A Novel Multimodal Gaze-Controlled Hindi Virtual Keyboard for Disabled Users

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***Abstract*—Over the last decade, there has been a gradual increase in the number of people with mobility and speech impairments who require novel communication devices. Most of the recent works focus on the Latin script; there is a lack of appropriate assistive devices for scripts that are specific to a country. In this paper, we propose a novel multimodal Hindi language virtual keyboard based on a menu selection with eight commands providing access to spell and type 63 different Hindi language characters along with other functionalities such as the delete command for corrections. The system has been evaluated with eight able-bodied individuals who performed a specially designed typing task. The spelling task has been achieved in three different modalities using: (*i*) a mouse, (*ii*) a portable eye-tracker, and (*iii*) a portable eye-tracker combined with a soft-switch. The performance has been evaluated over the changes that occur with the use of each modality in terms of typing speed and information transfer rate (ITR) at both the command and letter levels for each participant. The average speed across participants with mouse only, eye-tracker only, and eye-tracker with soft-switch were 17.12 letters/min, 10.62 letters/min, and 13.50 letters/min, respectively. The ITRs at the command and letter levels were about 67.58 bits/minute and 62.67 bits/minute, respectively, with only the eye-tracker option. Based on its robustness, the proposed system has the potential to be used as a means of augmentative communication for patients suffering from mobility and speech impairment, and can contribute to substantial improvement in their quality of life.**

I. Introduction

Information and communication technologies (ICTs) have become an integral part of day-to-day life in every sphere of human activity. Whereas many people take this situation for granted, people with disabilities face lots of difficulties in using ICT applications properly [1]. The problem becomes more urgent as there has been a substantial increase in the number of disabled people during recent times. For instance, population surveys showed disabled people constitute more than 40-80 million (about 5%) of total population (1.02 billion) of India with physical disabilities preventing them from easily using a standard keyboard, screen, and mouse set-up [2]. Among the five types of disabilities on which data had been collected in the 2001 Census, a major portion of this population is affected by mobility impairment (27.9%) and speech impairment (7.5%) [2], [3]. In particular, people with severe movement disabilities may have physical impairments that substantially limit their ability for fine motor control. They may therefore not be able to type and interact using a normal keyboard and a mouse [4]. Hence, interacting efficiently with a computer as a means of communication and/or control (e.g., document typing, message sending, operating other augmentative and entertainment devices) becomes a challenge for them [5], [6]. In this scenario, the use of appropriate assistive technologies is essential for ensuring accessibility to such people [7]. However, the development of new assistive technologies depends on the type of users and the adaptation of available devices such as keyboard, joystick to develop advanced technologies for locked-in patients [8], [9]. Disabled people who are not completely locked-in may still partially be able to use their body part and gaze to control and communicate with an assistive device. Recently, gaze based control of wheelchair has been implemented successfully [10], [11], which has shown a strong potential of gaze based assistive technology.

Currently, a large range of eye-tracking devices are commercially available in the market providing several functionalities, level of precision and price range. Some research studies involve high precision eye-tracking devices to measure a variety of eye characteristics (i.e., saccades, smooth pursuit, and fixation) [12], but they are expensive. However, cost effective systems and non-invasive remote camera-based eye-trackers [13], [14] can be efficiently used along with some enhancements. New technological advancements such as affordable non-invasive eye-trackers provide a substantial platform to design low cost assistive technologies, where users do not need any physical contact with eye-tracker device [15]. Although, a key concern in eye-tracker based interfaces is to quantify the intention of the user and this issue is aggravated by involuntary eye movements leading to unwanted selection of items (Midas-Touch problem) [16]. Multimodal and hybrid interfaces have been utilized to counter these issues in previous works [11], [17]. Furthermore, the addition of new constraints to the system such as the duration of the gaze attention on a particular selected item can be an effective solution to resolve the Midas-touch problem. Moreover, it can be possible to point to the target item with the eye-tracker, and make the selection with other input devices such as a soft-switch.

