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Design and implementation of an eye gesture perception system based on electrooculography

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ABSTRACT

People with motor diseases have suffered from deprivation of both verbal and non-verbal communication abilities. Fortunately, some of them still retain coordination of brain and eye-motor. To establish a stable communication way for these disabled people, this paper presents an eye gesture perception system based on Electrooculography (EOG). In order to implement a high-accuracy of unit saccadic EOG signals recognition, we propose a new feature extraction algorithm based on Common Spatial Pattern (CSP). We first establish a CSP spatial filter bank corresponding to 8 saccadic tasks (i.e., up, down, left, right, right-up, left-up, right-down, and left-down), then use it to linearly project raw EOG signals and treat the outputs as feature parameters. Furthermore, eye gestures recognition has been carried out by identifying and merging unit saccadic segments in terms of pre-defined time sequences. Experiential results over 10 subjects show that the recognition precision of unit saccadic EOG and eye gesture are 96.8% and 95.0% respectively, which reveal the proposed system has a good performance of eye gestures perception.

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1. Introduction

Nowadays, thousands of people are currently suffering from motor diseases such as injured-vertebra, apoplexy or poliomyelitis, Motor Neuron Disease (MND), Amyotrophic Lateral Sclerosis (ALS), etc. (Deng, Hsu, Lin, Tuan, & Chang, 2010). These diseases have extremely limited their peripheral mobility or even speech, and the patients have few possibilities to communicate. Fortunately, most of them still retain coordination of brain and eye-motor (Birbaumer, 2006; Postelnicu, Girbacia, & Talaba, 2012). Since eye movements can be controlled volitionally to some degree and tracked by the modern techniques, eye movements detection is a feasible approach to establish a way of communication in these cases. Eye gesture, a consecutive sequence of distinct relative eye movements segments, provides richer interaction commands by combining them according to different time sequences (Vaitukaitis & Bulling, 2012). The higher the accuracy of eye gestures perception are, the better communication practicability is. Thus, achieving a high-accuracy eye movement detection is a crucial challenge for establishing a practical eye gesture-based communication system.

One of the most popular approaches for eye movement detection is based on video analysis, which has been attracted considerable attention in recent years. For example, Tafaj et al. performed an unparameterized, adaptive Bayesian online clustering algorithm to distinguish saccades from fixation clusters (Tafaj, Kasneci, Rosenstiel, & Bogdan, 2012); Santini et al. presented an online Bayesian decision theory identification algorithm to extend identifiable types of eye movement, i.e., fixations, saccades, and smooth pursuits (Santini, Fuhl, Kübler, & Kasneci, 2016); Similarly, Raimondas et al. employed a random forest machine learning technique to detect fixations, saccades, and post-saccadic oscillations (Zemblys, Niehorster, Komogortsev, & Holmqvist, 2017); Nystrm and Holmqvist designed an adaptive velocity threshold to classify fixation, saccade, and glissade (Nyström & Holmqvist, 2010). Furthermore, some practical video-based Human Computer Interaction (HCI) systems have been developed. Among them, Zhang et al. proposed a gaze gestures recognition system by computing isophote and gradient features of eye movement video stream (Zhang, Smith, Smith, & Farooq, 2016); Braunagel et al. presented a driver-activity recognition system using video-based eye-tracking data combined with head tracking data under conditionally autonomous driving scenarios (Braunagel, Kasneci, Stolzmann, & Rosenstiel, 2015); Steil and Bulling used long-term visual behavior

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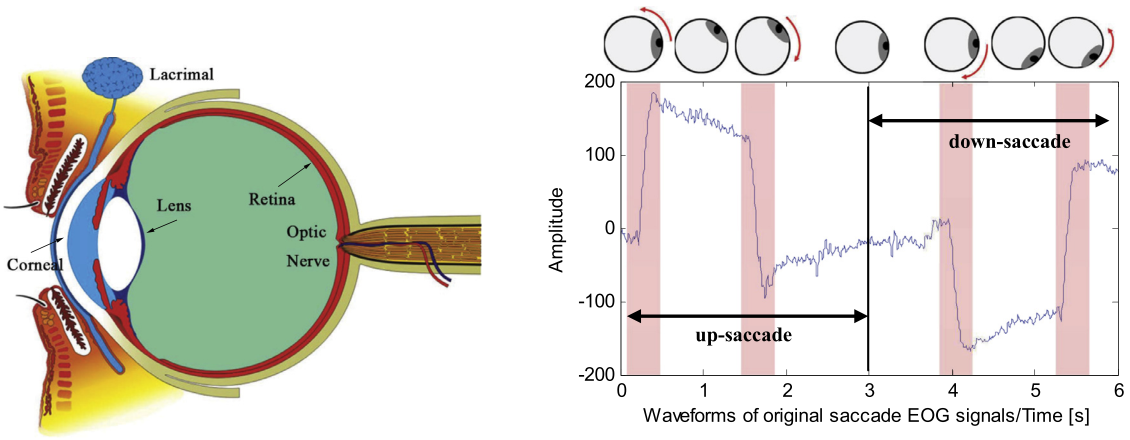
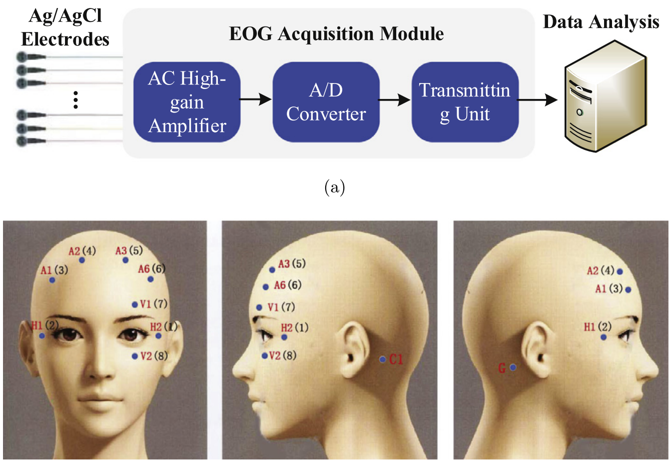


