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Design of virtual keyboard using blink control method for the severely disabled

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ABSTRACT

In this paper, a human–machine interface with the concept of "blink control" is proposed. The human–machine interface is applied to an assistive device, namely "blink scanning keyboard", which is designed specifically for the severely physical disabled and people suffering from motor neuron diseases or severe cerebral palsy. The pseudo electromyography (EMG) signal of blinking eyes could be acquired by wearing a Bluetooth headset with one sensor on the forehead and the other three on the left ear of the user. Through a conscious blink, a clear and immediate variation will be formed in the pseudo EMG signal from the users' forehead. The occurrence of this variation in pseudo EMG signal could be detected and filtered by the algorithms proposed in this paper, acting like a trigger to activate the functions integrated in the scanning keyboard. The severely physical and visual disabled then can operate the proposed design by simply blinking their eyes, thus communicating with outside world.

1. Introduction

The functionality and practicability of technological products have been perfected; however, for the users with disabled limbs, even paralyzed, these products are very difficult to use, or are even unusable. Therefore, methods using image processing or physiological signals for detecting human eye movement and blinks have been proposed [1–3], and these methods have been applied to the research and development of various computer interfaces for the physical and mental disabled. The former is referred to as the eye movement based control method and is also called "eye-tracking system" or "eye mouse" [4–10]. The other method is based on eye blink detection [11–14], using eye blinks and a special interface to communicate with others and control software.

Lin et al. proposed an eye-tracking system with one video CCD camera and a frame grabber to analyze a series of images taken of the human pupil when gazing at a screen. In the proposed design the computer will produce speech according to the location of where the eyes are gazing [15]. Usakli and Gurkan designed an electrooculography (EOG) based system using a virtual interface to notify in writing the needs of the disabled. Considering the bio-potential measurement pitfalls, the EOG-based system allows users to achieve environment control with only the eye movements [16]. Lewandowski and Augustyniak implemented a system controlled by moving eyeballs to allow users with upper limb dysfunction to use computer. The eyeball movements are detected by the proposed system, which sent transmitting diodes according to the measurements of reflected infrared radiation collected by detectors placed in the goggles worn by the users [17].

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Bala et al. presented an algorithm to analyze the features of the face and eyes in video image sequences. They used skin color information to improve the system speed [18]. Kirbiš and Kramberger proposed a mobile device for disable people, which can perform different operations through left eye gaze and right eye gaze separately by analyzing the EOG potentials [19].

Although the various kinds of assistive tools have been developed for several years with many of these products tested by the disabled, some of them are still not very popular. For example, the eye-tracking system needs to be adjusted before using, the process of adjusting is too difficult to operate for both healthy people and the disabled, and the cost is still very high. Hence, a virtual scanning keyboard based on the blink control method is proposed in this paper with improving the above disadvantages, and is designed specifically for the severely physical disabled and people suffering from motor neuron diseases or severe cerebral palsy.

Since the blink control cannot be considered only as a unilateral control, more functions can be assigned to conscious left eye blink, right eye blink and simultaneous left/right eye blink [19], and it would make the scanning keyboard more practical and friendly. While considering the main user of proposed keyboard is the people suffering from motor neuron diseases or severe cerebral palsy, they cannot only blink the right eye or left eye nimbly. Hence, the scanning keyboard is designed to be controlled by blinking left eye and right eye simultaneously. The pseudo electromyography (EMG) signal generated from a user's blink is acquired by a Bluetooth headset and transmitted to a PC through wireless transmission, and the noise is eliminated by a self-derived algorithm. The transient variation of a pseudo EMG signal of a "conscious blink" is observed and used for controlling the scanning keyboard. Moreover, the intelligent character selection function is added in the scanning keyboard for promoting the typing speed. Fig. 1 illustrates the system framework of the proposed human–machine interface using blink control method.

The severely disabled can select phonetic symbols on the scanning keyboard through blinking their eyes simultaneously, and repeat this step to type Chinese characters on the screen for communications with others. In such a communication mode, the user's needs can be known, and misunderstandings resulted from difficult communication with nursing personnel can be reduced effectively.

2. Methods of scanning keyboard using eye blink control

2.1. *The algorithm of pseudo EMG signal filtering and eye blink control*

The forehead sensor, or called reference sensor, is used to create a reference potential to reduce the influences of outer electrical fields and disturbances that are created by facial activities. The reference sensor serves as a reference feedback in the automatic gain loop of Bluetooth headset. The difference between the left earlap against to the forehead reference is measured by the headset, and the signal gain becomes stable when no muscular activity is detected. While blinking eyes, this stable condition will be broken due to the disturbances from the forehead muscle, and the output signal will vary with the strength of blinking. Hence, the output signal is defined as a pseudo EMG signal of the forehead in this paper for blink control.

When the forehead pseudo EMG signal is successfully read, the amplitude of pseudo EMG signal would hold as a constant value without blinking as shown in Fig. 2(a). While it would change significantly during a "conscious blink", as it is enlarged or greatly reduced, compared with a relaxed state (including unconscious blinks) as shown in Fig. 2(b). It is observed that the pseudo EMG signal amplitude increases as the strength of blink increases. Therefore, a threshold T could be obtained, and the functions of scanning keyboard are triggered according to the relation of pseudo EMG signal amplitude and threshold T. More specifically, the blink control could be realized by conscious blink.