Human-computer interaction based applications have been developed [18], [19], [20] in English language, where the eye-tracker devices are used to provide computer inputs to select the target items on a visual display unit. It shows that the human gaze behavior is strongly correlated to user intentions, and it has the potential to generate a large number of commands; eye-tracking devices have become a popular choice as an input modality. However, there is a strong need of an effective virtual keyboard based on robust multimodal human

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computer interface for the Hindi language (i.e., the national language of India) so that the large population of disabled people of India can improve their daily life. Still, there can be various inherent complications involved in the development process. The composition of text in Hindi language contains a large number of letters, matras (i.e., diacritics), halants (i.e., killer strokes) and other complex characters [21], [22]. Hence, typing in Hindi language using QWERTY keyboard is not an easy task as significant training is required to compose the text [23]. In previous studies, a QWERTY keyboard has been optimized to design virtual keyboard applications in Bengali and Meitei language [24], [25]. A wide range of assistive software applications are commercially available in the international market for English language, which are close to this area of usage [26], [27]. However, there is no such application available or even designed in Hindi language so far. Moreover, the usage of these applications has been confounded by their higher purchasing costs and language barrier. These issues need to be taken into account to design an effective and user friendly graphical user interface (GUI) towards a better assistive technology development for Hindi users.

In this work, we propose a novel multimodal Hindi language virtual keyboard. The development of this system involves consideration of three key factors. First, the constraints of the users such as the language of communication and affordability. Second, a user friendly and effective graphical user interface to overcome the Midas-touch issue. Third, a robust platform wherein different modalities can be implemented for disabled people. This paper proposes a Hindi virtual keyboard with only eight commands that work as a menu to select 46 different letters, 11 different matras (i.e., diacritics) or halants (i.e., killer strokes), 5 punctuation marks. The system also includes a space and an additional delete command to correct errors. The virtual keyboard needs two consecutive steps for enabling a command. First, the user has to point to the item that must be selected. A red pointer on the visual display unit can be moved to the chosen location and a visual feedback is 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 to be executed. Once the item has been selected by the user, the system will provide an audio feedback.

A key issue is the accuracy of the eye-tracker, which may limit the number of commands that can be accessible at any moment. This is because the calibration has to be updated when the user changes his head and body position over time. The aim of this study is to focus on the human-computer interaction issues with eye-tracking and to propose a multi-modal interface to resolve these issues. Our study is designed as follows. First we present a novel robust Hindi virtual keyboard using gaze detection that also includes visual and audio feedback, and its evaluation on 8 healthy participants. Second, we evaluate the performance of the virtual keyboard in different conditions to assess the effect of different types of control on the GUI: the computer mouse only, the eye tracker only, and the eye-tracker with a soft-switch. 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 soft-switch, the user must gaze at the target item, and validate the selection with a switch button. This paper is organized as follows: Section II describes the overview of the proposed Hindi virtual keyboard. Section III explains the experimental protocol used. Section IV presents the results. Section V discusses the significance of the work and its implication in assistive technology, and Section VI gives the conclusion.

II. System overview

The developed GUI consists of two main components, which are depicted in Fig 1. The first component is a possible command display where total eight commands have been presented. The second component is an input text display where the user can see the output text in real time. The position and tree structure of these eight commands (c1 to c8) are depicted in Fig. 2. The presented tree structure has to be followed for entering any particular command. The tree structure is composed of two different levels: the first level includes seven commands (c1, c7) which are dedicated for the selection of a particular group of letters with matras. Apart from these seven, another command c8 is provided for inclusion of miscellaneous functionalities such as delete and space. Moreover, it contains the required punctuations marks to complete any sentence. At the second level, each of the first level items contains eight distinct characters and further selection of these characters can be performed by initiating a particular command at this level. The selection of any letter can be done using the provided tree structure of commands. In other word, if the user selects any of eight commands at level one, the layout is transformed into second level structure and the letters appear according to tree structure of commands (see in Fig. 1 right panel). Each of these eight commands can be used to type letters to complete a sentence. The principle of this virtual keyboard is inspired by a brain-computer interface (BCI) virtual keyboard based on the detection of steady state visual evoked potentials [28].

