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A Systematic Analysis of Literature on Dwell-Free Eye-Driven Typing

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Abstract—This paper provides the literature on the emerging technology of dwell-free eye-driven typing. Different techniques are discussed along with the advantages and disadvantages of each. Furthermore, it outlines the limitations of this technology and how these are being tackled with present techniques.

Keywords—Dwell-based eye-typing, Dwell-free eye-typing, Image processing, Computer vision

I. INTRODUCTION

Communication is an essential part of the human life throughout the years. Different forms of communication have evolved from speech to sign-language including the use of keyboards with the rise of the technological era. Speech-impaired individuals will face barriers when trying to use speech as a mode of communication. Through Human-Computer Interaction (HCI) [1] such individuals regained the ability to communicate by interacting with physical devices (e.g. keyboard). However, to ease communication for different impairments such as Amyotrophic Lateral Sclerosis (ALS) which degenerates voluntary muscular movement over time [2].

Augmentative and Alternative Communication (AAC) [3] devices provide a virtual on-screen keyboard which can be used with low-cost eye-trackers. These do not require the user to make any physical movement to type a sentence. Consequently, communication is achieved through eye movement. Most developed techniques utilise a specific dwell-time [4]. It means for the user to select the desired character, the user must gaze at it for a specific amount of time for at least the dwell-time. Therefore, it negatively affects the eye-typing rate since it establishes a limit on the maximum number of words per minute (WPM) with leading eye-typing systems allowing a range of 7 to 20 WPM [5]. To improve the rate of input, a dwell-free technique has been proposed in which every character gazed at by the user (irrespective of the time spent) forms part of the input trace. As a result, popularity for the 'dwell-time' technique decreased since 2016 [6] which coincided with the introduction of the 'dwell-free' eye-driven typing technique.

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Rest of the paper is organised as Section II discusses the technology used for Dwell-free eye-driven typing. Section III presents features and advantages of Dwell- free techniques. Section IV discusses the applications, examples and limitations of the technique. Section V presents the states of the art in detail followed by conclusions and future scope in section VI.

II. TECHNOLOGY

To achieve dwell-free eye-driven typing, computational requirements are very minimal. It requires only an eye-tracking device and an on-screen keyboard [7]. The role of the eye-tracker is simply to map the user'sgaze coordinates onto the on-screen keyboard as the gaze was a mouse pointer. The eye-tracker can be either heading mounted (Figure 1) or attached to the computer (Figure 2).

Figure 1. Head Mounted Eye Tracker [8]

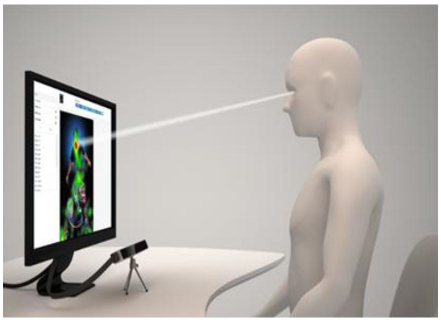

Figure 2. Eye-Tracker attached to a computer [9]

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III. FEATURES AND ADVANTAGES OF DWELL FREE TECHNIQUES

The major feature of the dwell-free technique is the improved rate of eye-typing. Kristensson and Vertanen[10] compared the rate of dwell-freetechnique. The comparison results are shownin Figure 3 which clearly depicts the theoretical typing rates at several dwell-times with three different overheads. The overhead time is the time taken to search for the required keys and to fix any errors. The dwell-free experiment conducted by Kristensson and Vertanen produced the purple colour graph line which indicates a rate of 46 WPM. Using data from various studies, they found out that the average overhead is approximately 300ms and this is the value that can be assumed to compare both techniques. With this knowledge and the above graph, they concluded that even if the dwell-time was reduced to 100ms, the words-per-minute rate would still be considerably lower than the dwell-free technique, since the overhead is approximately 300ms and will not change. It was also noted that such low dwell-times would probably cause typing errors.