The threshold T could be determined through the automatic mode. In the automatic mode, the users would be asked to blink purposely within a period of time, and the corresponding data will be recorded, and the threshold T could be obtained by applying Nearest Mean Reclassification Method as follows:

Step 1: Sorting the acquired pseudo EMG signal with the absolute value of amplitude, and forms an increasing sequence from small value to large value. The difference of two neighboring amplitude is denoted as d_1, $d_2, \ldots, d_{n-1}$, where n is the data number of acquired pseudo EMG signal.

Step 2: Let M denote the average value of the above differences as an initial guess, and could be illustrated as below:

$$M = \frac{\sum_{i=1}^{n-1} d_i}{n-1} \tag{1}$$

These differences could be separated into two groups according to M, that is, the differences which are equal or greater than M forms one group, and the corresponding average value of this group is M_1. The differences that are smaller than M forms the other group, and the corresponding average value of this group is M_2.

Step 3: The new clustering threshold M' could be illustrated as below:

$$M' = \frac{M_1 + M_2}{2} \tag{2}$$

If M is equal to M', then the process is ended, and the threshold $T = M'$. Otherwise, let $M = M'$ and repeat steps 2 and 3 until M' is converged to M.

The threshold T of conscious blink could be determined precisely and automatically through above algorithm. In other words, the conscious and unconscious blink could be recognized by the relation:

$$\begin{cases} \text{conscious blink} & \text{if } |F_t| \geq T \\ \text{uncinscious blink} & \text{else } |F_t| < T \end{cases} \tag{3}$$

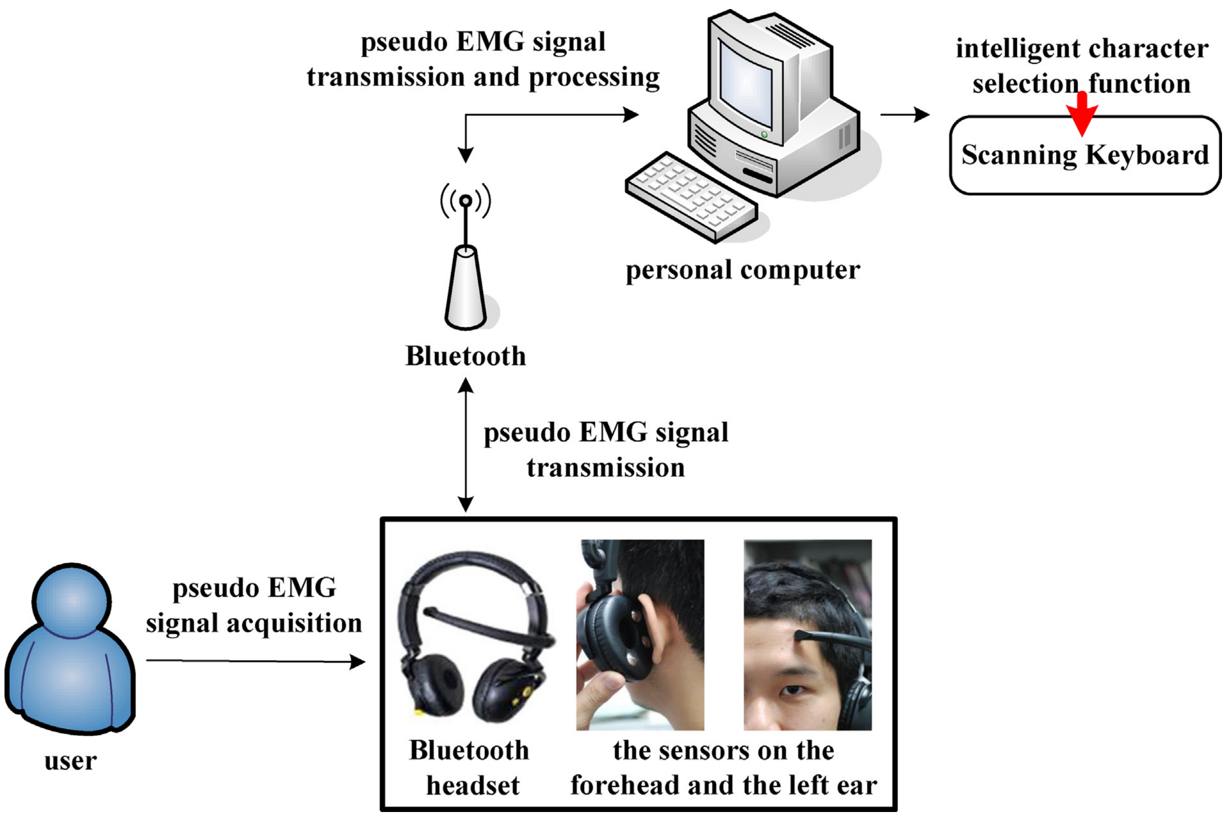

Fig. 1 – The system framework of proposed human–machine interface.

where F_t denotes the pseudo EMG signal amplitude at time t.