Contrary to regular keyboards where an experienced user has to only focus on the screen with the text and not on buttons of the keyboard, in a virtual keyboard an experienced user will only focus on the buttons and not on the text that is displayed. For this reason, it is important to provide to the user an efficient feedback about the selection of a command to avoid the user to shift his gaze to the message box that contains the text to verify its content. Moreover, the last word display facility is also incorporated with the GUI where user can see the last selected word in bottom of the input text display. The visual feedback was provided to user for each of the command in terms of change in color of the button border while looking at the command. Initially, the color of the button border is silver (RGB: 192,192,192). When the user pays attention to a button for a duration of t time, the border color changes linearly in relation to the dwell time Δt, the button becomes greener overtime. The RGB color is defined

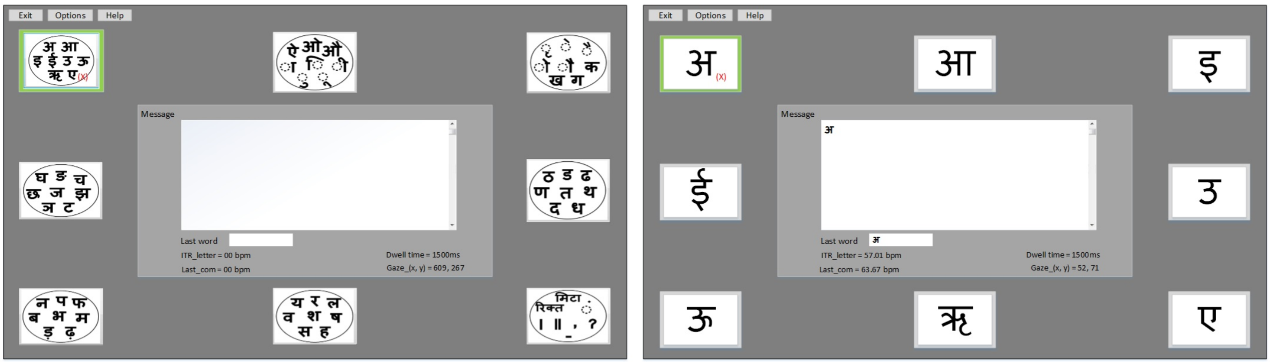

Fig. 1. Layout of proposed Hindi virtual keyboard application in level one when c1 is selected (left) and level two after the selection of c1 (right), with the eight commands (from left to right, top to bottom).

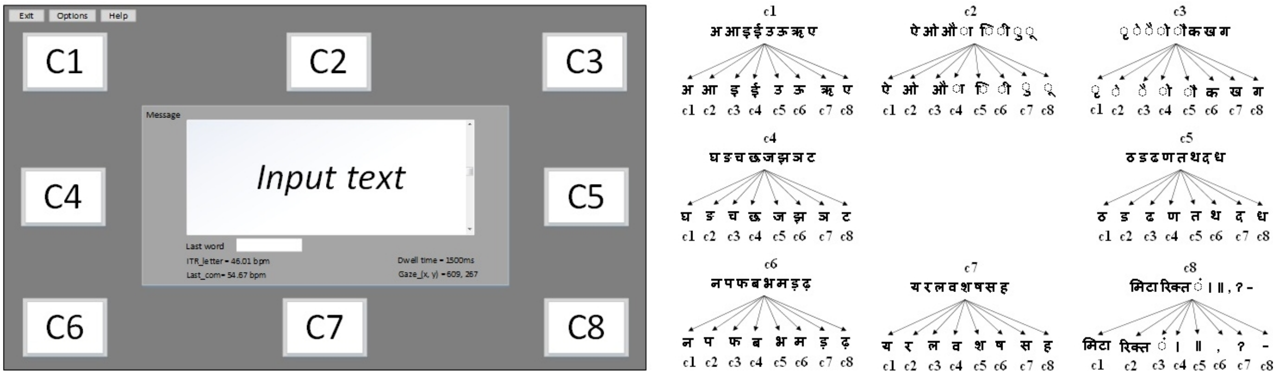

Fig. 2. The position of eight commands in the Hindi virtual keyboard application (left), the tree structure depicting the command tags used for letter selection (right).

as (R=u,G=255,B=u), where $u = 255 * (\Delta t - t)/\Delta t$ (see in Fig. 1, when c1 is selected). The experiments were conducted using a dwell time of 1.5 s. The visual feedback is to allow the user to continuous adjust and adapt his/her gaze to the expected region on the screen. The eye-tracker SDK [13] was used to acquire the gaze data. Prior to each experiments, a 9-point calibration scheme was applied to estimate the accurate point of gaze. Each calibration was for about 20 seconds. No pre-training session is required for the users.

III. Experimental protocol

A. Participants

Eight consenting healthy male and female volunteers participated in this study. They were in the age range of 26-33 years (mean age=29.7, standard deviation=2.3). Four participants had vision correction (they are reported with the * sign in the subsequent sections). No participant had prior experience of using an eye-tracker with the application. Participants were advised regarding the purpose and nature of the study. No financial benefit for the participants was associated with the experiments. The Helsinki Declaration of 2000 was followed while conducting the experiments.

