ISSN 2394-3777 (Print)
ISSN 2394-3785 (Online)
Available online at www.ijartet.com

International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)
Vol. 4, Special Issue 11, March 2017

EYE TRACKING BASED VITRUAL KEYBOARD FOR DISABLED PEOPLE

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***Abstract*—new portable and noninvasive eye-trackers allow the creation of robust virtual keyboards that aim to improve the life of disabled people who are unable to communicate. This paper presents a novel multimodal virtual keyboard and evaluates the performance changes that occur with the use of different modalities. The virtual keyboard is based on a menu selection with eight main commands that allow us to spell 30 different characters and correct errors with a delete button. The system has been evaluated with 18 adult participants in three conditions corresponding to three modalities: direct selection using a mouse, with the eye-tracker to point at the desired command and a switch to select it, and with only the eye-tracker for command selection. The performance of the proposed virtual keyboard was evaluated by the speed and information transfer rate (ITR) at both the command and application levels. The average speed across subjects was 18.43 letters/min with the mouse only, 15 letters/min with the eye-tracker and the switch, and 9 letters/min with only the eye-tracker. The later provided 57.46 bits/min at the letter and command levels, respectively. The results show to what extent a drop of performance can occur when switching between several modalities. While the speed decreases when controlling the virtual keyboard with the eye-tracker only, the system's performance remains functioning for severely disabled people who have their gaze as one of their only means of communication.**

***Index Terms*—Eye-tracker, graphical user interface (GUI) design, human–computer interaction, performance evaluation, virtual keyboard.**

I.INTRODUCTION

Thanks to assistive technology, it is possible to propose new adaptive solutions that can improve the independence of people with disabilities. Assistive technology allows disabled people to perform essential daily tasks, which are necessary to live, work, and communicate with family members and friends. A large number of disabilities such as patients with neurolocomotor disabilities or amyotrophic lateral sclerosis are real challenges for care givers and assistive technology [1]. Patients with severe speech and motor impairment, who are not able to speak nor use sign language, require specific human–computer interfaces to communicate with the world [2], [3]. Depending upon the type of disability, communication devices have to be customized in relation to the constraints imposed by the user, from the adaptation of existing devices (e.g., keyboard, joystick), to the creation of advanced technologies (e.g., brain–machine interfaces in the case of locked-in patients [4]). Disabled people who are able to control their gaze can use their eyes as a means for communication (e.g., for controlling a wheelchair [5], [6]). In addition, the information obtained from the eyes reflects the psychological state of the user, and therefore, it can be used to detect fatigue.

An eye-tracker is a device that measures the person's eye features (e.g., gaze durations, gaze position, pupil size, saccadic velocities, and saccadic amplitudes [8]) and enables the analysis of a person's gaze. Different eye-tracking solutions have been available for decades [9], [10]. Invasive systems use special head wear (e.g., a head-mounted eye-tracking system [11]) or sensors placed on the subject [12], (e.g., electrooculography [13]), whereas noninvasive eye-trackers have no physical contact with the user. Furthermore, a key issue in interfaces with an eye-tracker is the measure of intention, which can be difficult to interpret. This is due to the amount of involuntary eye movements, which lead to the involuntary selection of items (the Midas touch [14]). A solution to this problem is to add some constraints such as the duration of attention on a particular item. In addition, it is possible to point at an item with the eye-tracker and to select the item with other input devices such as a switch. Another issue to manage with the use of the gaze is its un- natural procedure for selection as the gaze is typically used to only point at an item, i.e., an action is not directly implied. Furthermore, the communication of the observed item is achieved through another sense (e.g., motor action with finger-pointing, the voice).