However, the value of F_t may be positive or negative, so the absolute value $|F_t|$ is taken.

Since the pseudo EMG signal amplitude resulted from a conscious blink does not generally occur alone, and could be divided into three situations, pairwise positive magnitudes and negative magnitudes occur successively (Fig. 3(a)) and continuous positive magnitudes (Fig. 3(b)) and continuous

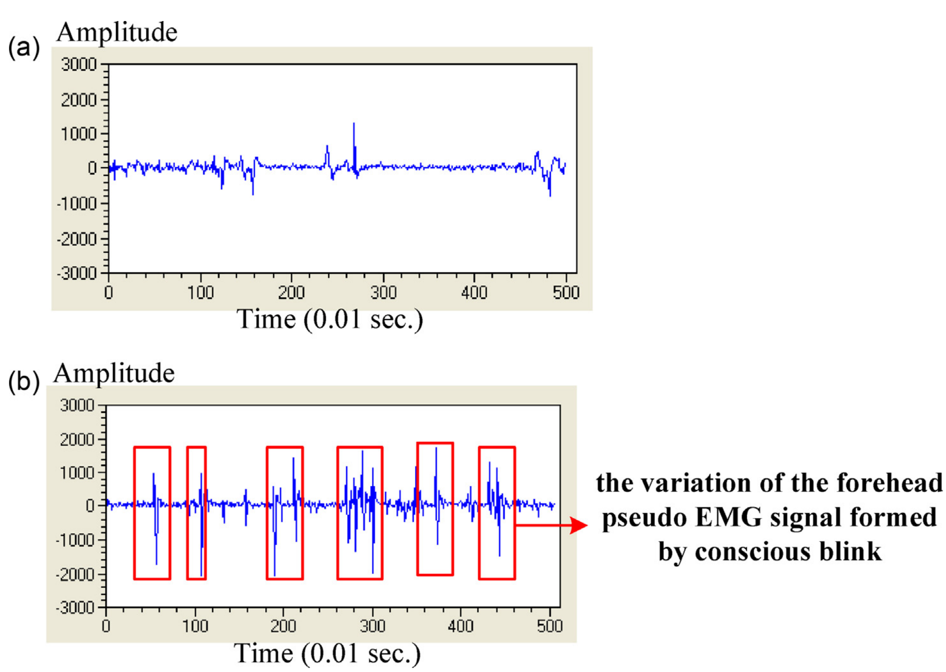

Fig. 2 – (a) The general waveform of the forehead pseudo EMG signal and (b) the waveform of the forehead pseudo EMG signal when conscious blink.

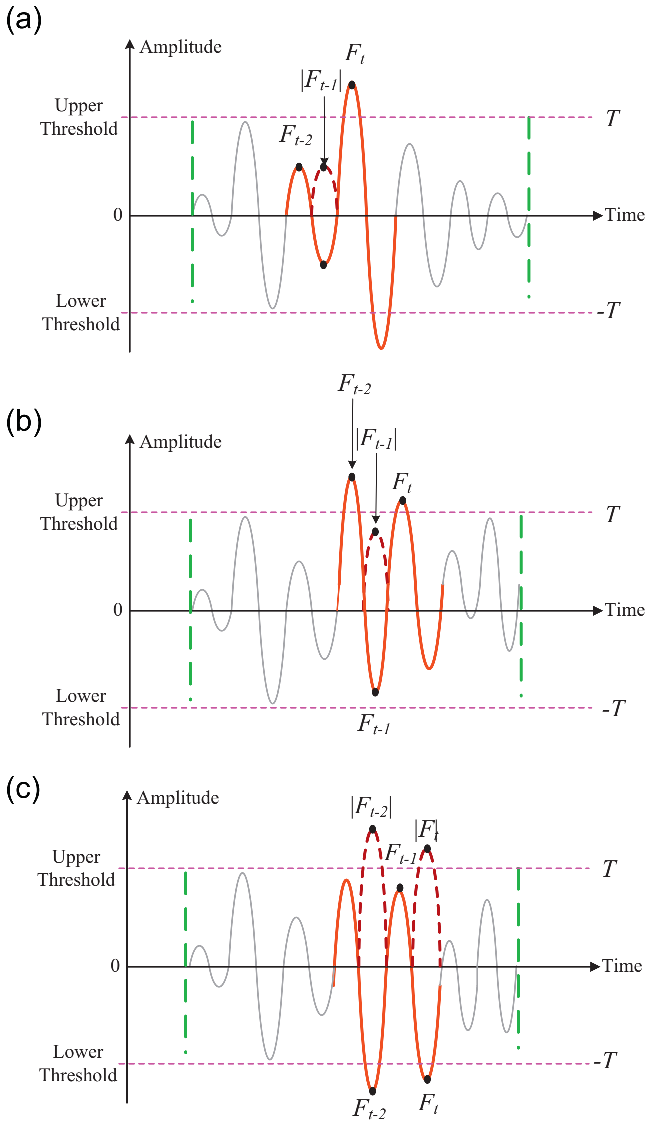

Fig. 3 – (a) The pairwise positive magnitudes and negative magnitudes of the pseudo EMG signal occur successively, (b) the continuous positive magnitudes of the pseudo EMG signal occur pairwise and (c) the continuous negative magnitudes of the pseudo EMG signal occur pairwise.

negative magnitudes (Fig. 3(c)) occur pairwise. Although the time interval is very short, the system determines if it exceeds the threshold twice that may cause typing errors.