B. Materials

The EyeTribe [13] eye-tracker was used for pursuing eye gaze of the participants. The data was recorded at 30 Hz sampling rate. It involves binocular infrared illumination with spatial resolution (0.1 (RMS)), which records x and y coordinates of gaze and pupil diameter for both eyes in mm. The participants were seated on a comfortable chair in front of the computer screen. The distance of participant from computer screen (Asus VG248, 24 inch, resolution: 1920×1080, 144 Hz refresh rate, 350 cd/m2) was about 80 cm. The vertical and horizontal visual angles were measured approximately 21 and 36 degree, respectively. The size of the each command button on screen was 5×3 cm.

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Fig. 3. Predefined sentence (39 characters) to spell during typing spelling.

C. Design and procedure

The experimental protocol is designed to write a predefined sentence of 39 characters (78 commands if there are no errors) (see Fig. 3). This predefined sentence was formed with various combination of words in order to obtain a relatively constant number of commands for each of the eight items. Choice of this sentence was also justified by the novelty of the system to the participants. The performance of the system was evaluated by three different conditions. First, the participants are able to use the mouse to determine and select the items on computer screen. It means participants can directly click on the represented commands on screen which they want to be selected. This condition was included to find out about the performance with the GUI without eye-tracker. In the second condition, eye-tracker only was used by participants for pointing and selection of the items. When participants point to the item on screen using their gaze, the corresponding command button border color becomes green and based on pre-defined duration of dwell time, the item is selected. In the third condition, the eye-tracker and soft-switch were used in a hybrid mode, where the item is determined through gazing, and the item selection is made by pressing the soft-switch. In this condition the participants can press a soft-switch button once they received the visual feedback (i.e., the color of the determined item becomes green) from gaze. Prior to the experiments, participants were advised to avoid moving their body and head position during the tests.

D. Command selection with the eye-tracker

The screen was divided into two parts: the commands display and input text display (middle screen). Therefore, the gaze coordinate with respect to input text display were discarded. The item was selected based on users paying attention on corresponding command button (i.e., box) during the Δt ms. The selection of particular item is done by calculating the Euclidean distance between the target item (distance consider from center position of target button) and the gaze coordinates, if the gaze coordinates remain in same region (i.e., nearest to the target item) for Δt ms duration the particular item is selected. In other case if gaze coordinate changes from one to another region less than Δt ms then the timer for the selection is reset to zero.

E. Performance evaluation

The several performance indexes such as number of letters spelt per minute, the information transfer rate (ITR) at the basic letter level ITR_{letter} and command level ITR_{com} [29], and the mean and standard deviation of the time to produce each command were used to evaluate the performance of the Hindi virtual keyboard. In our case at command level, the number of possible commands is 8 ($M_{com} = 8$) these commands correspond to the selected item through eye-tracker. The number of commands at the letter level is 63 ($M_{letter} = 63$), which consider the Hindi letters, matras (i.e., diacritics), halants (i.e., killer strokes), basic punctuation, and space button. The delete button was used as a special command to correct the errors. The ITR is calculated based on total number of actions (i.e., basic commands and letters) and the amount of time that is required to perform these commands. To define the ITR all these different commands and letters were assumed as equally probable and there is no typing error. The ITR is given as follows:

$$ITR_{com} = log_2(M_{com}) \cdot \frac{N_{com}}{T} \quad (1)$$

$$ITR_{letter} = log_2(M_{letter}) \cdot \frac{N_{letter}}{T} \quad (2)$$

where N_{com} is total number of produced commands by the user to spell N_{letter} characters. T is total time to produce N_{com}. The maximum speed, ITR_{letter}, and ITR_{com} with dwell time of 1.5 s are set to 20 letters/min, 119.54 bits/min, and 120 bits/min, respectively.

