A Step towards Affordable Gaze-sensitive Communication Platform for Disabled: Proof-of-concept Study

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***Abstract*—The elderly and disabled people with motor-impairment often experience limited mobility and speech problem. As a result, it robs away their independent living and makes them dependent on their caregivers for their day-to-day activities. They are often unable to express their needs and communicate with others, thereby getting alienated from the rest of the society. Expert therapists and well-trained nurses can help in addressing this problem. However, limited availability and high cost of availing such specialized services, especially in middle income countries like India, makes it difficult for most people to access these services. Thus, alternative technology-assisted solutions become critical. However, most of the existing technology are often costly and also does not address severe disability. In fact, most neurological disorders are often accompanied with paralysis, thereby making communication by gesturing/speaking a challenge for these individuals. Thus, eye gaze-based assistive technology which can serve as a communication platform can be a potent alternative. The currently available gaze-based solutions mostly need calibration and sometimes lengthy set-up process, which limits their applicability. In our present work, we have developed a computer assisted gaze-based communication platform that requires no calibration and has easy set-up capability. A preliminary pilot study performed with 10 healthy participants showed that our system has an average accuracy of 98% as far as reliable representation of user's choice is concerned. Our Usability study incorporated 4 stroke patients and the preliminary results are promising. Thus, this paves the way towards the design of a communication interface that has potential for use by the disabled.**

Keywords—Eye tracking; Disabled; Communication

I. INTRODUCTION

Elderly and disabled individuals often face a lot of challenges in their community lives due to limited mobility, inability to express their needs and in communicating with others. This disability often makes them dependent on caregivers. Sometimes families can afford to have nurses at homes to attend to the needs of these individuals having limited communication capabilities. These nurses are trained to understand the needs of the patients. However, given the scarce availability of adequately trained nurses [1] particularly in developing countries like India, the elderly and disabled are often deprived of adequate nursing support. This becomes critical given the high prevalence of such individuals. Estimates show that about 64/1000 rural elderly and 55/1000 urban elderly suffer from one or more types of disabilities, with loco-motor disability being the most common [2] thereby requiring them to communicate with their caregivers for assistance to satisfy their daily needs. According to the United Nations Population Division (UN 2011), the share of India's population aged 60 and older is projected to climb to 19 percent of the total population in 2050 [3]. Among the elderly population, many of whom can be rural with limited access to specialized healthcare centres, the possibilities of individuals suffering from severe disabilities who have lost their ability to voluntarily control the movements of their limbs [2] are more. Faced with limited availability of healthcare resources added to the high cost of availing specialized services [1] and restricted accessibility to often remotely located healthcare centres [4], researchers have been exploring alternative assistive techniques to help this target population.

With a motivation to help these elderly and disabled individuals to assist them in the execution of their day-to-day activities and in turn lead a self-sustained life, researchers had come up with several smart and sophisticated devices e.g. MYO arm band [5], Fin ring [6], Head band [7], voice recognition system [8], Camera Mouse [9], etc. The MYO arm band [5] senses the electrical activity in muscles that control hands and fingers, used to interact with computers without having the need to touch any input device. But, its use is restricted only for the people who are able to move their limbs effectively to make different controlling gestures. Fin is a wearable gesture based ring [6], which can detect swipes and taps of one's hand. However, it creates a limitation for people who are unable to voluntarily control their limbs, such as, Amyotrophic Lateral Sclerosis (ALS) and quadriplegia patients. A computer-based device [7] has been designed for allowing partially disabled individuals to use their head movements to type characters. The voice recognition system [8] serves as an alternative communication modality for those who find it difficult to control their limbs but still have ability to speak. However, this might still not be applicable for those suffering from severe motor disabilities and have difficulty in speaking in a way that can be deciphered by the machine. The Camera Mouse [9] is another system that can track various body features like lips, nose, thumb and the whole eye etc. with a video camera and translates the data into the movements of a pointer on the computer screen, just like a mouse pointer. This has been used for playing video games, accessing computer, typing and communication purposes. So, Camera Mouse is effective for those people who have control over their head, foot or hand. Thus, investigators have been exploring other modalities as a medium of communication for individuals with severe disability.