To solve the mentioned problem, the previous two pseudo EMG amplitudes F_{t-1} and F_{t-2} should be considered when recognizing conscious blink according to Fig. 3(a)–(c). Hence, Eq. (3) could be modified as below:

$$\begin{cases} \text{conscious blink} & \text{if } (|F_t| \geq T) \wedge (|F_{t-1}| < T) \wedge (|F_{t-2}| < T) \\ \text{unconscious blink} & \text{otherwise} \end{cases} \quad (4)$$

Eq. (4) could be interpreted as the pseudo EMG amplitude F_t resulted from each blink is compared with the previous two pseudo EMG amplitudes. Through consciously blinking, the user can decide whether to select characters or activate certain function of scanning keyboard according to Eq. (4), and

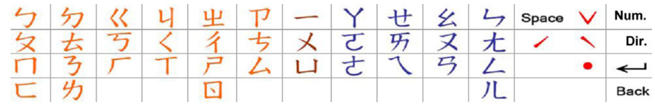

Fig. 4 – The scanning keyboard is composed of phonetic symbols and function keys.

the above misjudgment can be effectively prevented using this algorithm.

2.2. *The design of scanning keyboard*

The scanning keyboard allows the vocal, physical, and visual disabled to be able to independently communicate with others. The Chinese phonetic symbols are selected as input signals using blink control method, hence, the complete Chinese characters or sentences are typed on the computer screen.

2.2.1. *Phonetic symbol selection using column and row scanning*

The scanning keyboard is composed of 13 × 4, 52 grids, and each grid corresponds to a phonetic symbol or function key as shown in Fig. 4. To enable each grid of scanning keyboard to simulate the function of regular keyboard, each virtual key of scanning keyboard is linked with a key of regular keyboard through virtual key code. The transformation is shown in Table 1.

Table 1 – The transformation between each virtual key on scanning keyboard and a real keyboard.

Chinese phonetic symbol	Corresponding virtual key code
{"ㄅ","ㄆ","ㄇ","ㄈ"},	{0x31, 0x51, 0x41, 0x5A}
{"ㄉ","ㄊ","ㄋ","ㄌ"},	{0x32, 0x57, 0x53, 0x58}
{"ㄍ","ㄎ","ㄏ"},	{0x45, 0x44, 0x43}
{"ㄐ","ㄑ","ㄒ"},	{0x52, 0x46, 0x56}
{"ㄓ","ㄔ","ㄕ","ㄖ"},	{0x35, 0x54, 0x47, 0x42}
{"ㄗ","ㄘ","ㄙ"},	{0x59, 0x48, 0x4E}
{"ㄧ","ㄨ","ㄩ"},	{0x55, 0x4A, 0x4D}
{"ㄚ","ㄛ","ㄜ"},	{0x38, 0x49, 0x4B}
{"ㄝ","ㄞ","ㄟ"},	{0xBC, 0x39, 0x4F}
{"ㄠ","ㄡ","ㄢ"},	{0x4C, 0xBE, 0x30}
{"ㄣ","ㄤ","ㄥ","ㄦ"},	{0x50, 0xBA, 0xBF, 0xBD}
{"space","ˊ"},	{VK_SPACE, 0x36}
{"ˇ","ˋ","˙"},	{0x33, 0x34, 0x37}
{"number","direction", "Enter","Back"}	{VK_DOWN, VK_LEFT, VK_RETURN, VK_BACK}