(a) (b)

Fig. 1. Fundamental principle of EOG generation: (a) the anatomy of the eyeball, (b) the denoised EOG signals with marked segments showing the two main eye movement characteristics: up-saccade and down-saccade.



(a)

(b)

Fig. 2. EOG acquisition system. (a) the block diagram of EOG acquisition instrument, (b) the positions of EOG electrodes. A1, A2, A3, A4, V1, V2, H1, H2, G and C1 are names of Ag/AgCl bio-electrodes. Blue dots are their positions, and numbers in brackets are the index of bio-electrodes.

data to recognize everyday human activities, such as eating, reading, or being on travel without supervision (Steil & Bulling, 2015).

The most challenging research for the video-base method is illumination change. In order to overcome this problem, Fuhl et al. used edge filtering and ellipse evaluation algorithm to enhance the robustness in real-world scenarios (Fuhl, Santini, Kübler, & Kasneci, 2016); Dongheng et al. integrated feature-based and model-based approaches to acquire stable eye tracking (Li & Parkhurst, 2005); Zhiwei et al. combined Kalman filtering and mean shift to suppress the effects of active illumination (Zhu, Ji, Fujimura, & Lee, 2002). Although the above algorithms have obtained improvement of detection robustness, the performance of the video-based method cannot be guaranteed in dark or insufficient illumination environments. Electrooculography (EOG), a measuring technique used in this work, provides another possibility to record eye movements (Barea, Boquete, Mazo, & López, 2002a). Compared with the video-based method, illumination change has little impact on EOG (Majaranta & Bulling, 2014), and it is also an inexpensive method for long-term eye movement recording (Barea, Boquete, Ortega, López, & Rodríguez-Ascariz, 2012; Bulling, Ward, Gellersen, & Troster, 2011; Deng et al., 2010). Meanwhile, the video-based method is generally not adopted for 24-hour detection task due to the drastic change of illumination during the whole day time (Hansen & Ji, 2010; Li, Zhu, & Chen, 2016). As an effective complementation of the video-based method, the EOG-based approach can facilitate the improvement of eye movement detection without any requirement on environmental illumination. At present, several EOG-based HCI systems have been implemented, such as the wheelchair controller (Barea, Boquete, Mazo, & López, 2002b), the visual navigation interface (Postelnicu et al., 2012), a virtual keyboard (Usakli & Gurkan, 2010), etc., which have proven the validity of the EOG for HCI applications.

During the procedure of implementing EOG-based HCI systems, saccade detection, the simultaneous movement of both eyes (Bulling et al., 2011), is a key step. To complete this function, some remarkable methods have been proposed. In which, Clement (Clement, 1991) used the visual angle of raw EOG signals in the time-domain to extract saccadic segment and transfer them to the recognizer. Aungsakun (Aungsakun, Phinyomark, Phukpattaranont, & Limsakul, 2011) and Soltani (Soltani & Mahnam, 2013) found that amplitude of eye movement signals could produce a rapid change when eyeballs are rolling, and this characteristic could be utilized to extract eye movement parameters. In addition, Vidal (Vidal, Bulling, & Gellersen, 2011) and Bulling (Bulling, Weichel, & Gellersen, 2013) employed statistical features (e.g., mean, variance, direction, continuous wavelet coefficients, etc.) to recognize eye movement. These methods, however, are mainly concentrated on time/frequency-domain characteristics extraction and single-channel unit EOG signals analysis, while ignore the spatial-domain information which can provide richer distinguishable characteristics to accurately identify unit eye movement signals.

To address this problem and improve the performance of EOG-based saccadic detection, a feature extraction method based on Common Spatial Pattern (CSP) was presented in this paper. Initially, we computed the space position information of eye movement sources using the CSP algorithm, which is able to present a clear distinction at pre-defined saccadic tasks (i.e., up, down, left, right, right-up, left-up, right-down, and left-down). On this basis, we further designed an 8-class eye gesture (i.e., vertical, horizontal, diamond, “Z” model, square (CW), square (CCW), plus, and multiply) perception algorithm by capturing and analyzing consecutive unit saccadic signals in terms of different time sequences. The experimental results validated the feasibility of using EOG to

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