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# Enhancing Interface Efficiency: Adaptive Virtual Keyboard Minimizing Keystrokes in Electrooculography-Based Control

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## A B S T R A C T

Rapid technological developments, one of which is technology to build communication relationships between humans and machines using Biosignals. One of them is Electrooculography (EOG). EOG is a type of biosignals obtained from eye movement. Research related to EOG has also developed a lot, especially for virtual keyboard control. Research on virtual keyboard control based on eye gaze motion using electrooculography technology has been widely developed. Previous research mostly drew conclusions based on time consumption in typing paragraphs. However, it has not been seen based on the number of eye gaze motions made by the user. In this research, an adaptive virtual keyboard system is built, controlled using EOG signals. The adaptive virtual keyboard is designed with 7x7 dimensions and has 49 buttons, including main buttons, letters, numbers, symbols, and unused buttons. The layout of the adaptive virtual keyboard has six zones. Each zone has a different number of steps. Characters located in the same zone have the same number of steps. The adaptive feature is to rearrange the position of the character's button based on the previously used characters. In the experiments, 30 respondents controlled static and adaptive virtual keyboards with 7 paragraphs typed. Adaptive mode rearranges the position of buttons based on k-selection activities from respondents. the k numbers are 10, 30, 50, 70 and 100. Two virtual keyboard modes are evaluated based on the number of steps required to type the paragraphs. Test results show that the performance of the adaptive virtual keyboard can shorten the number of user steps compared to static mode. There are tests of the optimal system that can be reduced up to 283 number of steps and from respondents, that can reduced up to 258 number of steps or about 40% of steps. This research underscores the promise of EOG-driven adaptive virtual keyboards, signaling a notable stride in augmenting user interaction efficiency in typing experiences, heralding a promising direction for future human-machine interface advancements.

## INTRODUCTION

Technological developments move so fast and rapidly. technology offers convenience from all sides[1]–[3]. Many people use technology in the form of computers to make their work easier and more productive[4], [5]. One of the developing technologies is building communication between humans and machines or robots using biosignals technology[6]–[8].

Biosignals are a type of signal that can be detected from living creatures[1]. Biosignal is an alternative that can produce a variety of signals that can be measured and monitored. The signals produced are in the form of bioelectric signals and non-bioelectric signals. There are many types of biosignals, one of which is Electrooculography (EOG)[9], [10].

EOG is a type of biosignals obtained based on eye movement activity[6], [10], [11]. Eye movement activities consist of horizontal vertical movements and blinking. Horizontal movements include eye movements left and right. Meanwhile, vertical movements include eye movements up and down[12], [13]. Utilization of EOG signals is one method that has been widely developed in establishing communication between humans and machines[12], [14]. The development of EOG research has been carried out with various implementations, such as virtual keyboards as communication aids[8], [14]–[17], robot manipulator control[4], wheelchair control[18], [19], robot control[1], [20], mouse control[5], game development[2], IoT Application development[21], internet browsing application development[22], alarm system[23] and other developments.

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The development of the Virtual Keyboard was carried out so that it could become a communication tool for users with physical limitations[2], [3], [5], [16], [24]–[26]. It can also make things easier for users based on how little time it takes to type characters[27]. One of the research being developed is a virtual keyboard with finger movement control, where two types of virtual keyboard are used, namely the QWERTY virtual keyboard and the virtual alphabet keyboard. In this research, two types of algorithms were used. From the test results, algorithm I takes 6.7 seconds per character, while algorithm II takes 5 seconds per character[27].

When the eyes control the Virtual Keyboard via EOG signals, things will be different. In other research, virtual control of a static alphabet-shaped keyboard using EOG signals has been developed[15]. This research shows that the system accuracy was 100%, with an average speed of typing characters of 12 seconds/character[15]. Another Virtual Keyboard development with the Hindi language type has been developed. The time required to type one character is 5.62 seconds[28].

Usakli's research [8] also developed an HCI (Human Computer Interface) system using a virtual keyboard with electrooculography signal control. By classifying horizontal and vertical signals and using the nearest neighborhood algorithm for signal classification, performance is obtained at 95%. In other research, virtual menu control has also been developed based on Jaw signal control[29], where the system's performance for selecting the target menu is 5.1 seconds.