Literature indicates one's eye gaze as an additional modality by which a disabled individual can communicate with the external world [10] which is often operational and under voluntary control on a macro level of even ALS and quadriplegic patients [11]. Thus, under such circumstances, an eye gaze sensitive system may provide a critical assistive interface for communicating a patient's needs to the external world. The commercially available eye tracking systems include Tobii X60, X120, Tobii eyeX, Tobii Pro X2-30 Eye Tracker [12], Google glasses [13], etc., that can record eye movements with high accuracy are very expensive. Thus, there is a need to design a low-cost user-friendly eye gaze sensitive communication platform that can be used by the elderly and the physically challenged individuals.

There are certain challenges that are generally faced in eye tracking like accuracy, drift, calibration and the Midas-Touch problem (in which the user's intention is indistinguishable from the visual attention) [14]. The eyes cannot be used directly as a mouse, because they are never "off" [15]. In fact, one's eyes continually jump from one point to next on a visual stimulus, even when the person thinks he is looking steadily at a single object [15]. Thus, one of the main problems when using eye-gaze for selection purpose is to somehow combine it with a "clutch" that can engage/disengage eye-gaze control [16]. However, despite these disadvantages, using eye-gaze as an input modality is advantageous as it is very natural and presents an intuitive way of interaction [17]. One's eyes can be used as a computer peripheral for control purpose like a computer mouse. The eye interaction is typically faster than interaction with a mouse [10]. Also, it is found that the time required to move the eyes is hardly related to the distance to be moved, unlike most other input devices [16]. Literature indicates the use of eye gaze -computing systems by individuals who can't move their hands [10] [18]. Hence, eyes serve as an excellent input device, especially in field of Human Computer Interface (HCI) [15] [19].

Literature shows ample evidence of eye gaze being used as pointing device in HCI based applications, e.g., word typing [21] [22] [23], playing video games [25], controlling electrical appliances [21] [22] and for communication [21]. For example, Sewell and Komogortsev [20] developed a webcam based eye tracker while using artificial neural network However, these researchers mentioned limitations of their system being longer training time required by neural network and failure to detect eyes in presence of one's glasses. Again, another research group described a prosthetic device called ERICA (eye-gaze-response interface computer aid) which tracks one's eye movements applied for control, recreation and communication purposes [21]. This system, though very costly, is effective and allows the disabled to type text by gaze, browse internet, read and write emails, and play games. Eye word processor along with peripheral controller has been designed to assist ALS patients in typing words, controlling some appliances such as television, light and calling a nurse and writing sentences to communicate [22]. They have used Electro-oculography (EOG) where electrodes need to be attached around the patient's eyes which might not be comfortable to the patient. Additionally, it requires a 3-point calibration for its setup. Also, the selection of the desired region of interest was not user-friendly, since the selection was not made directly, but, instead, the user had to move through a series of steps in order to communicate his requirement. A powerful communication device called Eyemax [23] using eye gaze as input, has also been designed for ALS to write emails and to express their personal feelings. However, it is very costly. Yu-Luen et al. [24] have developed an eyeglass-type Infra-red (IR) controlled computer interface for the disabled, specifically for spinal cord injured (SCI) patients, to control the keyboard and mouse and operate a tongue-touch switch to be used as power switch. Kaufman et al. have presented an inexpensive eye-controlled user interface for interaction with video games [25]. However, they have used it for entertainment and not as a communication interface. In [26], a gaze-based interaction system for people with cerebral palsy has been designed for communication purposes. They have used SMI (SensoMotoric Instruments) iView X HED which is a head mounted eye tracker device. They have used an adaptive switch for enabling the selection of icon words which again requires the user to have good control over their hands. In spite of the fact that pioneering contributions have been made by the previous research studies who have applied one's eye gaze as a communication modality for individuals with disabilities, these studies have not demonstrated its applicability for patients with stroke who also have motor disorders. Additionally, they have not used a remotely located eye tracking mechanism that does not require preliminary calibration thereby making it less intrusive, user-friendly and also cost-effective.