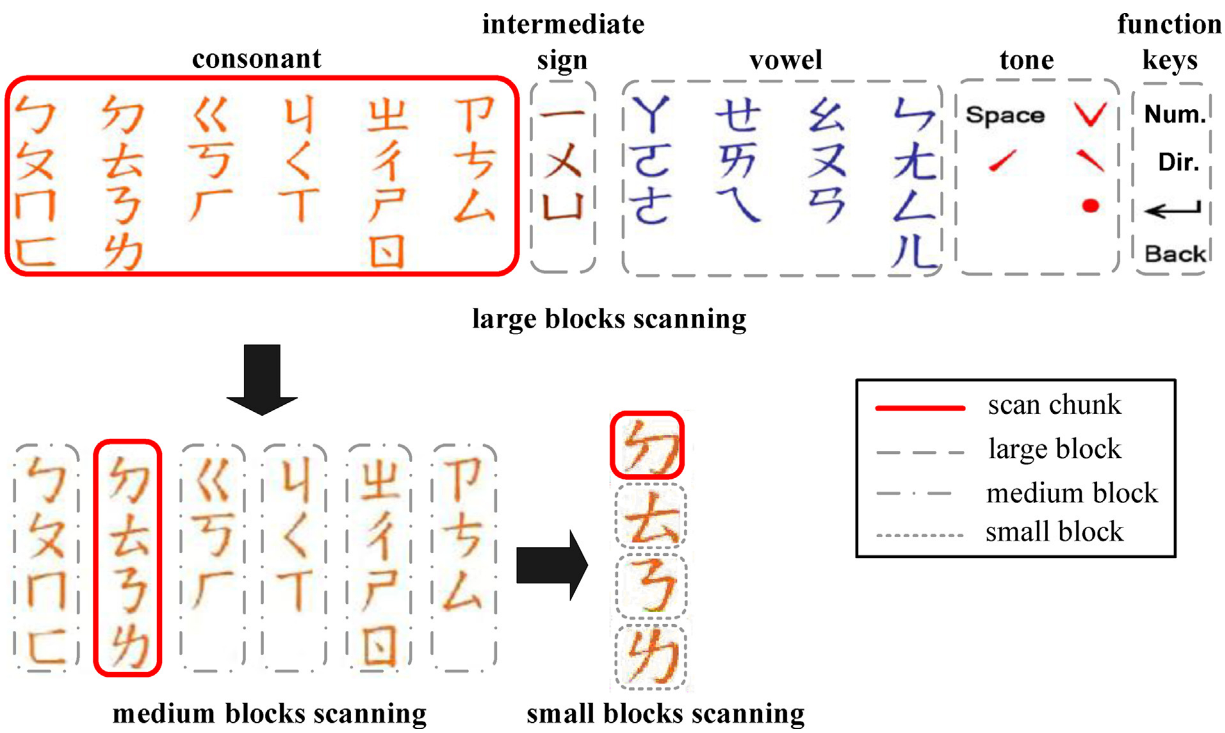

Fig. 5 – The scanning architecture of the phonetic symbols and function keys on the scanning keyboard.

In the scanning keyboard, each blink controls only one operation, while the other operations are controlled automatically by system at the same time. Therefore, the proposed keyboard is designed for automatic row and column scanning, and the users only need to select the desired phonetic symbols through conscious blinks. The phonetic symbols and function keys on the designed keyboard are divided into five large blocks; each large block contains medium blocks, and medium blocks contain small blocks. The large blocks are scanned automatically. When a large block is selected by the user through conscious blinks, the medium blocks are scanned, and then the small blocks are scanned. Hence, the phonetic symbols are generated, and complete words and sentences can be typed by repeating the above process as shown in Fig. 5.

If a wrong block is selected, the user should stop typing for two scanning cycles, and the scan chunk will return to scan the blocks of upper level automatically. While a wrong phonetic symbol is selected, the user needs to select the backspace key (Fig. 5) to delete the wrong symbol.

2.2.2. *Intelligent character selection function*

Due to the language feature of Chinese, there are a very large number of homophones in spelling. More specifically, there are many different Chinese characters with the same pronunciation and spelling, but with different meanings. To improve the typing speed and accuracy, an intelligent character selection function is implemented based on above premise in scanning keyboard. The Chinese phonetic system is composed of consonants, vowels, intermediate signs, and tones. To simplify the notations, every Chinese phonetic symbol is given a codeword for following illustrations as shown in Table 2.

The consonant, intermediate sign, vowel, or tone would only be selected once in spelling, and the tone is selected only when the spelling is finished. For example, when spelling "我" (the synonym of "I" in Chinese), the intermediate sign I_2 is selected first, the following one will not be a consonant but the vowel V_2, and finally the tone T_3. According to the same rule, when spelling "二" (the synonym of "Two" in Chinese), the first input is the vowel V_{13}, it is impossible to select a consonant or intermediate sign as the next input, and the only selection

Table 2 – Chinese consonants, vowels, intermediate signs, and tones.

Type	Composition of phonetic symbol
Consonant	ㄅ=C_1, ㄆ=C_2, ㄇ=C_3, ㄈ=C_4, ㄉ=C_5, ㄊ=C_6, ㄋ=C_7, ㄌ=C_8, ㄍ=C_9, ㄎ=C_9, ㄏ=C_{11}, ㄐ=C_{12}, ㄑ=C_{13}, ㄒ=C_{14}, ㄓ=C_{15}, ㄔ=C_{16}, ㄕ=C_{17}, ㄖ=C_{18}, ㄗ=C_{19}, ㄘ=C_{20}, ㄙ=C_{21}
Intermediate sign	ㄧ=I_1, ㄨ=I_2, ㄩ=I_3
Vowel	ㄚ=V_1, ㄛ=V_2, ㄜ=V_3, ㄝ=V_4, ㄞ=V_5, ㄟ=V_6, ㄠ=V_7, ㄡ=V_8, ㄢ=V_9, ㄣ=V_{10}, ㄤ=V_{11}, ㄥ=V_{12}, ㄦ=V_{13}
Tone	space=T_1, ˊ=T_2, ˇ=T_3, ˋ=T_4, ˙=T_5