Based on typing time from research that has been carried out, a virtual keyboard controlled by the eyes will take longer to type one character when compared to a virtual keyboard controlled by other than the eyes. This causes eye fatigue. Therefore, this research developed an adaptive Virtual Keyboard system to control eye movements via EOG signals. Adaptive systems can be a solution to reduce the number of eye movements to reach the target character. The adaptive system is developed based on the most used character frequencies.

## METHODS

This study presents an innovative remedy to mitigate the impacts of eye fatigue inherent in virtual keyboard operation. The proposed solution introduces an adaptive virtual keyboard meticulously crafted to dynamically shift button positions, a feature governed by an intricately devised adaptive algorithm. Central to this system is the utilization of ocular activity, meticulously tracked and harnessed via electrooculography (EOG) signals, illustrated in detail in Figure 1. These EOG signals, captured from the eye, undergo transmission to a data acquisition system (DAQ), facilitating the extraction of a refined signal. Subsequently, this pristine signal is relayed to a computer housing the virtual keyboard application, where the adaptive functionalities are implemented and orchestrated.

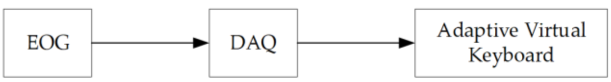
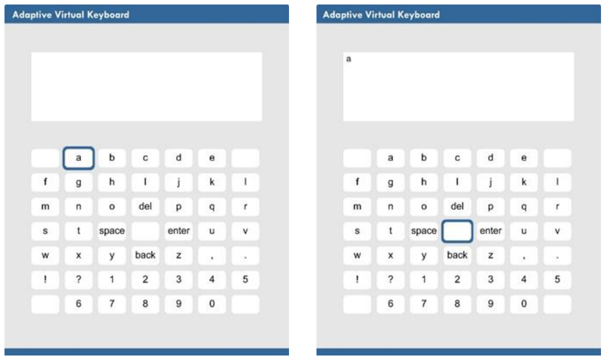



Figure 1. The main system of virtual keyboard adaptive controlled by eyes.

### *Virtual Keyboard*




a b

Figure 2. (a) Active menu with the blue line around and (b) Selecting menu appear on display.

The virtual keyboard is designed to have 7×7 dimensions of buttons, so this keyboard has 49 buttons. This design is based on the virtual keyboard's character requirements and considers its symmetrical size[14]. There is a button in the keyboard's center, without special characters or commands to the system. This button is the reference point for the eye to operate the virtual keyboard. The virtual keyboard has four main buttons, namely "enter", "space", "backspace" and "delete". This keyboard is equipped with 26 letters buttons from "a" to "z", 10 keys for numerical from "0" to "9", 4 symbols consisting of dots(.), comma(,), an exclamation mark(!) and question mark(?). Then four unused buttons are located on each corner of the square.

Users have two main activities when operating the virtual keyboard: moving and selecting the button. Then, they must move the active button from the center point to a button before choosing the desired one. The movement from one button to another button is also called a step. The steps used in this virtual keyboard are left, right, up, and down. The current active button position is indicated by a blue button, as shown in Figure 2(a). Selecting a button means displaying the characters owned by the button on the monitor or activating the main button. Figure 2(b) shows the monitor display when a button is selected, and the active button's position backs to the center after a button is selected.

The location of a button on the virtual keyboard has its pattern based on the optimal number of steps required to move the active button from the center to the button. This 7×7 virtual keyboard has six zones. Each zone is constructed based on the number of eye gaze motions required to go to that button and indicated by the active button. The zone-0 is the center of the virtual keyboard. The main buttons are the functional keys consisting of "enter", "space", "backspace" and "delete" which are located in zone-1. This zone has the same properties as zone 0. Both zones are immobile, and the button stays at the same location during the implementation of virtual keyboard adaptive. Zone-2 is the closest dynamic zone from the center. The adaptive ability to change the button's location caused this zone to be dynamic. The farthest dynamic zone from zone-0 is zone-5. The active button must move at least five steps from the center to this zone. Figure 3 shows the zone area from zone-0 to zone-5.
The adaptive virtual keyboard boasts a dynamic functionality that recalibrates button positions based on their frequency of use within a designated timeframe.

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Figure 3. Adaptive virtual keyboard with six zones.

Table 1. The Rank and the zone of menus

| **Rank** | **Zone** |
|---|---|
| 1 to 8 | 2 |
| 9 to 20 | 3 |
| 21 to 32 | 4 |
| 33 to 40 | 5 |

This intricate system employs a meticulous calculation of button usage, arranging these buttons based on a hierarchical ranking to precisely reposition them within the virtual keyboard layout during updates.