A large number of methods have been discussed in the literature for gaze estimation, eye-tracking [15]–[19], and head movement detection [20]. Head movement detection can be required when the user can move their head during the experiment as opposed to the use of a chinrest, which is built to establish the position of the observer in psychophysical experiments. In fact, a robust eye-tracker should be able to track not only the gaze, but also the user's head position and orientation in order to avoid errors. These methods include adaptive calibration [21] and a limited number of calibration points [22], [23]. Furthermore, the performance is limited by the system itself, i.e., from eye- trackers using a common webcam to high quality eye-trackers with good optics [24]. Different eye-trackers are available in the market, offering various functionalities with a wide price range and precision. As some studies require a high level of precision to measure eye characteristics, such as saccades [25], [26], a precise eye tracking system is expensive. Due to the price, this type of system has not been developed, and authorities may be hesitant to fund expensive communication devices. Currently, a new market has emerged with relatively

ISSN 2394-3777 (Print)
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Available online at www.ijartet.com

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Vol. 4, Special Issue 11, March 2017

inexpensive remote camera-based eye-tracker solutions [27], [28]. With this non- invasive solution, the eye-tracker is placed near the computer screen. Hence, the user does not need to wear special glasses or any other device that includes
Despite pioneer works for the use of eye-tracker as a device for computer input [29], [30], the number of applications using eye-tracker for virtual keyboards remains limited. A reliable eye detection and tracking system is a key component in human–computer interaction as it allows us to better understand visual attention and the users' needs. Virtual keyboards represent the state-of-the-art application for testing novel human–computer interaction systems. Novel and adapted virtual keyboards still need to be developed to help a large number of disabled people to communicate and use a personal computer. When using virtual keyboards to assist a disabled person, the particular characteristics of the disabilities, such as the ability to press a button, or to control gaze, should be taken into account. Various systems have been proposed, in particular, brain–computer interface (BCI) using noninvasive electroencephalography (EEG) recordings has been a fundamental active research field for the development of virtual keyboards that allow severely disabled people to communicate [31]. Recent BCI systems include a combination of different modalities, such as eye-tracking [32]. Noninvasive BCIs based on the detection of event-related potentials, such as the P300, have been the pioneer application in this field. Most of the efficient BCIs require the user to control their gaze to select an item. This requirement is related to the detection of even-related potentials where the graphical user interface (GUI) of the P300 speller presents all the letters on the screen, and the user has to select an item by paying attention to the item [33]. BCIs using steady-state visual evoked potential detection are based on the same principle; the user has to look at an item on the screen in order to select it. BCIs based on motor imagery do not require gaze control to spell. However, the GUI for this type of BCI requires gaze control to read instructions presented on the screen, and to follow the feedback of the application. Despite the recent advances in BCI, the accuracy and the information transfer rate (ITR) remain too low to be widely used. In addition, other constraints include the price and the time that is required to prepare the subject to use a system. The BCI user has to wear an EEG cap or helmet in order to use a system. Overall, human–computer interface systems based on EEG signals are considered more difficult and less reliable approaches than eye tracking. Furthermore, the interest of BCI for disabled people is often justified only for a small population, such as locked-in patients, who have BCI as their only means of communication. [7] discussed about an eye blinking sensor. Nowadays heart attack patients are increasing day by day."Though it is tough to save the heart attack patients, we can increase the statistics of saving the life of patients & the life of others whom they are responsible for. However, the ability to control the gaze is least affected by disabilities. In fact, severe disabilities, such as spinal cord injuries, do not affect eye movement. Hence, virtual keyboards based on gaze detection can serve a potentially high number of patients and disabled people (e.g., quadriplegia).

a camera that points directly to one or both eyes. These inexpensive devices lead, therefore, to new interests in human–computer interaction systems using eye-tracking technology.

A key challenge to provide a reliable portable and affordable solution for a virtual keyboard based on gaze detection is the ability to take into account the constraints of the eye-tracker and human–computer interaction design. For instance, the layout of a regular keyboard can be an obstacle for its use with an eye-tracker because the proximity of the buttons increases the possible confusion of the gaze detection procedure. In this paper, we propose a virtual keyboard with only eight commands that work as a menu to spell 30 different letters. The system includes word completion and an additional command for corrections. The virtual keyboard requires two consecutive steps for enabling a command. First, the user has to point to the item that must be selected. A pointer on the screen can be moved to the chosen location, or a feedback can be provided on the chosen location. Second, the user has to approve the location of the pointer in order to select the corresponding item to enable a command. The main problem is related to the accuracy of the eye-tracker, which may limit the number of commands that can be accessible at any moment as the calibration data should be updated when the user changes his head and body position over time. The present study focuses on human–computer interaction issues with eye tracking and has the following two main contributions: First, it presents a novel robust virtual keyboard using gaze detection that also includes visual and audio feedback, and its evaluation on 18 healthy subjects; second, we evaluate the performance of the virtual keyboard in three conditions to assess the effect of different types of control on the GUI: the computer mouse, the eye-tracker and a switch, and the eye-tracker only. With only the eye-tracker, the user must gaze at the target item for at least a specific period of time (the dwell time), whereas with the eye-tracker and the switch, the user must gaze at the target item and validate the selection with a button. The remainder of the paper is organized as follows: The proposed virtual keyboard is first described in Section II; then, the experimental protocol is detailed in Section III. The results are presented in Section IV, and their implications are finally discussed in Section V.