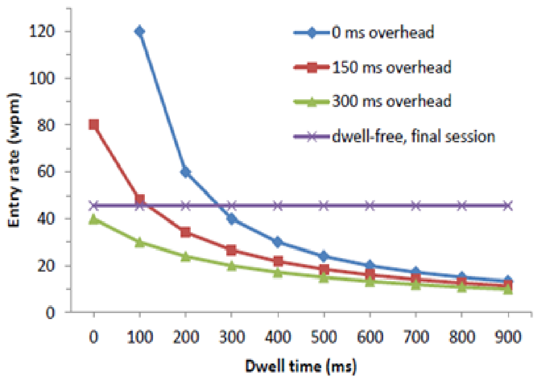

Figure 3. Different eye-typing rates at different dwell-times and overhead times [10]

The prominent advantage offered by this technique is the radical improvement in the rate of eye-typing. Through the omission of dwell-time, users are provided with the ability to simply look at the desired character without any specific duration to activate a character key. Through experiments, participants managed to reach on average a rate of 46 WPM, which is more than twice as much the rate achieved when using a dwell-based technique [10]. In doing so, this technique prevents setting a maximum typing limit on the users. Moreover, even though this advantage may seem to increase fatigue due to the fast text-entry rate. Sarcar [11] claims the contrary, i.e., participants using this technique found it to be less fatiguing than alternate methods which make use of an on-screen keyboard.

IV. APPLICATIONS AND LIMITATIONS OF THE TECHNIQUES

The competence of typing with the help of a gaze-driven approach for users having speech or motor impairment is essential[12]. People with conditions such as motor neuron disease (MND) may not be able to use other means of communication apart from their eyes. This shortcoming raised importance for other modes of input such as eye-typing [13]which is the act of looking at letters with the help of an on-screen keyboard, by using the eye-tracker.

A commercial example of dwell-free eye-driven typing is the Tobii Dynavox Communicator 5 [14]. This tool provides speech generation that allows communicationthrough the features that it possesses.The dwell-free technique is used in this tool for eye-driven typing and ismarketed toincrease typing-speeds by 50-100%. A beta tester for the Communicator 5 stated that using a dwell-free typing technique is almost as fast as a normal conversation [15].

Lochtefeld et al. [13] investigated challenges when developing Eype, a technique that aims to minimise dwell-time. They also discussed several different challenges as follows:

1. **'Visual Search' Challenge:** The main concept of a dwell-free technique is that the user is required to gaze over the intended character without the need to dwell for a specific amount of time. For novice-users (which may consist of users who are not accustomed with the QWERTY keyboard layout), this may hinder performance since it is probable that the input trace consists of bundles of noisy characters. This makes it more difficult to deduce the intended word. [13]

2. **'Initial Letter' Challenge:** This challenge complements the 'visual search' challenge. Whereas physical keyboards can safely rely on the initial letter identifying the intended word through this technique cannot depend on the first letter. The reason being that the user may have performed a visual task (resulting in characters being selected) before selecting the first letter. As a solution to this, the first few letters of a word in the input trace can be considered to be the 'first letter', but this approach increases the search space [13].

3. **Extra- letter, Neighbour-letter and missing-letter errors:** Eype exhibits three common text entry errors; "extra-letter error, neighbour-letter error and missing-letter error" [13]. The extraletter error can be achieved when gazing over the intended character. In doing so, the user's gaze may pass over points handling other characters which will accidentally form part of the input trace. Moreover, the neighbour-letter error occurs when a letter, which is a neighbour to the intended letter, is selected [16]. Finally, the missing-letter error occurs when letters forming part of the desired word, are left out from the input trace [17].

V. STATE OF THE ART

Various techniques have been proposed highlighting different ways to overcome

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challenges brought forward by dwell-free eye-driven typing. This literature review will focus on five main techniques. These are compared in terms of performance and robustness.

