Design of Optimal Keyboard Layouts for a Mental Speller

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Abstract. Most mental spelling systems based on brain-computer interface (BCI) technology require subject's eye movements to detect a target character. However, many patients with severe neuromuscular disorders have difficulty quickly moving their eyeballs from a letter to another. In this study, we introduce optimal keyboard layouts that can reduce the visual scanning distance. The average eye-scanning distance was calculated for each keyboard layout generated by genetic algorithm (GA), and then optimal keyboard layouts with shortest eye-scanning distance were found. We tested most frequently used 268 English words, and compared the eye-scanning distances estimated for the proposed optimal keyboard layouts and a conventional layout with an alphabetical arrangement. As a result, our proposed optimal keyboard layouts could significantly reduce the average moving distance by about 1.4 times.

Keywords: Mental Speller, Optimal Keyboard Layout, BCI, Electroencephalography (EEG)

1. Introduction

One of the most widely studied applications of electroencephalography (EEG)-based brain-computer interface (BCI) is the BCI speller, which enables the disabled people to express their thoughts by focusing on target characters. Most of conventional BCI spellers are commonly based on the basic assumption that the users have normal eye movements and thus are able to maintain an open gaze at a target character consistently. However, it is difficult for many neuromuscular patients to quickly control their eyes [Balaratnam et al., 2010; Sharma et al., 2010], requiring some interval between consecutive typings to provide the patients with time to move their eyeballs from one letter to another. Therefore, reducing the time required for visual scanning should enhance the overall performance of the mental speller.

To date, most BCI spellers have used an $n \times n$ matrix keyboard layout generally displaying each character in alphabetical order, without considering the patients' impaired oculomotor function. Thus, a keyboard layout design to reduce eye movements required for spelling target characters is required. In this study, we found optimized keyboard layouts that minimize the eye-scanning distances using genetic algorithm (GA).

2. Material and Methods

To search optimal keyboard layouts, we used GA, which is one of the most popular heuristic optimization algorithms. Three different population sizes were tested, 20, 40, and 60. Each individual in the population corresponded to a 5 by 5 matrix keyboard layout in which twenty-five English alphabets were randomly placed except the alphabet 'Z' (the least used one).

The objective function to be minimized was defined as the mean eye-scanning distance taken when typing widely used 268 English words. When the population size of 20 was used, five pairs of individuals were selected based on the fitness proportionate selection, also known as roulette-wheel selection, and then five offspring (25% of the population size) were then generated by order crossover. Finally, five worst individuals were replaced by the newly generated offspring, and this procedure was repeated 2000 times. To alleviate premature convergence due to trapping in a local optimum, the generated offspring were randomly mutated with a predetermined probability. In the cases of the population sizes of 40 and 60, the numbers of iteration were set to 1000 and 670, respectively, in order to match the total number of individuals (approximately 40,000) tested in the three different population datasets. The individuals having the best fitness values were selected for each population as the optimal keyboard layouts. The mean eye-scanning distances of the optimal keyboard layouts were compared with that of the conventional keyboard layout arranging characters in alphabetical order. For the calculation of distance, we assumed that the both width and height of each cell were 1.

3. Results

Fig. 1 shows the optimized keyboard layouts when the population sizes were set to 20, 40 and 60, respectively. The mean eye-scanning distances taken when the eyes move from one character to another were 1.85, 1.85 and 1.87 for the population sizes of 20, 40 and 60, respectively. In the case of the conventional keyboard layout (alphabetical order), the mean eye-scanning distance was 2.68. It is worth noting that the most frequently used five letters (E, T, A, O, I) were placed around the centers of the optimized keyboards, as shown in Fig. 1.

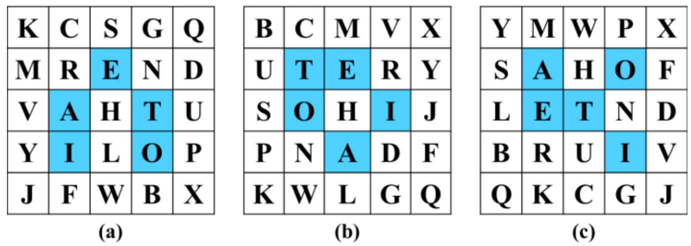

Figure 1. *The optimal keyboard layouts- (a) population size: 20, (b) population size: 40, (c) population size: 60. The turquoise-colored cells denote the most frequently used five letters in English words, i.e.,E, T, A, O, I.*

Fig. 2 shows a representative example demonstrating that the optimal keyboard layouts can reduce the eye-scanning distances, compared to the conventional keyboard layout. A word 'WATER' was used for the example. In particular, we could confirm from visual inspection of Fig. 2 that the optimal keyboard can significantly shorten the eye-scanning distance.

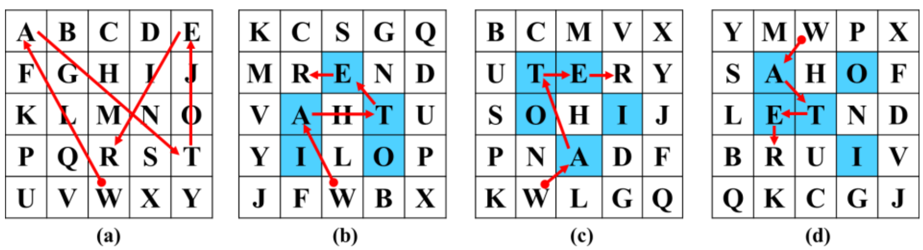

Figure 2. *Examples of eye movements needed to visually scan a word 'WATER'- (a) the conventional keyboard layout (alphatecial order); the optimal keyboard layouts when population sizes were (b) 20, (c) 40, and (d) 60.*

4. Discussion

In the present study, we designed optimal keyboard layouts that can reduce the eye-scanning distance when applied to BCI spellers. Considering that some patients suffering from neuromuscular disorders have difficulty controlling their eyes [Balaratnam et al., 2010; Sharma et al., 2010], we expect that BCI spellers adopting the proposed optimal keyboard layouts can not only reduce tiredness of the patients, but also increase the performance of the BCI spellers.

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References

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