II. SYSTEM OVERVIEW

The GUI of the virtual keyboard is composed of two main components: the center of the screen where the text is displayed, and the edge of the screen where the possible commands are displayed. A screenshot of the system is depicted in Fig. 1. The virtual keyboard is based on a tree selection with eight commands (c_1 to c_8) (see Fig. 2). A similar principle was applied in a virtual keyboard using the detection of steady-state visual evoked potentials [34]. The tree has two levels. In the first level, five commands (c_1 to c_5) are dedicated to the selection of the letters: "ABCDEF," "GHIJKL," "MNOPQR," "STUVWX," and "YZ_.?!."

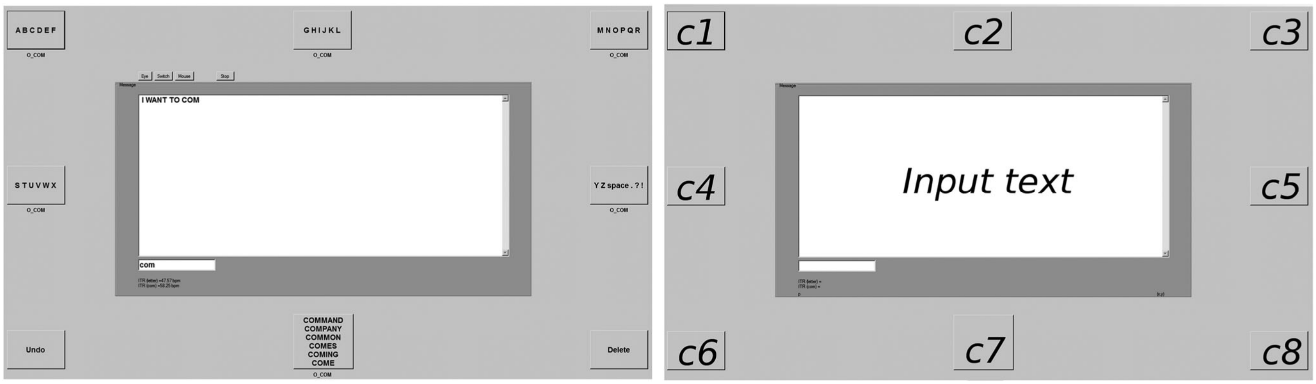

Fig. 1. Representative screenshot of the application (left) with the eight commands (from left to right, top to bottom) and their position (right).

By considering an equiprobability for the different commands and letters, the ITR is defined as follows: $\mathrm{ITR}_{com} = \log_2(M_{com}) \cdot N_{com}/T$, and $\mathrm{ITR}_{letter} = \log_2(M_{letter}) \cdot N_{letter}/T$, where N_{com} is the total num- ber of produced commands to spell N_{letter} characters. In addition, we provide the ratio R between the number of produced com- mands and the optimal number of commands to spell the input text (the double of the number of characters, including spaces, as each character requires two commands), $R = N_{com}/2N_{letter}$, $R \geq 1$. With a dwell time of 2 s, the maximum speed, ITR_{letter}, and ITR_{com} are 15 letters/min, 73.60 bits/min, and 90 bits/min, respectively.