The more often a button is used, the closer it will be to the center of the virtual keyboard or zone-0. As stated earlier, zone-0 is the center of the virtual keyboard, not filled with characters or functions. In comparison, zone-1 contains essential functions for typing. The first two zones are statics without the adaptive ability to change position.

Table 1 serves as an insightful guide, delineating button positions within specific zones contingent upon the frequency-based ranking of their usage. The allocation of buttons within each zone corresponds directly to the hierarchy of their usage, facilitating an intuitive layout. For instance, Zone-2, housing eight-button locations, exclusively accommodate the first eight most frequently utilized buttons. Zones-3 and zone-4, comprising 12 buttons position each, intricately accommodate buttons based on their ranking, with Zone-3 spanning from the 9th to the 20th ranked button and Zone-4 accommodating buttons from the 21st to the 32nd rank. Finally, Zone-5 strategically accommodates a select set of eight buttons, ranging from ranks 33 to 40, epitomizing the systematic and efficient organization of buttons within the adaptive virtual keyboard system.

### *Electrooculography*

The eyes' activities generating the electrooculography signal are the system's input. Four electrodes are attached around the human face to detect eye activity. The ground (G) and reference (R) electrodes are in the middle of the brow. The first channel (Ch1) is the electrode just under the right eye, and the second channel (Ch2) is attached to the left side of the left eye. The illustration of electrode position are shown in Figure 4.


Figure 4. The electrode positions

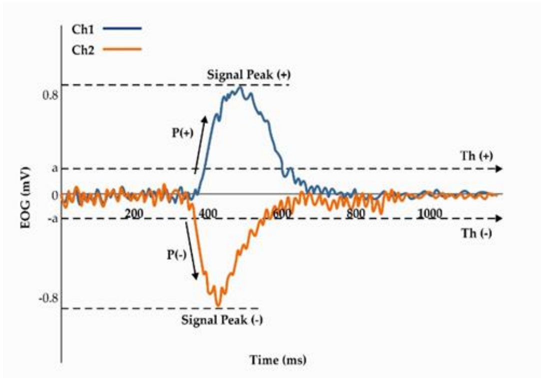


Figure 5. EOG Signal for left gaze motion.

The attribute of EOG used in this study is the amplitude in millivolt (mV). The threshold value distinguishes eye activities that appear with noise signals. There are two threshold types: positive (Th+) and negative (Th-) thresholds. If the signal passes the positive threshold the first time, it is called a positive polarity signal.

This crucial signal analysis involves discerning polarity based on the wave passing through specific thresholds. When the signal traverses the negative threshold initially, it denotes a negative polarity, indicating specific eye movement characteristics. In Figure 5, a demonstrative illustration elucidates this phenomenon, portraying an exemplary EOG signal attributed to the leftward gaze motion, further underscoring the nuanced interpretation of signal behaviors associated with distinct eye movements.

### *Experiment*

This comprehensive research underwent a series of meticulously conducted experiments, all ethically sanctioned under Approval No. 521/UN.16.2/KEP-FK/2021 at Universitas Andalas. The cohort consisted of 30 participants aged between 20 to 25 years, ensuring robust health conditions and the absence of cross-eye conditions. The initial experiment focused on critical determinants: establishing threshold values, signal polarity, and algorithmic methodologies for precise eye activity assessment. Methodically, threshold values were calibrated considering sensor output during static eye states and unblinking intervals. Subsequently, the second experiment aimed to rigorously evaluate the adaptive virtual keyboard's performance, specifically assessing its efficacy in minimizing gaze motions, representing a pivotal stride in optimizing user interaction and interface efficiency.

Participants engaged in controlling two virtual keyboard modes: static and adaptive. Notably, the adaptive mode triggered layout updates following k-selection activities, with k values of 10, 30, 50, 70, and 100, meticulously employed in this study.

