A Multimodal Interface to Resolve the Midas-Touch Problem in Gaze Controlled Wheelchair

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***Abstract*— Human-computer interaction (HCI) research has been playing an essential role in the field of rehabilitation. The usability of the gaze controlled powered wheelchair is limited due to Midas-Touch problem. In this work, we propose a multimodal graphical user interface (GUI) to control a powered wheelchair that aims to help upper-limb mobility impaired people in daily living activities. The GUI was designed to include a portable and low-cost eye-tracker and a soft-switch wherein the wheelchair can be controlled in three different ways: 1) with a touchpad 2) with an eye-tracker only, and 3) eye-tracker with soft-switch. The interface includes nine different commands (eight directions and stop) and integrated within a powered wheelchair system. We evaluated the performance of the multimodal interface in terms of lap-completion time, the number of commands, and the information transfer rate (ITR) with eight healthy participants. The analysis of the results showed that the eye-tracker with soft-switch provides superior performance with an ITR of 37.77 bits/min among the three different conditions (p<0.05). Thus, the proposed system provides an effective and economical solution to the Midas-Touch problem and extended usability for the large population of disabled users.**

I. INTRODUCTION

People who suffer from mobility disability face many difficulties in activities of daily living (ADL), which include feeding, toileting, dressing, grooming, and bathing [1]. A large set of assistive technologies has been developed to improve the life quality of these people, in particular, involving the powered wheelchair [2]. Several input modalities such as eye-tracking, electromyogram (EMG), electroencephalogram (EEG), and kinetic sensors have been exploited to control the wheelchair. The joysticks and sip-puff control devices are the most commonly used input methods, however, a joystick typically is unsuitable for upper-limb mobility impaired people whereas sip-puff control is non-intuitive [3]. Therefore, multimodal controls including eye-tracking, touch, and voice command have been explored to allow a maximum number of patients and people with disabilities to use efficiently a wheelchair [4].

Effective navigation has been achieved for wheelchair using a brain- computer interface (BCI) and head movement controller [5]. Current literature also suggests significant performance improvement for gaze-controlled based wheelchair controllers by incorporating free view solutions and scanning techniques [6], [7]. Augmentative and alternative communication (AAC) system has been developed using access switches [8]. These switches require minimal motor control and are available in a wide variety to be used by any active body part of the user i.e., hand, foot, mouth or head. In our previous studies, soft-switch has been implemented effectively with eye-tracking to design an AAC system [9], [10]. Furthermore, BCI devices have been implemented for rehabilitation of users upper-extremity in combination with eye-tracking where BCI and eye-tracking were used for continuous control of the exoskeleton device and decoding the user intentions, respectively [11]. Similarly, an eye-tracking device with combination of haptic feedback in virtual reality based games has been developed for rehabilitation purposes [12]. BCI is a fast growing technology and has become a nearly reliable type of control for building practical applications for rehabilitation and communication [13], [14]. However, numerous factors including lack of concentration, stress, and environmental noise can confound its performance in real-world situation [15].

On the contrary, as human gaze behavior is strongly correlated to user intentions, and has the potential to generate a large number of commands, eye-tracking devices have become a popular choice as an input modality. Towards further technological development, low-cost eye-tracking devices have been implemented successfully for replacing the mouse in the GUI and controlling the robotic devices [16]. Eye-tracker based wheelchair interfaces face major challenges for command selection wherein gaze and dwell time durations are used for pointing and selecting commands simultaneously. The command selection can be increased by choosing a short dwell time duration, although it may lead to false item selections due to involuntary eye movements, i.e., the Midas touch problem. Conversely, if the dwell time is too long, it can lead to the user discomfort.