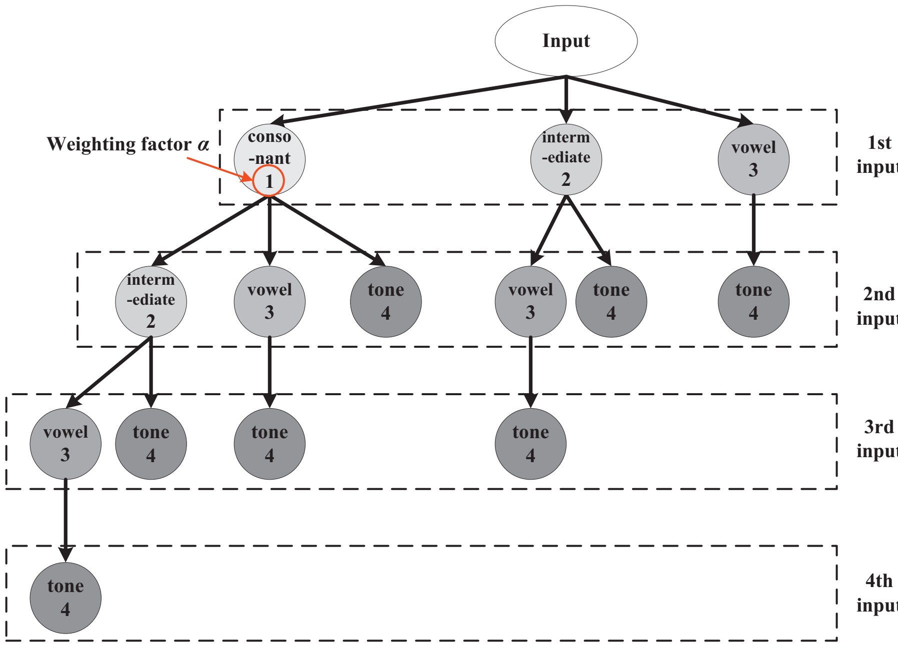

Fig. 6 – The possible input order of typing a single Chinese character.

would be the tone T_4. Hence, a weighting factor α could be set, $\alpha \in Z$ and $1 \leqq \alpha \leqq 4$, which corresponds to all the Chinese phonetic symbols, according to possible priority of input. The consonant, intermediate sign, vowel, and tone then could be expressed as the following crisp sets:

$$\text{Consonant} = \{C_1, C_2, \ldots, C_{20}, C_{21}\} = \{C_i | C_i = 5i + \alpha, \quad \alpha = 1, \quad 1 \le i \le 21\} \tag{5}$$

$$\text{Intermediate sign} = \{I_1, I_2, I_3\} = \{I_j | I_j = 5j + \alpha, \quad \alpha = 2, \quad 1 \le j \le 3\} \tag{6}$$

$$\text{Vowel} = \{V_1, V_2, \ldots, V_{12}, V_{13}\} = \{V_u | V_u = 5u + \alpha, \quad \alpha = 3, \quad 1 \le u \le 13\} \tag{7}$$

$$\text{Tone} = \{T_1, T_2, T_3, T_4, T_5\} = \{T_v | T_v = 5v + \alpha, \quad \alpha = 4, \quad 1 \le v \le 5\} \tag{8}$$

The weighting factor α could be interpreted as the priority of typing inputs, more specifically, the corresponding α of current input should be definitely greater than the α of previous input. Hence, the scanning keyboard could only scan the next possible blocks according to the α of current input entered by the user. The possible input order of typing a single Chinese character is concluded in Fig. 6, which also illustrates the rule of intelligent character selection function:

$$W(x_n) > W(x_{n-1}) \tag{9}$$

where $x_n, x_{n-1} \in \text{Tone} \cup \text{Vowel} \cup \text{Intermediate sign} \cup \text{Consonant}$ and $W(x) = x\%5$; x_n denotes the current typing input, x_{n-1} denotes the previous typing input, and $W(x)$ is the value of weighting factor of input x.

For example, if the user selects C_1, the corresponding weighting factor α is 1. Meaning the weighting factor α of next input must be greater than 1, thus, the next input could only be a vowel, a intermediate sign, or a tone, and the scanning keyboard will only scan the above three areas. Therefore, the typing speed of users could be improved according to the aforesaid principle. For other languages with the same spelling feature as Chinese, their phonetic symbols can be divided into several crisp sets in advance, and the concept of proposed intelligent character selection function can be directly applied.

3. Experimental results and discussion

A Bluetooth headset produced by Neuro Sky company is used in this paper for acquiring the pseudo EMG signal derived from blinking. The data were transmitted between the headset and the computer through Bluetooth with a customized port and baud rate. The headset has four sensors, three are at the left ear and the other one is at the left forehead, as shown in Fig. 1. The pseudo EMG signal reading frequency is set as 10 Hz, and the pseudo EMG signal is quantified as the integer value from −2048 to +2047. According to the experimental results, the pseudo EMG signal is within −1000 to +1000 when normal users are relaxed or blinking unconsciously, and the blinking strength is nonlinearly proportional to the absolute