Table 2. Seven texts typed using the virtual keyboard

| Text | Content |
|---|---|
| 1 | kota bukittinggi terletak di pegunungan bukit barisan, sekitar 30 km dari kota padang. posisinya ada di tepi ngarai sianok dan dikelilingi dua gunung, yakni gunung singgalang dan gunung marapi. karena berada di ketinggian 909 hinggal 941 mdpl, wilayah kota bukittingi memiliki hawa yang cukup sejuk. |
| 2 | zimbawe adalah sebuah negara tanpa lautan, dikelilingi oleh afrika selatan d iselatan, botswana di barat, zambia di abrat daya, mozambique di timur dan di timur laut. inyangani adalah gunung tertinggi di zimbawe dengan ketinggian 2.592 meter. perbatasan barat lau ditandai oleh sungai zambezi. |
| 3 | universitas andalas adalah salah satu perguruan tinggi negri di indonesia yang terletak di kota padang, sumatera barat, indonesia. universitas ini merupakan universitas tertua di luar pulau jawa. universitas andalas terdiri dari lima belas fakultas, dengan sebagian besar terletak di limau manis. |
| 4 | presiden pertama republic inodneisa, soekarno yang biasa dipanggil bung karno, lahir di surabaya, jawa timur, tanggal 6 juni 1901 dan meninggal di jakarta, 21 juni 1970. dalam sidang bpupki tanggal 1 juni 1945, soekarno mengemukakan gagasan tentang dasar negara yang disebut dengan pancasila. |
| 5 | randang adalah masakan daing bercerita rasa pedas yang menggunakan campuran dari bumbu dan rempah rempah. rendang merupakan masakan tradisional yang berasal dari minangkabau. masakan ini dihasilkan dari proses memasak yang diapnaskan berulang ulang dengan santan kelapa dan butuh waktu yang lama. |
| 6 | tenggalamnya kapal van der wijck adalah film drama romantis indonesia tahun 2013. film ini diadaptasi dari novel karangan buya hamka. tenggelamnya kapal van der wijck mengisahkan tentang perbedaan latar belakang sosial yang menghalangi hubungan cinta sepasang kekasih hingga berakhir dengan kematian. |
| 7 | dokter adalah seorang tenaga kesehatan yang menjadi tempat kontak pertama pasien dengan dokternya agar dapat menyelesaikan semua masalah kesehatan yang dihadapi secara menyeluruh, bersinambung, dan dalam koordinasi serta kolaborasi dengan professional kesehatan lainnya secara efektif dan efisien. |

K-selection is a limit on the number of characters that the participants have input. Assessment of the adaptive virtual keyboard's efficacy centered on the quantification of steps essential for typing. The evaluation encompassed the transcription of seven succinct paragraphs in Bahasa Indonesia, meticulously displayed in Table 2. An intriguing caveat emerges without a capital letter display within the designed virtual keyboard, signifying a developmental facet awaiting enhancement.

## RESULTS AND DISCUSSION

### *Threshold and Signal Polarity to Determine Eye Activities*

The threshold value is determined first before further research is carried out. The threshold value is determined based on the noise signal value when the eyes are inactive. Figure 6 shows the noise signal for more than 10 seconds. The signal peaks are taken and processed to obtain the maximum and minimum values of the signal. It is hoped that a noise signal will never exceed the threshold value, whether it is a positive or negative peak of noise.

Table 3 encapsulates vital data presenting the spectrum of minimum and maximum noise values attributed to each channel. These specific noise signal parameters wield significant influence in formulating the threshold criteria, leveraging the utmost and minimal peak values as pivotal determinants in the meticulous design of these thresholds.

Table 4 delineates directional indicators linked to different movements for two specific channels. For Channel 1 (Ch1), the symbols indicate movement directions as follows: an absence of any symbol (-) signifies an upward movement, a positive symbol (+) denotes a downward motion, positive symbols (+) are associated with leftward movements, and negative symbols (-) represent rightward motions. Conversely, in Channel 2 (Ch2), the indications for directional movements vary slightly: a lack of a symbol (-) correlates with upward motions, a positive symbol (+) aligns with downward movements, the absence of a symbol (-) indicates leftward motions, and positive symbols (+) are linked to rightward movements. This table effectively illustrates the directional associations for distinct movements within the respective channels, providing a clear reference for the directional cues associated with each movement direction.