Thus, in our work, we have designed a gaze-based user interface which can be used as a communication medium even by patients with severe motor disabilities and have restricted speaking capability, e.g., stroke. The patients are expected to communicate only with the help of their eyes. The objectives of this paper are two-fold, namely (1) To design a Gaze-sensitive user-friendly and cost-effective communication interface and (2) To present the results of a preliminary usability study designed as a proof-of-concept application and used by few stroke-affected individuals to understand the feasibility of such a communication platform for this population. In addition, we also present our observations from a pilot study involving healthy individuals to show the accuracy of our system to collect user inputs from eye gaze.

This paper is organized as follows: Section 2 presents the system design. Section 3 describes the methodology. In Section 4 we present the results and discussions. Conclusions and future work have been discussed in Section 5.

II. SYSTEM DESIGN

Our gaze-sensitive communication platform consists of (A) webcam-based module (B) graphical user interface (GUI) for data collection (C) hardware-software handshake module.

(A) Webcam based module.

In our present work, we have used a simple night-vision webcam to capture one's images. These images obtained from the webcam were first converted into grayscale images. Our algorithm detected the face region followed by detection of eyes' region by using Haar Cascade classifier. We have used Circular Hough Transform for localization of eye ball in the eyes' region and OpenCV libraries to extract gaze-related features [27]. Once the eye balls are localized, they are tracked by the webcam and our algorithm, developed in-house, is used to identify the movement of one's eye balls with respect to the visual targets/options shown on the screen. Fig 1 shows the schematic block diagram explaining the steps followed in our algorithm.

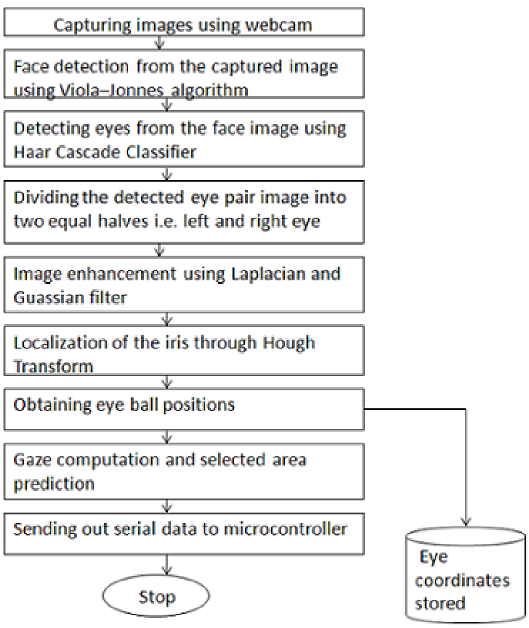

Fig. 1: Schematic block diagram of the algorithm

(B) Graphical User interface (GUI) for data collection

GUIs were designed using C++ to offer option choices to the participants on a computer (laptop) screen. Only three GUIs used text presented in two languages, namely, Hindi and English, for the option choices. The subsequent GUIs presented the option choices as relevant pictures. The participant was expected to communicate his option choice by fixating his gaze at the appropriate Region of Interest (ROI) specifying the option. Our algorithm was used to record the participant's 2D gaze coordinates. Based on the 2D gaze coordinates, our algorithm inferred the corresponding options (presented on the visual stimulus screen) being chosen by the participant. In response to the participant's option choice, our system spoke out the option choice by triggering a pre-recorded audio file. The audio feedback was kept loud enough, so that it can alert the caregivers or nurses attending the participant. Thus, this serves as a communication medium that is particularly helpful for the disabled who can't speak and communicate