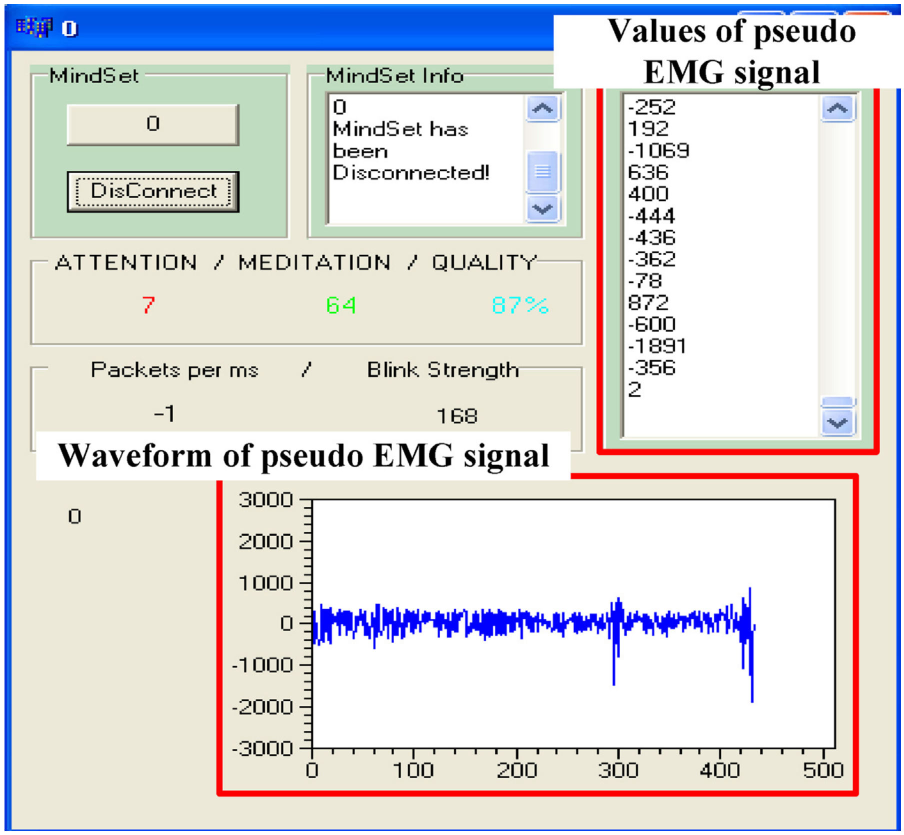

Fig. 7 – The software interface of pseudo EMG signal acquisition and Bluetooth connection.

value of pseudo EMG signal, and the maximum value is +2047 and the minimum value is −2048 in this system. Fig. 7 illustrates the software interface of pseudo EMG signal acquisition and Bluetooth connection.

Unlike other digital phonetic keyboards, the proposed system provides more independence. When running the scanning keyboard program, a virtual keyboard is built on the computer screen. The phonetic symbols are scanned in various chunks according to the intelligent character selection rule. The scanned chunk is circled in a red box, and the sound of scanned phonetic symbol is pronounced, hence, even the visually impaired can also operate the proposed system through this way. In addition, the scan interval could be increased and decreased depending on the users' capabilities. The human machine interface of blink scanning keyboard is shown in Fig. 8. The MS notepad will be opened automatically when the program is executed, and MS Word and other text software can be also switched to adopt to improve the level

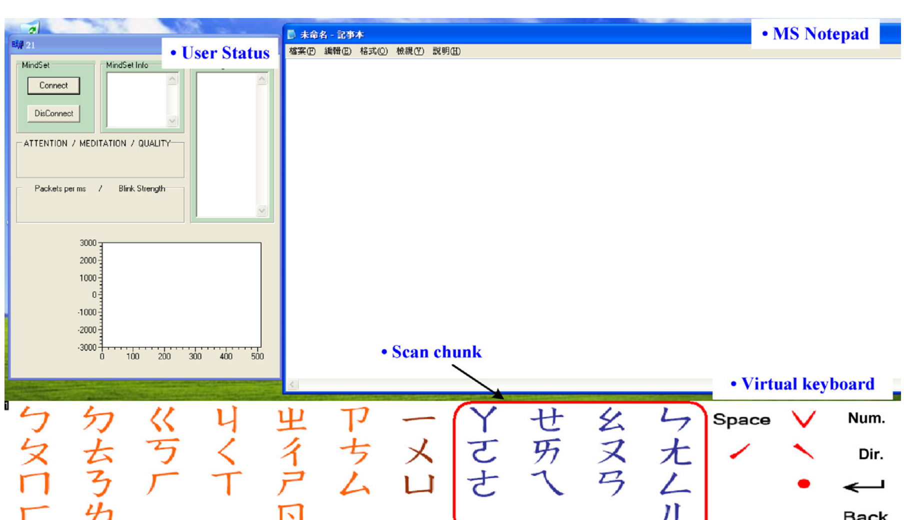

Fig. 8 – The human–machine interface of blink scanning keyboard.