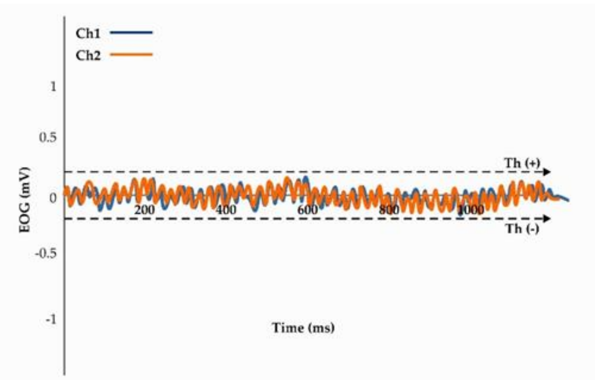


Figure 6. The noise of EOG Signal

Table 3. Parameter of noise signal.

| | Ch1 (Volt) | Ch2 (Volt) |
|---|---|---|
| Maximum | 0,15 | 0,1388 |
| Minimum | -0,13 | -0,1681 |
| Standard Deviation | 0,04267 | 0,05795 |


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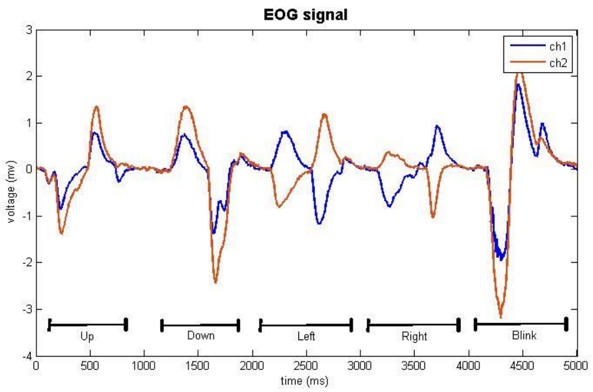



Figure 7. Polarity and amplitude of EOG Signals each gaze motion

Table 4. The polarity of EOG Signals

| | Up | Down | Left | Right |
|---|---|---|---|---|
| Ch1 | - | + | + | - |
| Ch2 | - | + | - | + |

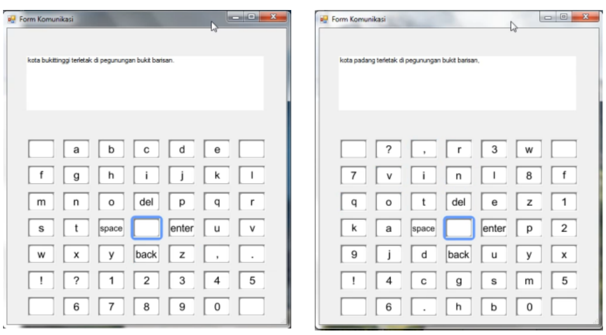
Table 5. Gaze Motion and Action

| No. | Gaze | Action |
|---|---|---|
| 1 | Right | Move right |
| 2 | Left | Move left |
| 3 | Up | Move up |
| 4 | Down | Move down |
| 5 | Blink | Select |

Based on the polarity of signals and eye movements, the action of each eye movement is determined in table 5, such as moving to the right, left, up, down and blinking.

### *Adaptive Virtual Keyboard Performance*

Seven short paragraphs have been determined in the experiment, which respondents will test. Table 6 shows the number of characters for each paragraph. Figure 8 shows the static and adaptive virtual keyboard testing interface (k-30 selection) when typing text by respondents. The test carried out is by counting the number of steps for each paragraph. The optimal and respondent number of steps is calculated manually for each character inputted.



(a) (b)

Figure 8. Interface of Virtual Keyboard with text (a) Static (b) Adaptive (k-30 Selection)

Table 6. The number of characters for each paragraph.