IV. Results

The virtual keyboard performance is presented for the three conditions in Table I for copy spelling. The condition with the mouse provides the best performance with an average speed of 18.43 ± 3.62 letters/min. This condition is used as a baseline to assess the drop of performance that is achieved by changing the mouse, a common computer device that is familiar to all the subjects, to a different type of modality. With the eye-tracker and the button to select an item on the screen, the average speed is 15.26 ± 3.97 letters/min. With the eye-tracker only, the average speed decreases to 9.30 ± 1.07 letters/min. A Wilcoxon signed-rank test was conducted with a Bonferroni correction applied, showing that the mouse only provides a faster speed than the eye-tracker and the button, which is faster than the eye-tracker only ($p <$ 10e-3). The same pattern of performance is observed for ITR_{letter}, where the performance drops from 85.39 ± 15.75 with the mouse, to 71.72 ± 18.70 with the eye-tracker and button, to 44.96 ± 5.18 bits/min with the eye-tracker only. However, there is no difference of performance between the mouse and the eye-tracker with the switch for ITR_{com}. Moreover, for R, there is also no difference between the mouse ($R = 1.02 \pm 0.03$) and the eye-tracker ($R = 1.05 \pm 0.07$). These results show that subjects make more errors when they use the eye-tracker with the button compared with the two other conditions ($p <$ 10e-2), but these errors do not impact ITR_{com}. Finally, ITR_{com} is always greater

rs, and not to spell letters. The average time to produce a command is 1661 ± 971 ms when subjects use only the mouse and increases to 1810 ± 1031 ms when subjects

a pointer was use the eye-tracker with a button. With 3116 ± 1241 ms for the eye-tracker only, it shows that the chosen dwell time of 2 s was on average not too short.

In order to evaluate the gain of speed that may happen when two consecutive commands are on the same location, the different commands were clustered into two groups: those that were identical to the previous command $c_i(t) = c_i(t-1)$ $1 \leq i \leq 8$, and the rest. Pairwise comparisons in the three conditions with a Wilcoxon signed-rank test confirmed a significant difference in the three conditions between the two groups of commands ($p <$ 10e-4). The average time to produce a command at the same location as the previous one was 1476 ± 392, 1566 ± 428, and 2731 ± 356 ms for the mouse, the eye-tracker and the switch, and the eye-tracker only, respectively, compared with 1698 ± 333, 1865 ± 505, and 3223 ± 297 ms for other commands. During the free spelling condition, the average number of letters spelled-out was 13.11, with an average speed of 9.48 ± 1.42 letter/min, $\mathrm{ITR}_{com} = 57.46 \pm 5.25$ bits/min, and $\mathrm{ITR}_{letter} = 44.96 \pm 5.18$ bits/min. Posthoc analysis did not reveal any difference between free spelling and copy spelling. The corresponding decision points, i.e., the coordinates on the screen that were selected by the subjects, are presented in Fig. 3. They show the relative stability of the gaze detection and a sufficient precision from the eye-tracker with the proposed GUI.

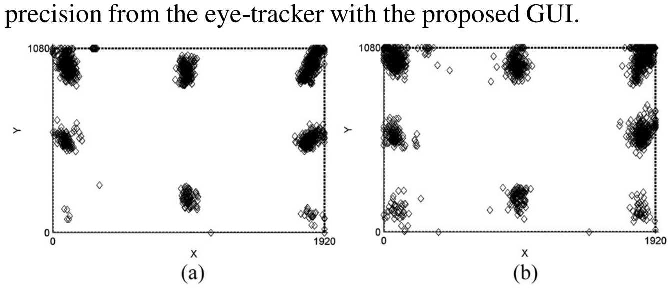

Fig. 3. Coordinates of the decision points obtained from the eye-tracker for all the subjects. (a) Eye-tracker + Switch. (b) Eye-tracker only.

V. Conclusion

In this paper, we have proposed a novel virtual keyboard based on a tree selection that includes word completion, visual, and audio feedback. The system can be used as a benchmark to evaluate different eye-tracking approaches. The system can be used with three modalities: with the mouse, the eye-tracker and a button, and the eye-tracker alone for both pointing at an item and its selection. The system was designed to take into account issues that can occur with a portable eye-tracker, offering a competitive performance with other assistive technology devices. The evaluation on 18 healthy adult participants has demonstrated the robustness of the system in both free spelling and copy spelling. Further works will include an extended menu selection with digits to write numbers and additional items to increase the possibilities of the system. Finally, a new study will be carried out to evaluate the performance with disabled people who will directly benefit from the application.

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