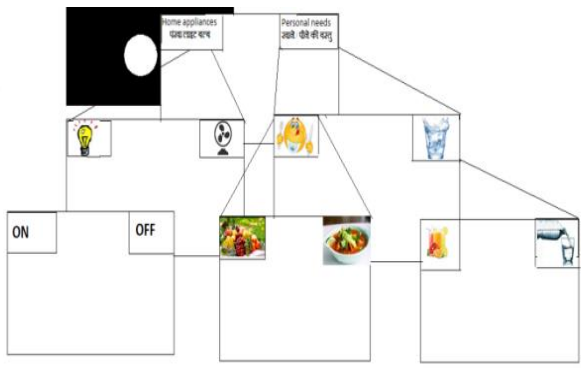

Fig. 2: Graphical user interface showing different screens

their needs. The first screen had two options, namely, 'home appliances' and 'personal needs'. If the participant chose 'home appliances', then our system offered the next screen displaying two options, e.g., light and fan (presented as pictures, as shown the Fig.2). Likewise, for 'personal needs', our system prompted 'hungry' and 'thirsty' options (presented as pictures, as shown the Fig.2). Once the user moved through the second screen, based on the options chosen, our system offered the corresponding third screen with the options as 'ON' / 'OFF' (presented as text, as shown the Fig.2) and some food items / drinks (presented as pictures, as shown the Fig. 2).

(C) Hardware-software Handshake Module

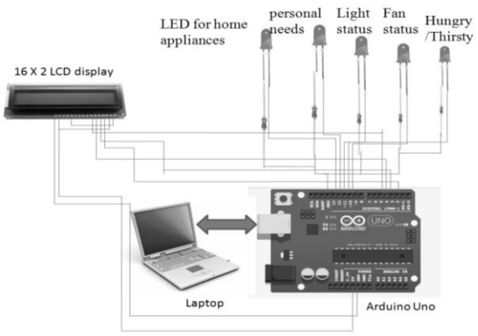

Fig. 3: Hardware Configuration

The Fig.3 shows the circuit diagram of the hardware configuration used comprising of task computer (laptop), Arduino Uno, Liquid crystal display (LCD) and few LEDs as output indicators. The task computer was used to present the visual stimuli as GUIs (section II (B)) to the participants. Additionally, the task computer was integrated with a webcam (section II (A)). The communication interface presented on the task computer was integrated with external peripherals through the Arduino Uno. The Arduino Uno [28] was connected to the task computer at the COM port and its digital pins were connected to the peripheral output devices. One output was 16 X 2 LCD display for presenting text messages and the other output was an array of LEDs representative of the option choices of the user. These LEDs can be used for providing the visual representation of the patient's choice to the caregiver.

III. Methodology

A. Participants

TABLE 1
HEALTHY PARTICIPANTS' CHARACTERISTICS

ID	AGE (Years)	DOMINANT SIDE
H1 (m)	28	Right
H2 (f)	23	Right
H3 (m)	25	Right
H4 (m)	25	Right
H5 (m)	25	Right
H6 (f)	30	Right
H7 (m)	25	Right
H8 (f)	27	Left
H9 (f)	27	Right
H10(m)	36	Right

Note: m:male; f:female

TABLE 2
STROKE PARTICIPANTS' CHARACTERISTICS

ID	AGE (Years)	POST-STROKE PERIOD (Years)	AFFECTED SIDE
P1 (m)	46	9	Right
P2 (f)	45	4	Left
P3 (m)	54	1.5	Right
P4 (m)	52	2	Right

Note: m:Male; f:Female

In our present work, we have designed a preliminary usability study to understand the efficacy of our gaze-based system to be used as a communication platform for users with motor disabilities, e.g., stroke who are often characterized by limited motor capability, difficulty in speaking, etc. However, before starting our usability study, we wanted to carry out a pilot study with healthy participants to understand whether our communication platform is capable of making reliable inference from one's gaze data. Tables 1 and 2 show the participants' characteristics.