| | Text | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| A | 36 | 48 | 47 | 44 | 62 | 51 | 51 |
| B | 5 | 13 | 4 | 7 | 7 | 5 | 3 |
| C | 1 | 0 | 0 | 1 | 2 | 3 | 2 |
| D | 12 | 14 | 12 | 10 | 14 | 10 | 13 |
| E | 11 | 17 | 20 | 14 | 12 | 19 | 31 |
| F | 0 | 1 | 1 | 0 | 0 | 2 | 4 |
| G | 23 | 11 | 8 | 18 | 14 | 16 | 8 |
| H | 3 | 5 | 2 | 1 | 5 | 9 | 7 |
| I | 32 | 27 | 27 | 20 | 13 | 20 | 14 |
| J | 1 | 0 | 1 | 5 | 0 | 2 | 1 |
| K | 17 | 3 | 5 | 8 | 11 | 12 | 11 |
| L | 7 | 11 | 12 | 8 | 8 | 12 | 8 |
| M | 5 | 9 | 5 | 6 | 13 | 10 | 9 |
| N | 27 | 21 | 21 | 26 | 32 | 31 | 27 |
| O | 5 | 4 | 3 | 6 | 2 | 4 | 10 |
| P | 7 | 2 | 4 | 7 | 8 | 5 | 6 |
| Q | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| R | 8 | 10 | 18 | 12 | 15 | 10 | 13 |
| S | 7 | 6 | 20 | 12 | 13 | 9 | 16 |
| T | 13 | 18 | 17 | 8 | 5 | 10 | 13 |
| U | 15 | 10 | 15 | 10 | 11 | 4 | 4 |
| V | 0 | 0 | 4 | 0 | 0 | 3 | 0 |
| W | 2 | 3 | 1 | 1 | 1 | 2 | 0 |
| X | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Y | 4 | 2 | 1 | 3 | 4 | 4 | 6 |
| Z | 0 | 6 | 0 | 0 | 0 | 0 | 0 |
| , | 3 | 4 | 3 | 6 | 0 | 0 | 2 |
| . | 3 | 3 | 2 | 1 | 3 | 3 | 1 |
| ! | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ? | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 0 | 6 | 0 | 1 | 0 |
| 2 | 0 | 2 | 0 | 1 | 0 | 1 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 4 | 1 | 0 | 0 | 1 | 0 | 0 | 0 |
| 5 | 0 | 1 | 0 | 1 | 0 | 0 | 0 |
| 6 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 4 | 1 | 0 | 3 | 0 | 0 | 0 |
| 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 |

That way, before testing respondents, the average optimal number of steps for each paragraph is calculated on either a static virtual keyboard or an adaptive virtual keyboard.

Table 7 displays a comprehensive overview of different typing modes and their impact on the optimal number of steps required for task completion. The static mode, acting as the baseline, necessitated an average of 972 steps. However, the adoption of adaptive modes, notably represented by k-10, k-30, k-50, k-70, and k-100, showcased substantial reductions in the average optimal steps. Notably, the k-10 adaptive mode emerged as the most efficient, indicating a remarkable decrease of 283 steps compared to the static mode, signifying its superior task-completion optimization.

Table 7. The average optimal number of steps for static and adaptive mode

| No. | Mode | Average optimal number of steps | Difference static and adaptive mode |
|---|---|---|---|
| 1 | Static | 972 | - |
| 2 | k-10 | 688,29 | 283,71 |
| 3 | k-30 | 705,86 | 266,14 |
| 4 | k-50 | 723,57 | 248,43 |
| 5 | k-70 | 740,14 | 231,86 |
| 6 | k-100 | 773,57 | 198,43 |

As the 'k' value increased within the adaptive modes, while all remained more efficient than the static mode, there was a discernible trend of diminishing returns in the extent of step reduction. This pattern suggests that while adaptive modes consistently outperform the static mode in minimizing the number of optimal steps, the degree of improvement diminishes as the 'k' value escalates. In conclusion, the analysis highlights the considerable efficacy of adaptive modes, particularly the k-10 mode, in significantly streamlining and expediting task completion by reducing the optimal number of steps required, albeit with diminishing gains as 'k' increases.

Table 8 shows the analysis of the presented table, which showcases compelling insights into the efficiency of different typing modes. The static mode, serving as the baseline, recorded an average of 1043.89 steps taken by respondents. However, implementing adaptive modes, particularly in k-10, k-30, k-50, k-70, and k-100, yielded marked reductions in the average number of steps. Notably, the k-10 adaptive mode emerged as the most efficient, demonstrating a substantial reduction of 258.9 steps compared to the static mode. As 'k' increased, although all adaptive modes remained more efficient than the static mode, there was a discernible diminishing return in the magnitude of step reduction. This trend suggests that while adaptive modes consistently outperform the static mode in reducing user workload, the extent of improvement diminishes as the 'k' value increases. Overall, the analysis underscores the efficacy of adaptive modes, particularly k-10, in significantly optimizing user interaction by minimizing the number of steps required to accomplish tasks compared to the conventional static mode.