To address the issues discussed previously, and increase the accessibility of a wheelchair control, the human-computer interaction system should include several modalities to allow different types of users to control a wheelchair in a convenient way. This work proposes a multimodal interface for people with upper-extremity mobility impairment such as those who cannot move their arms to control a powered wheelchair. The objective of the experiment is to observe the change in user performance during a wheelchair controlling task using different input modalities. Moreover, we proposed the multimodality function to overcome the Midas touch problem in wheelchair control thanks to the

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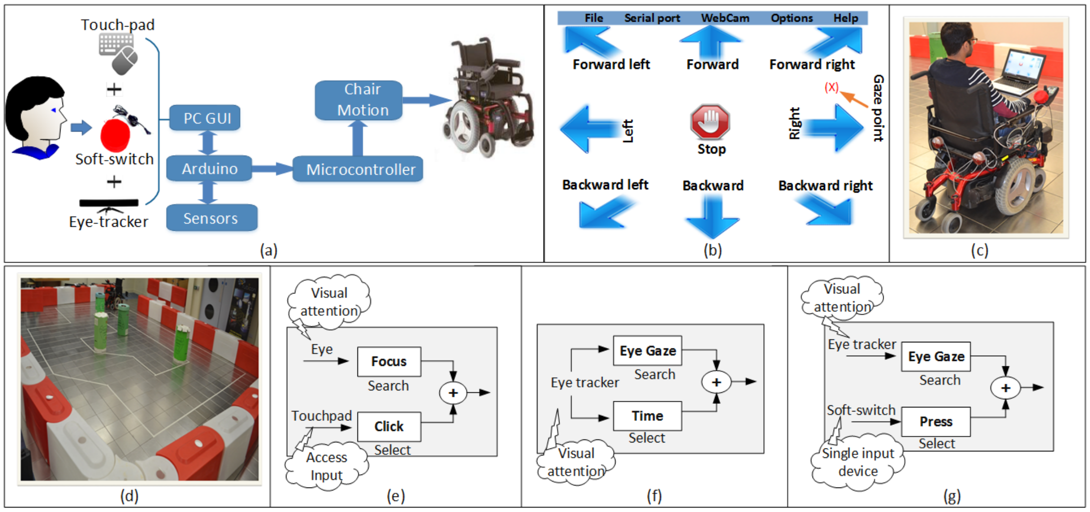

Fig. 1. System overview. (a) Block diagram of the proposed system, (b) Personal computer graphical user interface (PC GUI), (c) Organization of the system components, (d) View of the test trajectory, and (e-g) Proposed models of multimodal interface based on various input modalities, wherein the search and selection of the items are performed by (e) eyes without eye-tracker and laptop touchpad, (f) eye-tracker with dwell time, and (g) eye-tracker with soft-switch.

addition of a soft-switch, which can be accessed with any limb. The remainder of this paper proceeds as follows: Section II discusses the materials and methods, including the system overview along with the experimental protocol. Section III presents the results. Finally, Section IV discusses the significance of the work.

II. Material and Method

A. Participants

Eight healthy volunteers (mean age: 27.62±4.67, age range: 19-36 years) participated in this study. Four participants performed the experiments with vision correction. No participant had prior experience of using an eye-tracker, soft-switch, and powered wheelchair with the application. Participants were informed about the experimental procedure prior to the experiment. Furthermore, there was no financial reward provided for the participants. The Helsinki Declaration of 2000 was followed while conducting the experiments.

B. Multimodal Input Devices

Three different input devices were used in this study to control the powered wheelchair (see Fig. 1a). First, the touchpad of the laptop was used as a standard input modality. Second, a portable eye-tracker (The Eye Tribe Aps, Denmark) was used for pursuing the eye gaze of the participants [17]. Third, a soft-switch (The QuizWorks Company, USA) was used as a single-input device [18].

C. System Overview

Fig. 1a provides the block diagram of the proposed system. The system comprises of three major components: the input devices, a powered wheelchair, and a multimodal GUI. Input devices include an eye-tracker and a soft-switch. The eye-tracker is used to capture the point of gaze (POG) of the user and translate it into screen coordinates of a visual-display-unit (VDU), where the control panel for wheelchair navigation is displayed (see Fig. 1a). The eye-tracker is attached at the bottom of the VDU facing the direction of the users eyes (see Fig. 1c). The soft-switch is mounted on the right arm of the wheelchair on a movable arm rest, and the laptop is attached in front of the wheelchair on a horizontal platform (see Fig. 1c. The powered wheelchair consists of two active (center) and four passive (two rear and two front) wheels (see Fig. 1c. The active wheels are driven in differential mode for turning. The user can control the wheelchair by using the navigation control panel.

