively. These results show that despite the lower accuracy of POG estimates typically obtained with EOG data as compared to that obtained with VOG data [1], the LCSMapping algorithm still yields comparable performance. This shows that the latter manages to handle neighbouring letter error mappings well even though with the recorded EOG data, these are 1.8 times more frequent than those with the recorded VOG data. The choice of the neighbour weight w is also important. For VOG data this was found to be optimal at 0.2, which means that neighbouring letters contain relevant information for the detection of the intended word. For EOG data the optimal value was found to be 0.1, half of that used for VOG data, possibly because there are much more neighbour letter errors and hence are given less weighting. This procedure drives the number of common elements between the observable transition and potential transition to a maximum hence ensuring optimal performance of the dwell-free typing algorithm.

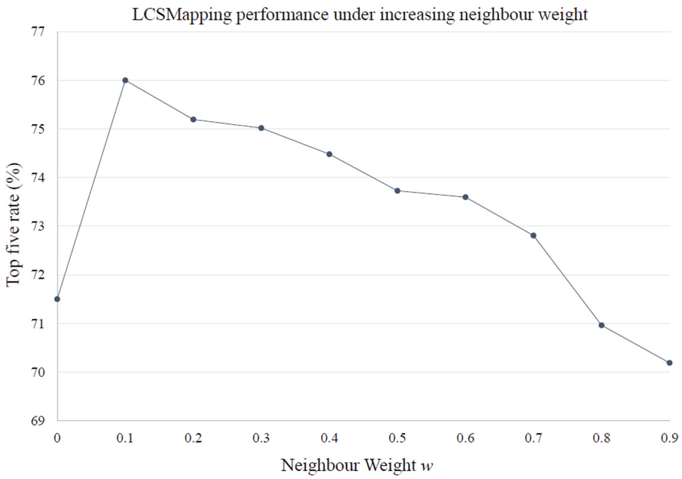

Fig. 3. LCSMapping performance under varying neighbour weight w using EOG data.

5 Conclusion

This work has presented the development of an EOG based dwell-free virtual keyboard application that relieves the user from the need to perform repetitive eye movements in order to input each character or dwell on each desired letter to select it. Instead, users can input a single word by sequentially glancing at the keys forming the desired word in a dwell-free manner. While providing a more natural mode of interaction, the proposed application also permits faster typing speeds since the use of dwell-times is only restricted to the first and last letter and for word prediction selection. In addition, the application can be operated in an asynchronous manner hence moving away from the need to perform specific actions during timed intervals or interacting with the application through saccades originating from the center of the virtual keyboard.

Subjects achieved an average top five rate of $79.00 \pm 13.37\%$ and $76.00 \pm 12.61\%$ when operating the application using VOG data and EOG data, respectively. In light of this, it can be noted that the LCSMapping algorithm [7] may be effectively tuned for EOG based dwell-free typing to compensate for the presence of selected letter errors which arise from the different levels of accuracy achieved from the two eye gaze tracking modalities. Given the small difference in the average top five rate, the proposed application makes the use of EOG signals as a viable alternative for operating an eye typing application. The achieved performance is expected to improve with increased subject familiarity with the typing application. Future work also aims to analyse the effect of the visual feedback provided in conjunction with the virtual keyboard layout used to help improve user interaction and system performance.

Table 1. Performance of the LCSMapping algorithm using VOG-based and EOG-based estimates.

Subject	Top five rate (%)	
	VOG	EOG
S1	95.00	70.00
S2	75.00	75.00
S3	80.00	55.00
S4	60.00	65.00
S5	90.00	90.00
S6	90.00	85.00
S7	55.00	95.00
S8	80.00	65.00
S9	95.00	90.00
S10	70.00	70.00
Average	79.00 ± 13.37	76.00 ± 12.61

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