IV. Results

The performance evaluation of the Hindi virtual keyboard was done based on the results collected from a fixed typing task experiment per participant for each condition. The spelling performances for all three conditions (i.e., mouse only, eye-tracker only, and eye-tracker with soft-switch) are presented in Tables I, II, and III, respectively. The condition involving the mouse only (a common computer device that is familiar to all the participants) provides best performance with an average speed 17.22 ± 4.54 letters/minute. This condition is used as a baseline to measure the drop in performance from switching from a mouse to another modality. For the condition with an eye-tracker only, the average speed decreases to 10.62 ± 2.63 letters/minute. The third condition comprises an eye-tracker and soft-switch to select the item on visual display unit, the average speed is 13.50 ± 4.93 letters/minute, higher than the eye-tracker only. The Wilcoxon signed-rank test was applied using Bonferroni correction method for multiple comparison, to compare the typing speed with mouse only and eye-tracker only. We found that mouse only leads to faster speed than eye-tracker only ($p<0.05$). The similar pattern of performance is measured from ITR_{letter} and ITR_{com} for each condition. The condition with mouse only provides the best performance for ITR_{letter} with an average 99.00 ± 25.54 as compared to 62.67 ± 15.28 with eye-tracker only and 77.10 ± 30.46 with eye-tracker and soft-switch. The performance drops from 102.04 ± 25.68 with the mouse only, to 67.58 ± 12.24 with the eye tracker only, to 85.26 ± 24.73 with eye-tracker and soft-switch for ITR_{com}. For each condition, the ITR_{com} was found greater than the ITR_{letter} which shows the impact of the delete command to correct errors on the overall performance. The average time to produce a command with mouse only condition is 1779 ± 477 ms, which slightly increases to 2061 ± 581 ms with eye-tracker and soft-switch. When participants use the eye-tracker only, the average time to produce a command is 2604 ± 467 ms, which indicates that selection of 1.5 s dwell time was on average not too short. In order to produce a first command, a participant required more than 10 s, as this participant probably moved before the start of the experiment, whereas some participants took more time to detect a particular command. The highest time to produce a particular command across three conditions was measured as 22 s with eye-tracker only. This problem occurs when a participant changes his position on the chair during the experiment.

V. Discussion

The proposed interface is the first example of a multimodal Hindi virtual keyboard using eye-tracking. The performance of this Hindi virtual keyboard using gaze control with a low

TABLE I
TYPING SPELLING PERFORMANCE FOR THE MOUSE ONLY.

Participant	Speed (letter/min)	ITR_{com} (bits/min)	ITR_{letter} (bits/min)	Average time (ms)								
				c1	c2	c3	c4	c5	c6	c7	c8	all
1.	12.74	79.38	75.41	2047	1861	1447	1508	2403	2098	2912	2886	2145±559
2.	24.42	143.28	143.28	1340	1133	930	956	1260	1424	1746	1032	1128±275
3.*	20.01	121.85	115.90	1021	1169	1211	995	1454	2014	2114	1414	1424±428
4.*	22.31	126.40	120.24	1126	1204	921	1016	1767	1591	1192	1358	1275±286
5.	13.39	75.28	71.60	1789	2439	2653	1099	2376	3017	2490	1723	2198±616
6.*	15.20	94.03	89.45	1843	1927	1647	1022	2110	2197	2702	1591	1880±494
7.	12.81	77.00	77.00	2119	1719	2702	1331	2283	3288	2693	2199	2292±611
8.*	16.86	99.08	99.08	1309	1359	2565	1015	2021	2348	2120	1645	1798±549
Mean	17.22	102.04	99.00	1574	1601	1760	1118	1959	2247	2246	1731	1779±477
Std.	4.54	25.68	25.58	426	465	769	196	428	641	574	574	426±136

TABLE II
TYPING SPELLING PERFORMANCE FOR THE EYE-TRACKER ONLY.

Participant	Speed (letter/min)	ITR_{com} (bits/min)	ITR_{letter} (bits/min)	Average time (ms)								
				c1	c2	c3	c4	c5	c6	c7	c8	all
1.	9.72	62.94	56.94	2832	1992	2063	2872	2255	3271	2805	3548	2705±562
2.	15.23	89.42	89.42	1880	2203	1805	1880	1953	2128	2005	1963	1977±133
3.*	12.87	75.61	75.61	2400	2103	1985	2126	2809	2412	2451	2253	2317±260
4.*	11.74	73.28	69.71	2081	2258	2118	2288	2713	2861	2598	2513	2429±285
5.	9.29	61.00	55.19	2650	2195	3042	4510	3330	3164	2712	2466	3009±713
6.*	9.35	64.09	55.55	2746	2238	2434	2774	2432	2524	3246	3300	2712±388
7.	6.58	47.66	39.13	3509	2664	3455	2482	3015	3667	4199	5636	3578±1000
8.*	10.19	66.67	59.77	2159	2737	2407	2472	2913	3473	2482	2653	2662±399
Mean	10.62	67.58	62.67	2532	2299	2413	2675	2677	2937	2812	3041	2674±467
Std.	2.63	12.24	15.28	519	263	566	809	444	546	661	1171	479±281

TABLE III
TYPING SPELLING PERFORMANCE FOR THE EYE-TRACKER AND THE SWITCH FOR THE SELECTION.