D. Data Acquisition

The eye-tracker data was recorded at a 30 Hz sampling rate. It involves binocular infrared illumination with spatial resolution (0.1 root mean square (RMS)), which records x and y gaze coordinates and pupil diameter for both eyes in mm. The soft-switch was used as a single-input device to select a command on the screen. Participants were seated in a wheelchair in front of the laptop screen. The distance between the participant and the laptop screen (FUJITSU, Bi-directional rotatable 13.3-inch, optimum resolution: 1280×800, 300 cd/m2, touch-screen) was about 400 mm.

E. Experimental Paradigm

The experimental protocol was designed to establish the feasibility of such a system in terms of testing all the functionalities and user interactions associated with the system. The basic functionalities of this system are eight navigation commands: moving forward (F), backward (B), left (L), right (R), forward-left (FL), forward-right (FR), backward-left (BL), backward-right (BR), and the stop command. The test was designed using test trajectory (see in Fig. 1d) where the users need to follow the track to reach the ending location (total travel distance was 16 m). There was a source location on the track where the wheelchair is located. There were three different combinations of the input modalities which provided three different conditions. The user had to complete the task with each of the modality.

First, the search of the target command was performed by the eyes and the participant used the touchpad to finally select the command (see Fig. 1e). Second, the eye-tracker was used for both search and selection purposes, participants focused the eye-gaze at the target command for a specific period of time, i.e., the dwell time, which results in the selection of that particular command (see Fig. 1f). Third, the eye-tracker along with the soft-switch was used in a hybrid mode wherein the user focused the eye-gaze to point to the target command, and the selection happens via a soft-switch (see Fig. 1g). The 2 s dwell time was considered during the whole experiment. With a wheelchair control panel using eye-tracking, it is necessary to provide an efficient feedback to the user that the intended command box has been selected in order to avoid mistakes and increase efficiency. A visual feedback is provided to the user as a change in the color of the border section of the observed command box. If the user observes a particular box for a duration of time t, the color of the border changes linearly in relation to the dwell time (Δt). The visual feedback allows the user to continuously adjust and adapt his/her gaze to the intended region on the screen. Thus, once a command button was pressed, the user can see the visual feedback, and then the control panel sends the command to the Arduino board using RS232 communication protocol, where an ATmega128 microcontroller based embedded system generates the control signals for wheelchair motion.

The view of an experimental test trajectory and a participant undergoing the test are shown in Fig. 1c-d. During the tests, the user interactions with the HCI were logged for analyzing the performance of the users in different experimental trials. A 9-point calibration scheme was applied to calibrate the eye-tracker prior to each experiment to estimate accurate POG. No pre-training session is required for the users. After each experiment, the user interaction log was kept in a database for analyzing the results.

F. Command Selection with the Eye-tracker

The command was selected based on the directed users gaze to the corresponding command box for Δt. The selection of a particular box is achieved by selecting the closest box using the Euclidean distance between the center of the box and the gaze coordinates. If the gaze coordinates remain in the same region, i.e., nearest to the target item, for Δt duration, then this particular item is selected. When the gaze coordinates change from one region to another in less than Δt ms, the timer for the selection is reset to zero.

The addition of the soft-switch with eye-tracking has helped to overcome the Midas touch problem, as the user can search the target command with the eye-tracker, and the selection can be done directly via the soft-switch. In other words, the searching of the command is done by the users gaze and selection is made directly and instantaneously through the soft-switch device. In the experiments, the soft-switch was pressed by the users dominant hand. Moreover, the color-based visual allow the user to continuously adjust and adapt his/her gaze to the intended region on the screen.

G. Performance Evaluation

Several performance indexes such as the total number of interactions, the lap completion time, and the information transfer rate were used to validate the system performance with powered wheelchair [19].

III. Results

For computing statistical significance, the Wilcoxon signed-rank test was applied using false discovery rate (FDR) correction method for multiple comparisons on performance indexes across the input modalities. The average lap-completion time (in second), the average number of commands, the average ITR (bit/min) for all three conditions (i.e., touchpad (TP), eye-tracker (ET), and eye-tracker with soft-switch (ETSS)) is presented in Fig. 2a-c, respectively. The TP condition (a common computer input that is familiar to all the participants) takes less time to complete the task with an average lap-completion time of 74.37±11.07 s. This condition was used as a baseline to measure the drop in performance from switching from a touchpad to another modality. The ETSS condition takes less time than ET condition ($p<0.05$). For instance, one participant took 233.45 s to complete the task with ET condition.