Kristensson and Vertanen [10] have come forward with dwell-free eye-typing which provides users with the ability to input phrases of text by gazing over the intended characters. The techniques' main idea is to analyse the user's gaze input trace while filtering out any noisy characters. Since each word entails a sequence of ordered letters, the intended word is generally recognised by detecting and extracting sequential letters from the input trace. Using this technique, the user's focus shifts from per character to per word [17]. Further, they considered this technique with a QWERTY keyboard layout. They claimed that dwell-free eye-typing drastically improved the rate of text-entry over other techniques making use of dwell-time since it waives dwell-timeouts. Users attained an average input rate of 46 WPM after approximately three-quarters of an hour which is more than twice as fast as the widely-used method of dwell-time. The gaze data showed that 51% of the time the individuals taking part enabled the characters by gazing through them. On the other hand, for the remaining percentage (49%), participants gazed inside a 1.5 key radii without entering the key. Thus, they contributed to finding a different research direction which was studied further by other researchers [10]. The techniques are discussed in the following section:

1. **Eype:**Eype, the technique proposed in [13] compares each word in the subset of possible words with the optimal input trace by using the Needleman-Wunsch-Algorithm[18]. Single letters affinity is calculated by allocating them into three particular groups being equal, different and neighbours. Every two letters are given a number, in which the optimal path in the end is that with the highest score attributed to it. Dynamic programming can then be used to effectively derive the best possible result.

2. **Filteryedping:**Pedrosa et. al[12, 19] proposed Filteryedping" is a filtered-based dwell-free typing technique. This technique is capable of filtering unwanted characters and can handle the extra letters error. The intended word is recognised with the help of a "lookup in a word frequency list" after the removal of noisy characters from the input trace. Although the input trace may consist of a large number of probable letter sequences, the majority are unlikely to make sense under the languagemodel.The user is required to dwell all the letters forming the desired word [12]. Each character key consists of a small visible area to assist the user to gaze at the centre detection area. The small width of a character key may cause errors due to false detection of gaze points over an adjacent key instead of the user intends to select. To overcome this problem, horizontal keys are overlapping and whenever a gaze occurs inside the overlapping region, a stream of characters is included (i.e. the concatenation of the two letters and the first letter). For example, if a gaze is detected between 'e' and 'r', the input trace would consist of the stream 'ere'. In this manner all possible instances are taken [19].

   To support the process of analysing the intended word known as eye-typing recognition, Filteryedping makes use of a frequency list. Eye-typing recognition is also supported by a "saccade detection and fixation smoothing algorithm" [20] which determines whether the current gaze point marks the "beginning of a saccade" or "a continuation of the current fixation". This algorithm is designed to determine the current fixation as a weighted mean of the points that are less than the saccade threshold apart and occurred within a specific duration. If both eyes are detected then Filteryedping takes into consideration the average position [19].

   This technique does not provide support for misspellings, missing or incorrect ordering of letters. Nonetheless, it does cater for the extra-letters error and as the name implies, the idea is to filter out eye-typing from noisy characters. Given the input string "Filteryedping", this technique will be able to produce words "filtered", "eye" and "typing" since all the letters are present in the input string in the correct order [19].

3. **EyeSwipe:** Kurauchiet. al [16]considered the missing and incorrect ordering of letters. In *EyeSwipe* the user is required to gaze at the first character and the last one of a word using "reverse-crossing" and glance at the proximity of the middle keys.

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Further, this technique overcomes the 'first-letter' challengethrough reverse-crossing whereby a key selection is made by moving the mouse pointer away from the intended character key, through the same region it went into it. Using this technique, candidate selection can safely rely on the initial and last characters. Hence, long words having three or more letters can be written faster than using a dwell-based technique. EyeSwipe retrieves all the matching words "from a lexicon stored in a trie data structure" which is a sorted tree data structure. The retrieved words are then sorted based on the similarity between the ideal path, having coordinates of points at the centre of keys, and the path inputted by the user's input trace [16].

This technique determines the ideal path through Dynamic Time Warping (DTW). This is used to find an optimal alignment between the user's gaze path and the ideal path [18]. The maximum amount of ideal character points forming a path, is the number of letters making up a word, often minus ten points due to double letters being treated as single letters. Followingexperiments, it was concluded that having reliable start and end letters is beneficial since users can gaze at other non-intended keys without affecting the word recognition [16].