Participant	Speed (letter/min)	ITR_{com} bits/min	ITR_{letter} bits/min	Average time (ms)								
				c1	c2	c3	c4	c5	c6	c7	c8	all
1.	15.99	108.83	92.94	1353	1233	1763	1488	1837	1697	1582	1766	1590±216
2.	12.90	80.95	75.95	1457	1852	2230	1534	2011	3506	2001	1648	2030±651
3.*	18.64	109.77	108.38	1347	1017	998	1377	1630	2650	1790	1777	1573±532
4.*	14.40	84.16	84.16	1660	1879	1609	1652	2641	2725	2357	2088	2076±452
5.	6.70	46.13	28.79	1817	2174	1734	1709	2492	5203	4330	2769	2779±1304
6.*	13.71	83.72	77.74	1880	1692	1412	1848	3211	1846	2120	1913	1990±533
7.	6.15	56.24	36.55	1980	2158	2861	2795	3106	3968	3386	3082	2917±639
8.*	19.53	112.25	112.25	1443	1327	961	1539	1660	2055	1764	1508	1532±321
Mean	13.50	85.26	77.10	1617	1666	1696	1743	2324	2956	2416	2069	2061±581
Std.	4.93	24.73	30.46	251	432	628	449	631	1204	955	562	534±328

cost and portable non-invasive eye-tracker has been presented. The performance was evaluated on three conditions to quantify the change in performance with respect to the change of modality. Although a drop in performance was expected across conditions. The performance with the use of eye-tracker remains high enough (i.e., 11 letters/min) to be used efficiently. 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. However, the distance between items was optimized in graphical user interface, to increase the robustness of the method to various changes of the head position and the body of users. The performance evaluation of virtual keyboard is based on several factors such as the type of users, length of the experiments, users' motivation and experience in typing task. Therefore, it is difficult to evaluate the performance of virtual keyboard. The word completion and word prediction affect the performance of virtual keyboard in typing task [30] and so to avoid this variation of performance, our proposed system was evaluated on the base of two commands per letter. The aim of present the system was to improve the communication means of disabled people. Further study will consider mobility and speech impairments patients to evaluate the performance of proposed system, wherein the eye-tracker only can be used to point the item on screen and soft-switch can be replaced by the detection of brain responses [31], [32].

As proposed system is based on the gaze control therefore, we have evaluated the performance of our system with virtual keyboard based on the brain response detection that requires the gaze control, such as steady-state visual evoked potentials (SSVEP) and P300 speller, and found that our system offers significantly higher performance than these systems. The ITR of P300 speller is about 25 bits/min [33] and the ITR of SSVEP speller is about 37.62 bits/min with an average speed of 5.51 letters/min [28], whereas the proposed system provides

67.58 bits/min with an average speed of 10.62 letters/min. The accuracy and speed in virtual keyboard application are important features which must be considered for designing an optimal GUI. Although increase in number of commands can allow to input large number of letters but at the same time it may decrease the accuracy of the system. Hence, a trade-off must be chosen between the accuracy of the selected item and the number of items that can be selected at any moment. However, this task is challenging as it is required to take into account constraints of eye-tracker and user interface. The system application layout provides the commands from left to right and top to bottom consisting of various letters and selection of any letter can be done by two level tree selection. The accuracy and speed can be improved using proper screen resolution with respect to the number of items and the enhancement of the graphical user interface to optimize the arrangement of the letter. The trade-off between accuracy and screen resolution will be considered in future studies.

VI. Conclusion

In this paper, a new multimodal non-invasive virtual keyboard using eye-tracking has been specifically created for the Hindi language. This Hindi virtual keyboard is based on tree selection method that includes audio and visual feedback for users with inclusion of 63 letters and extra delete command to correct the errors. Future work will involve further enhancement in the flexibility and usability of this system by adding electromyography signals as an input modality, and including extra commands to write the half letter scripts in Hindi language.

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