The average number of commands used in TP, ET, ETSS test conditions were 24±5.87, 29±4.65, 26.13±3.75, respectively. However, the TP condition used less number of commands among all the three conditions but ETSS condition required less number of commands compared to the ET condition ($p<0.05$). The average ITR with ETSS condition (37.77±9.7 bits/min) was found superior to TP and ET conditions ($p<0.05$). In particular, one participant achieved ITR of 57.81 bits/min. The ETSS condition provides a significant improvement in the ITR, which was about 14% higher than the ET condition. The overall results showed that the ETSS condition can be included to control the powered wheelchair.

IV. Discussion and Conclusion

The main focus of this study has been the current issues of gaze controlled powered wheelchair control, while incorporating multimodality with low-cost input devices. The effectiveness of the currently available systems is limited by Midas-Touch problem. The use of different modalities is key to improving the usability of a system that is principally aimed at people with severe disabilities. In addition to the type of the disability, the user must have the choice between several input controls for mastering the navigation of a wheelchair. After a severe injury, with issues related to depression, the graphical user interface must be optimized to reduce the stress of the user and maximize the performance. The proposed multimodal interface provides flexible modality options for the user to choose according to their needs. The major confounding factor to achieve high accuracy in

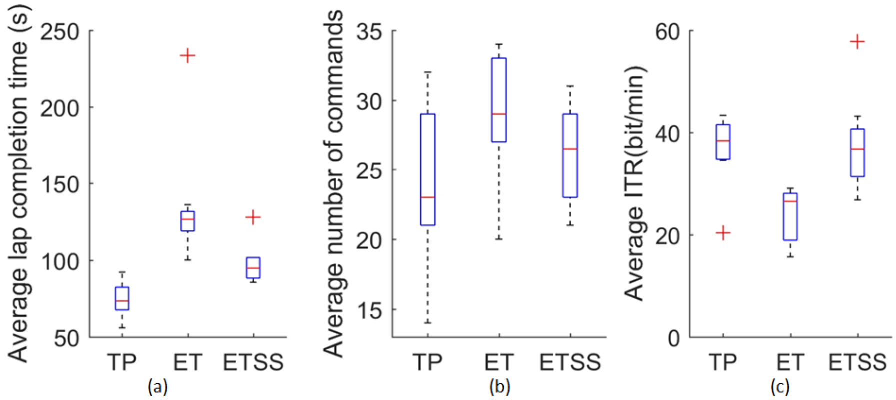

Fig. 2. Performance indexes across the three conditions (touchpad (TP), eye-tracker (ET), and eye-tracker with soft-switch (ETSS)). (a) The average lap-completion time (s), (b) The average number of commands, and (c) The average ITR (bits/min). *On each box, the central mark indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points not considered outliers, and the outliers are plotted individually using the '+' symbol.

an eye-tracker based system is the number of commands, which is further constrained by the quality of calibration method. We, therefore, optimized the size of the command button and the distance between them for increasing the robustness of the system to the involuntary head and body movements. This system also includes the real-time visual feedback for the users. The current limitation of this study is the limited number of commands but further these commands can be increased using tree-based menu [9] and, therefore, this concept can be utilized in designing AAC system for communicative and rehabilitative purposes for speech and motor impaired people.

The results of the present study support the conclusion that the performance of a gaze-controlled powered wheelchair can be significantly improvised by incorporating multi-modality with low-cost input devices. The proposed multimodal interface provides a simultaneous accessibility to an eye-tracker and a soft-switch device to improve the usability of the system. The soft-switch can be accessed by any limb of the user depending on their type of disability. The extension of the multimodal interface can be used to control any robotic device with powered wheelchair system [19], therefore, it can be used for powered wheelchair based rehabilitation of users upper-extremity using multimodal facilities. It is planned to enhance the flexibility of this multimodal interface further by synergistically adding a non-invasive BCI [20], [21], [22].

References

[1] A. Crawford *et al.*, "People with mobility impairments: Physical activity and quality of participation," *Disability and Health Journal*, vol. 1, no. 1, pp. 7–13, 2008.

[2] J. Wolff, C. Parker, W. B. Mortenson, and J. Mattie, "A survey of stakeholder perspectives on exoskeleton technology," *J. Neuroengineering Rehabil.*, vol. 11, no. 1, pp. 1–10, 2014.