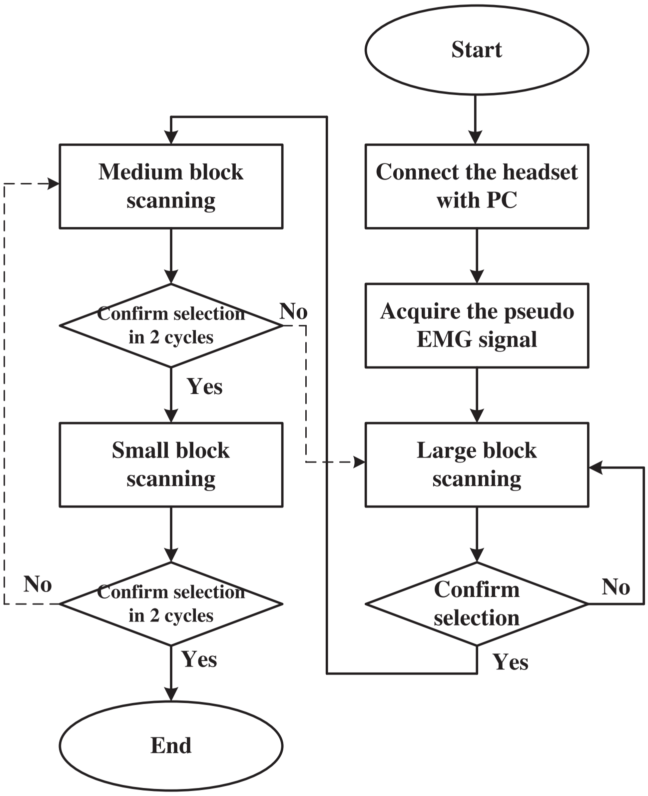

Fig. 9 – The operation flow of typing a single Chinese character with blink scanning keyboard.

of convenience. The operation flow of typing a single Chinese character with blink scanning keyboard is shown in Fig. 9.

The scanning keyboard is preliminarily tested by ten severely disabled users. Some of them suffer from motor neuron diseases, and only their eyes or a portion of limbs can move; while the rest users are severe cerebral palsy, their hands, fingers and legs cannot be controlled precisely due to the high tension of muscles. However, these users can still blink their eyes simultaneously, and the resulted pseudo EMG signal is strong enough to be detected by our design. Fig. 10 shows the result of scanning keyboard exercise, suggesting that the users could input about five Chinese characters per minute after ten days of exercise. It is worth pointing out that if the resulted pseudo EMG signal of a particular user is too weak to be detected, then the proposed scanning keyboard is not suitable to this special case. In other words, when the strength of conscious blink is very similar to the strength of unconscious blink by a particular user, the proposed scanning keyboard would yield misjudgments and become inapplicable.

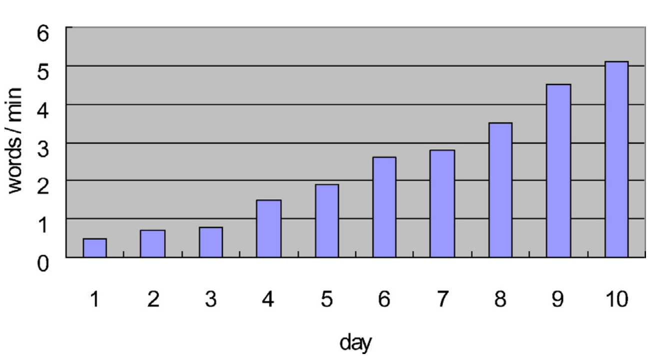

Fig. 10 – The result of scanning keyboard exercise with ten users with motor neuron diseases or severe cerebral palsy.

Table 3 – Comparison between proposed system and a former research.

Comparison	Type	
	Former research for eye tracking [6]	Proposed method
Adjust method	5 points correction	No need to adjust
Adjust time (s)	Average 30	0
Typing speed (s)	90–120 per word	20–40 per word
Cost	High	Low

The blink control system is also compared with the eye-tracking system developed by Lin et al. [6] as a former research, and the results are concluded in Table 3. Moreover, the proposed system is more applicable compared with other studies: it is unnecessary to learn any additional knowledge in advance, and the method of application is easy and not necessary to control δ wave, θ wave, α wave, and β wave, only the blinking strength need to be controlled, which is specifically suitable for the severely physical disabled and people suffering from motor neuron diseases or severe cerebral palsy.

4. Conclusions

A scanning keyboard with the concept of “blink control” is proposed in this paper. As the real-time variation of pseudo EMG signal exceeds the determined threshold, the function of scanning keyboard can be triggered. Typing by blink control and row/column scanning options of the scanning keyboard are convenient and innovative designs, and the typing time is shortened by adopting an intelligent character selection function. Compared with the traditional eye-tracking devices and eye-controlling systems, this blink control system is small, light, portable, and easily installed.

Many users suffer from motor neuron diseases, severe cerebral palsy and other serious diseases, where their body becomes gradually immovable, and only a portion of their eyes or limbs can act. The proposed design enables users with above severe disabilities to use these aids by simple blinks, providing a clear operating environment for the physical disabled. According to the experimental results, the scanning keyboard has been tested by ten users with motor neuron diseases or severe cerebral palsy, and also modified according to their opinions. Therefore, the proposed scanning keyboard has been improved and has good stability and practicability.

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