B. Experimental set-up

The experimental set-up (Fig 4.) included (i) 64-bit laptop with screen resolution of 1366 x 768 pixels; (ii) a night vision low cost webcam (i-ball CHD 12.0 face2face) with a resolution of 640 x 480 pixels that was placed at the top of the laptop screen (Lenovo-G50 Intel® Core™ i3-4010U CPU @ 1.70GHz × 4, 64-bit OS) towards the center position. Room illumination was kept uniform throughout the study. Please note that in our preliminary study, the position of the webcam was kept at center-top of the computer monitor and all the visual stimuli were displayed by our system towards the top of the computer screen. The reason behind such placement of visual stimuli was that if users looked towards the bottom of the screen, a major portion of their eyes were occluded to

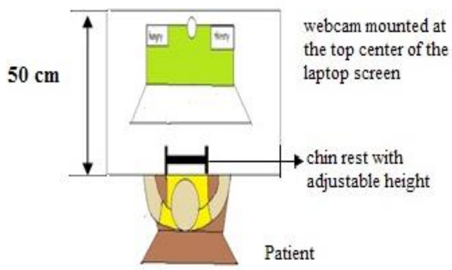

Fig. 4: Experimental setup block diagram

the webcam view, resulting in inappropriate representation of the user's actual 2D gaze coordinates by our system. In addition, our system did not need any calibration. However, the user was first asked to fixate at a visual stimulus (presented as a 'O') displayed at the center of the screen. The user's 2D gaze coordinates (X_{CENTER}, Y_{CENTER}) were then mapped to the center of the screen. Our system inferred the user's response to the presented option choices by comparing the participant's 2D gaze coordinates (X_{OPTION}, Y_{OPTION}) with the (X_{CENTER}, Y_{CENTER}).

C. Procedure

At the beginning of the experiment, the participant was asked to sit in front of the task computer. Then the experimenter explained the task that the participant was expected to perform by using a visual schedule. The participants were told that they can withdraw from the experiment whenever they felt uncomfortable. The experimenter then administered the signing of the consent form (by the caregiver of the patient). Then, the participant was asked to sit at a distance of approximately 50 cm from the screen. The participant was asked to use a chinrest for minimizing head movement. The experimenter then ensured that the participant's eyes were seen by the webcam. The entire study took approximately 2 min. At the end of the study, they were asked to rate their experiences and views on the ease of selection of the options, experience with the interface (GUI), ease of understanding the task and their overall experience with our system by using a 5-point scale.

D. Computation of Percentage Accuracy

$$\text{Percentage accuracy} = \frac{\text{Number of targets correctly hit}}{\text{Total number of targets}} \text{ X } 100\% \ldots\ldots (1)$$

In order to understand the reliability of our system in acquiring the information on the user's choice of options, we computed the percentage accuracy of our system, by using eq. (1), as far as the option choices (i.e., targets) displayed on the left top and right top of the computer screen.

IV. RESULTS AND DISCUSSIONS

A. System Acceptability

After the pilot trial with healthy participants, we carried out our usability study involving post-stroke patients. At the end of both the pilot and usability studies, the experimenter administered exit survey. Our intention was to find out whether our gaze-sensitive user interface was acceptable to our participants. We used a 1 - 5 scale for rating their feedback. Table 3 summarizes their feedback. On being asked the reason behind their feedback on 'ease of understanding the tasks', the participants said that they preferred the pictures being used to symbolize the option choices rather than only text (used in some of the GUIs). Thus, it can be seen from Table 4, that our system has feasibility of being accepted by the target population. In spite of being given the option of quitting from the study if uncomfortable with our system, all the participants completed the study. On being asked the reason behind their feedback on 'ease of understanding the tasks', the participants said that they preferred the pictures being used to symbolize the option choices rather than only text (used in some of the GUIs). Thus, it can be seen from Table 4, that our system has feasibility of being accepted by the target population. In spite of being given the option of quitting from the study if uncomfortable with our system, all the participants completed the study.