[3] C. S. Lin *et al.*, "Powered wheelchair controlled by eye-tracking system," *Optica Applicata*, vol. 36, no. 2-3, pp. 401–412, 2006.

[4] R. Maskeliunas and R. Simutis, "Multimodal wheelchair control for the paralyzed people," *Elektronika ir Elektrotechnika*, vol. 5, no. 111, pp. 81–84, 2011.

[5] J. S. Nguyen *et al.*, "Experimental study on a smart wheelchair system using a combination of stereoscopic and spherical vision," in *Proc. of the IEEE Engineering in Medicine and Biology Society*, 2013, pp. 4597–4600.

[6] S. I. Ktena, W. Abbott, and A. A. Faisal, "A virtual reality platform for safe evaluation and training of natural gaze-based wheelchair driving," in *Proc. of the IEEE/EMBS Neural Engineering*, 2015, pp. 236–237.

[7] P. Biswas and P. Langdon, "A new input system for disabled users involving eye gaze tracker and scanning interface," *J Assist Technol*, vol. 5, no. 2, pp. 58–66, 2011.

[8] S. Bhattacharya, A. Basu, and D. Samanta, "Computational modeling of user errors for the design of virtual scanning keyboards," *IEEE Trans Neural Syst Rehabil Eng.*, vol. 16, no. 4, pp. 400–409, 2008.

[9] Y. K. Meena *et al.*, "A novel multimodal gaze-controlled hindi virtual keyboard for disabled users," in *Proc. of the IEEE Eng. in Systems, Man, and Cybernetics*, 2016, pp. 3688–3693.

[10] H. Cecotti, "A multimodal gaze-controlled virtual keyboard," *IEEE Trans. Human Mach. Syst.*, vol. 46, no. 4, pp. 601–606, 2016.

[11] A. Frisoli *et al.*, "A new gaze-bci-driven control of an upper limb exoskeleton for rehabilitation in real-world tasks," *IEEE Trans Syst Man Cybern C Appl Rev*, vol. 42, no. 6, pp. 1169–1179, 2012.

[12] S. Deng *et al.*, "Multimodality with eye tracking and haptics: a new horizon for serious games?" *International Journal of Serious Games*, vol. 1, no. 4, pp. 17–33, 2014.

[13] J. d. R. Millán *et al.*, "Combining braincomputer interfaces and assistive technologies: state-of-the-art and challenges," *Front Neurosci*, vol. 4, no. 161, pp. 1–15, 2010.

[14] D. Rathee *et al.*, "Estimation of effective fronto-parietal connectivity during motor imagery using partial granger causality analysis," in *Proc. of the IEEE IJCNN*, 2016, pp. 2055–62.

[15] R. Rupp, "Challenges in clinical applications of brain computer interfaces in individuals with spinal cord injury," *Front Neuroeng*, vol. 7, no. 38, pp. 1–15, 2014.

[16] F. Marcela *et al.*, "Hands-free interaction with a computer and other technologies," *Universal Access in the Information Society*, vol. 8, no. 4, pp. 277–295, 2009.

[17] "The eye tribe, copenhagen, denmark," https://theeyetribe.com/, accessed: 2015-06-01.

[18] J. Singh and G. Prasad, "Enhancing an eye-tracker based human-computer interface with multi-modal accessibility applied for text entry," *Int. J. of Computer Applications*, vol. 130, no. 16, pp. 16–22, 2015.

[19] Y. K. Meena *et al.*, "Emohex: An eye tracker based mobility and hand exoskeleton device for assisting disabled people," in *Proc. of the IEEE Systems, Man, and Cybernetics*, 2016, pp. 2122–2127.

[20] ——, "Towards increasing the number of commands in a hybrid brain-computer interface with combination of gaze and motor imagery," in *Proc. of the IEEE Eng. in Medicine and Biology Society*, 2015, pp. 506–509.

[21] ——, "Simultaneous gaze and motor imagery hybrid bci increases single-trial detection performance: a compatible incompatible study," 2015.

[22] D. O'Doherty *et al.*, "Exploring gaze-motor imagery hybrid brain-computer interface design," in *Proc. of the IEEE Bioinformatics and Biomedicine*, 2014, pp. 335–339.