4. **GazeTry:** Liu et al. [21] proposed theGazeTry technique. Similar to the other techniques, the three dwell-free errors are also evident in GazeTry. However, this technique differs from the other discussed techniques. It provides improvement over Filteryedping interms of accuracy and support to text-entry errors [21].The challenges of neighbour and missing-letter errors are mitigated using a cost function. For each character forming part of the input trace, its neighbours are also considered. Although this will result in an increased search space, missing and neighbouring letters are assigned a cost to control the set of possible words [22-23].

Dwell-free typing is achieved through three modules; letter sequence generation, string matching and candidate ranking. Letter sequence generation is responsible for translating gaze-point coordinates to letters by deducing the closest letter for each time-point and generate the letter sequence from the input trace. Duplicate characters are merged and the ordering of letters is maintained. The string matching module determines the similarity between the letter sequence and potential words through the proposed Moving Window String Matching (MoWing) algorithm [22].

This algorithm makes use of two windows; the letter sequence windows (LSW, size is 1) and the word window (WW, size is 2, first position is WP1 and the second position is WP2). The algorithm performs string matching by comparing the letter in the LSW with the two letters in the WW. The cost for converting a letter to the same letter is 0 whereas converting it to a different letter is 1. To overcome the neighbouring-letter error, the algorithm considers two cases of converting a letter (L1) to a different letter (L2). If L2 is a neighbour of L1, the converting cost is less than 1 denoted as a neighbour cost. Contrarily, the cost is 1 and is denoted as an error cost. The extraletter error is addressed by moving the LSW forward at every loop whereas the moving condition for the WW is that the letter in the sequence window (SP) has been converted to the current WW by either matching SP with WP1, WP2 or SP is not the same as WP1 but is the same as WP2 or is a neighbour of WP2 [21].

The role of the candidate ranking module is to rank the potential words based on the conversion of the sequence of the cost ofletters to words in the dictionary. The lower this cost, the greater the probability that the letter sequence corresponds to the intended word in the dictionary [21].

5. **EyeK:** Chakraborty et al. [24] proposed EyeK technique. This techniques performs character selection byhovering inan inside-outside-inside manner over a character. The interaction phase requires the eye pointer to go over the key, move out of it and re-enter the key area to perform a selection. If the same character is to be repeated, the interaction phase is to be duplicated. Further refinement to this technique provides the user with more controlled eye movement. Key selection can be made by hovering the eye pointer over the intended key. Subsequently, a circular disk appears towards the upper side of the key. To perform a key selection, the eye pointer needs to move away from the current key to reach the prominent point and then move back inside the key. Similar to the first method, if more than one character is required the same process is to be repeated [24]. Therefore, the aim is to decrease visual search time, especially for novice typists. Unlike the technique used in Filteryedping, characters will not form part of the input trace by solely gazing over a character. Hence, noisy characters due to the attention drawn towards probable characters will not form part of the input trace

VI. CONCLUSIONS AND FUTURE SCOPE

Significant improvements were made in dwell-free eye-driven typing techniques. Nonetheless, most recent techniques show that results are still being improved in terms of accuracy when determining the user's desired word. In 2016, Kristensson and Zhai [21] published a patent suggesting a method for improving the rate of text-entry through the use of shorthand notation on a keyboard interface. The technique being brought forward in this patent can be adopted dwell-free techniques to further improve the rate of input. Despite the improvement in the rate of input when using dwell-free typing, the rate is still far from reaching that of speech which is approximately 163 WPM.

Similar to studies carried out to determine the performance of different keyboard layouts with dwell-based eye-driven typing, studies identifying the performance of different keyboard layouts when using a dwell-free approach can be made. The performance of novice or expert users is expected to vary much more than that when using a dwell-based approach. Novice users, who may not be accustomed with the QWERTY keyboard layout, may identify challenges since they would have to perform a visual search prior selecting each letter, which will result in more unwanted letters forming

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part of the input trace and hence leads to diminished accuracy. A dwell-based approach supersedes this challenge since the dwell-time reducesthe selection of unwanted characters significantly.

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