Table 8. The average number of steps from respondents for static and adaptive mode

| No. | Mode | Average respondents number of steps | Difference static and adaptive mode |
|---|---|---|---|
| 1 | Static | 1043,89 | - |
| 2 | k-10 | 784,99 | 258,9 |
| 3 | k-30 | 794,01 | 249,88 |
| 4 | k-50 | 806,72 | 237,17 |
| 5 | k-70 | 820,94 | 222,95 |
| 6 | k-100 | 846,89 | 197 |

Table 9. Comparison of the average number of optimal steps and respondents

| No. | Mode | Average optimal number of steps | Average respondents number of steps | Difference optimal and respondents number of steps |
|---|---|---|---|---|
| 1 | Static | 972 | 1043,89 | 71,89 |
| 2 | k-10 | 688,29 | 784,99 | 96,7 |
| 3 | k-30 | 705,86 | 794,01 | 88,15 |
| 4 | k-50 | 723,57 | 806,72 | 83,15 |
| 5 | k-70 | 740,14 | 820,94 | 80,8 |
| 6 | k-100 | 773,57 | 846,89 | 73,32 |

Table 9 shows the differences in the optimal number of steps and respondents. The table showcases the performance of various typing modes concerning the optimal and actual steps taken by respondents. The static mode, serving as the baseline, required an average of 972 optimal steps, yet respondents took an average of 1043.89 steps, resulting in a disparity of 71.89 steps. On the other hand, adopting adaptive modes, notably represented by k-10, k-30, k-50, k-70, and k-100, consistently displayed fewer average optimal steps, signifying improved efficiency in task completion. However, despite the reduction in optimal steps, respondents across all adaptive modes took more steps on average than the suggested optimal count. Notably, the k-10 mode demonstrated the lowest average optimal steps at 688.29, yet users took an average of 784.99 steps, indicating a substantial discrepancy of 96.7 steps. This suggests potential challenges in user adaptation or interface optimization within this mode. Overall, while adaptive modes showcase promise in reducing the optimal steps required for task completion, there exists a notable gap between the optimal and actual user performance across all modes, emphasizing the need for further refinement or user adaptation strategies to bridge this discrepancy and fully harness the efficiency potential of these adaptive modes

Figure 7 compares the average optimal steps and the actual steps undertaken by respondents, revealing a noteworthy disparity wherein the respondents' steps surpass the optimal count. This variance is primarily attributed to the inherent adaptation period requisite for respondents when acclimating to either the static or adaptive mode. The divergence between these counts underscores an essential aspect of user interface interaction—namely, the temporal adjustment period each user necessitates to familiarize

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themselves with the operational nuances of either mode. While contributing to the increased step count, this transitional phase illuminates the crucial role of user adaptation and the learning curve inherent in integrating novel technological paradigms, ultimately influencing the observed discrepancy between optimal and respondent steps.

The results of this research also require further studies based on a qualitative approach using heuristic evaluation methods and usability testing to get a response regarding the comparison between static and adaptive virtual keyboards.

Exploring virtual keyboard technologies across cited articles in Table 10 encompasses various methodologies and resultant performance metrics. Algorithmic intricacies, exemplified in [27], delineate subtle disparities between Algorithm I, commanding 6.7 seconds per character, and the more efficient Algorithm II, operating at a swifter 5 seconds per character. This spectrum of efficiency expands further, portraying varying input mechanisms. While [30] demonstrates a static alphabet-based virtual keyboard averaging 5.45 seconds per character, [15] exposes an EOG-based counterpart demanding a considerably prolonged 12 seconds per character. Furthermore, multimodal adaptations, as observed in [28], illustrate distinct input times—ranging from 3.5 seconds with a mouse to 5.64 seconds with an eye-tracker, and 4.44 seconds with an eye-tracker equipped with a soft-switch. Additionally, [8] introduces a static alphabet virtual keyboard boasting a remarkable 95% performance using the nearest neighborhood algorithm.

Noteworthy comparisons, such as the study in [26], shed light on design implications; while Type 2, featuring pictures and alphabet characters, operates at a speed of 7 seconds per character and 463 steps, Type 1's inclusion of pictures and QWERTY characters necessitates 8.7 seconds and 564 steps per character.

The entire article contained in this paper carries out performance tests based on the time consumed by the user. Based on the problems raised, the number of eye movements needed to type text also deserves attention, so in this experiment it was carried out based on the number of steps needed to type text. Amidst this array of findings, the proposed static and adaptive virtual keyboard, as highlighted in the present discussion, emerges as a beacon of potential enhancement. Its promising prospect includes the potential to curtail steps by up to 283 and uplift respondent performance by an impressive 258 steps, signifying a pivotal stride toward refining user interaction experiences.