TABLE 3
POST-STUDY SURVEY FEEDBACK

S. No	**Attribute**	**5-point scale**	**Averag e rating by H1-H10**	**Average rating by P1-P4**
1	Ease of selection of option choices	Very hard (1) – Hard (2) – Neutral (3) – Easy (4) – Very Easy (5)	5	5
2	Experience with the GUI.	Very good (1) – Good (2) – Neutral (3) – Bad (4) –Very Bad (5)	1	1
3	Ease of understand ing the task.	Very hard (1) – Hard (2) – Neutral (3) – Easy (4) – Very Easy (5)	5	5
4	Overall experience with the system	Very good (1) – Good (2) – Neutral (3) – Bad (4) –Very Bad (5)	1	1

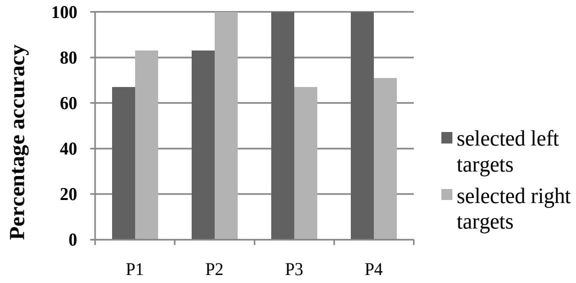

Fig. 5: Comparison of percentage accuracy for Stroke patients

B. Accuracy of our system

TABLE 4
PILOT STUDY RESULT

ID	LEFT TARGETS	RIGHT TARGETS
H1	100%	100%
H2	100%	100%
H3	80%	100%
H4	100%	100%
H5	100%	100%
H6	100%	100%
H7	100%	100%
H8	80%	100%
H9	100%	100%
H10	100%	100%

The accuracy of our system was computed by using eq. (1). For this we considered the number of targets that were correctly chosen, i.e., whether the interpretation by the system based on the participant's 2D fixation coordinates matched with the participant's actual choice. The pilot study with 10 healthy participants (H1-H10) revealed that our system was able to achieve an average accuracy of 96 % and 100 % respectively for the left and right targets.

C. Performance achieved by stroke patients while using our system

It can be seen from Fig. 5 that the performance achieved by the participants while attending to left and right targets, were different. We carried out further investigation to find the reason behind such variation in data. Specifically, participants P3 and P4 achieved greater accuracy in selection of the left target stimuli than that for the right. A possible explanation can be that both these patients had their right side as affected (Table 2). Similar was the case for P2 who had left side as the affected side. However, for participant P1 having right side as the affected side, we observe a different pattern with the right target selection being more accurate than the left. As per the experimenter's observation, P1's left eye was appearing as reddish in color compared to the right eye at the time of the study. Thus, the health condition of the eye might be the reason behind this anomaly as stated above. However, given the limited sample size of the stroke-surviving participants, it is difficult to generalize our findings.

V. CONCLUSION AND FUTURE WORK

In the current study, we have designed a gaze-based communication interface to enable the users to use their eyes to control peripheral devices and communicate their needs. This can serve as an alternative communication tool for the people with severe motor disabilities. Our system provides advantage of being remote, comfortable, cost-effective and user-friendly.

However, our preliminary study had some limitations. The number of participants, particularly, those with post-stroke involved in this study was limited and thus our inferences about the patients cannot be generalized. In future, we plan to extend the study to involve more participants. Further, our system can tolerate limited head movement within the field of camera-view. Our system has about 6 degrees visual angle accuracy which is quite less as compared to a typical eye tracker. Although, our preliminary results are promising, yet in future, we plan to work on improving the accuracy by using advanced algorithms. Our existing system can communicate the user's choice of options to caregivers who are located in the patient's neighborhood.

In future, we plan to extend our application with long-distance communication capability by incorporating Global system for Mobile communication (GSM) module in our hardware. The idea will be to inform a remotely located nurse/clinician/family member about the patient's needs. Another limitation of our existing system is that the GUIs are designed to provide visual stimulus (choice options) to the participants only at the top left and top right corners of the screen. The reason behind such a design was to avoid one's eyes from being occluded to the webcam view when trying to select targets at the bottom of the screen. Thus, in future, we plan to design proper mounting arrangement of our webcam so as to alleviate this limitation.

Our usability study, designed as a proof-of-concept application, has shown some promise in its applicability as a communication platform for individuals with disability. We believe that in future such a system can serve as an assistive communication medium for the disabled, thereby contributing to an improved community life.

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