Based on the research results, it is necessary to carry out further studies based on a qualitative approach using user experience methods such as heuristic evaluation[30] and usability evaluation[31], [32] so that the comparison with static and manual virtual keyboards can be seen.

Table 10. Comparison with previous research to proposed feature

| Topic | Feature | Result |
|---|---|---|
| Hand Gesture to control virtual keyboard[27] | Virtual keyboard QWERTY and Alphabet with Algorithm I and II (static) | Algorithm I needs 6,7 seconds per character. Algorithm II needs 5 seconds per character. |
| Hand Gesture to control virtual keyboard using Neural Network[33] | Virtual Keyboard Alphabet (Static) | average time needed 5,45 seconds per character |
| EOG-based virtual keyboard[15] | Virtual keyboard Alphabet (static) | average time needed 12 seconds per character |
| A Novel Multimodal Gaze-Controlled Hindi Virtual Keyboard[28] | Hindi Virtual Keyboard (Static) | average time needed with mouse only 3,5 seconds per character, with eye-tracker 5,64 seconds per character, with eye-tracker with soft-switch 4,44 seconds per character |
| An Electrooculagram Based Virtual Keyboard[8] | Virtual keyboard Alphabet (Static) | performance with nearest neighborhood algorithm is 95% |
| Real-Time Control of Virtual Menu Based on EMG Signal from Jaw[29] | Virtual menu (Static) | The performance of the system to select the desired menu is 5.1 seconds |
| Directional eye movement detection system for virtual keyboard controller[7] | Virtual keyboard Alphabet (static) | typing rate on virtual keyboard 25,94 seconds per character |
| Towards hand gesture-based control of virtual keyboards for effective communication[26] | Virtual keyboard Type 1 (include picture and QWERTY character) and Type 2 (include picture and Alphabet character) | based on the time consumed, type 2 takes less time, namely 7 seconds per character, compared to type 1 which takes 8.7 seconds per character. Based on the steps required, type 1 requires more significant steps, namely 564, compared to type 2, which requires 463. |
| **Proposed Topic** | **Static and Adaptive Virtual Keyboard** | **Optimal system can reduced up to 283 number of steps and performances from respondents can reduced up to 258 number of steps** |

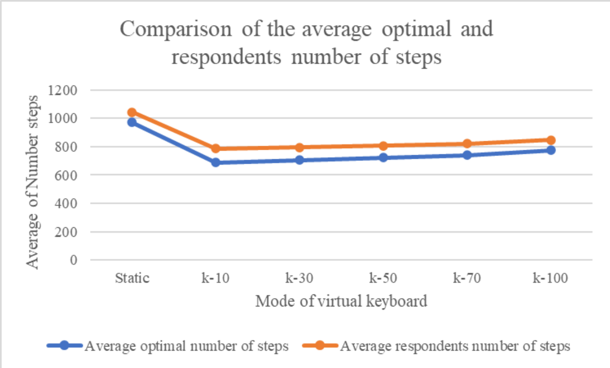

Figure 7. Comparison of the average optimal and respondents number of steps

## CONCLUSIONS

The culmination of our extensive research unequivocally underscores the prowess of the adaptive virtual keyboard in optimizing user interaction. Significantly outperforming the static mode, our findings vividly illustrate its remarkable efficiency in reducing user steps. Our evaluation comprised rigorous assessments involving the optimal number of steps and meticulous tracking of respondents' performance. Impressively, the optimal system demonstrated a staggering reduction potential of 283 steps, underscoring the profound impact of the adaptive approach. Moreover, respondents exhibited commendable improvements, effectively reducing their steps by an impressive 258, affirming the tangible benefits and potential advancements in user interface efficiency offered by this adaptive virtual keyboard paradigm. These compelling outcomes substantiate the significance of adaptive methodologies in refining user experiences and offer promising avenues to evolve virtual keyboard technologies.

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## CONFLICT OF INTEREST STATEMENT

One of the authors of this article, Muhammad Ilhamdi Rusydi, is a member of the editorial team of this journal. This relationship could potentially create a conflict of interest. However, several steps have been taken to ensure the review and publication process's integrity, transparency, and fairness.

1. The author was not involved in any stage of the article's editorial decision-making process.
2. The article was subjected to the same rigorous peer-review process as any other submissions, handled independently by another editorial board member.
3. Muhammad Ilhamdi Rusydi has no access to the review reports or any other privileged information regarding submitting his manuscript.

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