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Research article

Multi-target way of cursor movement in brain computer interface using unsupervised learning

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ABSTRACT

Brain-Computer Interfacing(BCI) helps physically disabled people to control multidimensional cursor movement in a real-life scenario. Noninvasive BCI techniques play a major role for this purpose. In this paper, we have proposed three algorithms of cursor movement using three well-known clustering methods (Minimum distance, DB-Scan and Gaussian Mixture Model). These proposed techniques are generally tested on motor imagery EEG data. We have performed multi-target based cursor movement using our previously proposed “FindTarget” algorithm (used for single target based cursor movement). However, we have also performed the comparative analysis of these three proposed algorithms based on internal & external validation indices and identified the best one for multi-target based cursor movement. The average accuracy of our proposed model is 68.4% (Kaggle dataset) and 70.36% (Openvibe dataset). We have evaluated the execution time of the proposed algorithms and found the most efficient proposed algorithm(O(n)) with respect to time and space for both the datasets. The result indicated that our proposed method gives more accuracy than all the previous methods of cursor movement. Our proposed method is more reliable, timely-efficient and experimental setup independent compared to other existing methods. If we choose the suitable algorithm based on time and space complexity then response time of multi-target based BCI system will be improved so that disabled people can effectively communicate with the external world.

Introduction

Brain-Computer Interface (BCI) is a useful communication system for physically disabled people with the neuromuscular disorder that does not require any peripheral muscular activity. The instructions generated by the brain can be represented as Electroencephalography (EEG) signal which contains some rhythmic pattern according to human's internal thought. The BCI reads the waves produced from the brain at different locations in the human head, translates these signals into device-specific actions or commands. BCI technology has mainly consisted of 4 sections (Signal acquisition, Signal processing, Feature extraction and classifications, Application Interface). Initially, raw EEG signal is captured from different electrodes in “signal acquisition” section. After the “signal acquisition” phase, the raw EEG signal is digitized, amplified and filtered in “signal processing” section and the useful features are extracted in “feature extraction” phase using different feature extraction process (Discrete Wavelet Transform, Power spectral density etc). Then based on useful features, the classification process is performed and finally, the output of classification phase has passed to the application interface. The application interface converted the signal into device-specific commands to interact with BCI system (Chakladar & Chakraborty, 2018).

Cursor movement is one of the important topics in BCI as with the efficient cursor movement paralyzed people can communicate more quickly with the external world. Many works have done on 1D,2D cursor movement but this is the first work for multitarget based cursor movement using unsupervised approach. The brain signal has captured using 32 and 11-channels electrode cap. Different electrodes are responsible for performing different actions of the brain. Electrodes (C3, C4, Cz etc) placed over the central cortex is related with motor and sensory functions and as we consider the only right-hand movement of the subject so we have only considered channel value of C3 electrode. In the Fig. 1, we have marked the specific electrode (C3) in the 10–20 electrode placement system for better observation. In our previous paper (Chakladar & Chakraborty, 2017), we have described the efficient way of cursor movement to a single target. The block diagram of cursor movement to single target has shown in Fig. 2. Initially cursor and target are set on the computer screen (Fig. 2(A)). After some time cursor moves to the fixed target (Fig. 2(B)) and when the cursor reaches the target then the target has vanished (Fig. 2(C)). Once the target has

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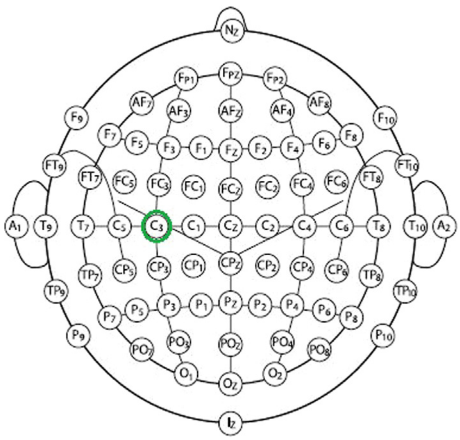

Fig. 1. Electrode placement as per 10–20 system Nomenclature, 1991. C3 is marked for right hand movement.

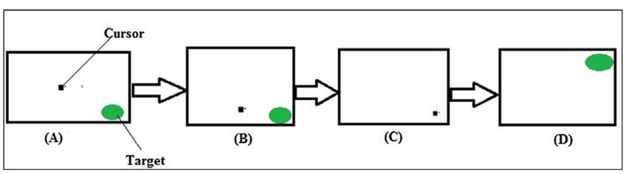

Fig. 2. Block diagram of cursor movement to a fixed target in BCI.

vanished then a new target has been appeared on the screen (Fig. 2(D)). In case of multi-target based cursor movement, a set of targets are assigned to a cluster based on selected clustering algorithm. The cursor has assigned to any cluster and cursor moves to the nearest target iteratively until all the targets within that cluster have vanished. When the cursor reaches the last target then entire cluster gets vanished.

In our paper, we have discussed multi-target based cursor movement using three clustering methods. After performing all types of analysis (behavioral, computational, performance) between three different methods of cursor movement, we find out the best method of cursor movement. If we choose the best method of cursor movement then bit transfer rate will be maximized which refers to higher throughput of the BCI system. This paper is organized as follows. Some prior works based on cursor movement with their applications and performance are discussed in Section "Literature review". In Section "Proposed work", we have described the proposed algorithm of cursor movement to multi-target based BCI system using three clustering methods (Minimum distance, DB-Scan, GaussianMixtureModel). In Section "Result and analysis", we have mentioned detail description of the datasets (Section "Datasets") and subjects (Section "Subjects") who participate in the experiment. In Section "Procedure", we have mentioned the procedure/design of experiment (two offline sessions based on "Kaggle" and "openvibe" dataset). Based on the two experiments mentioned in Section "Procedure", we have analyzed our algorithm and evaluated the performance of each proposed algorithms using different validation indices. Section "Discussion" shows the effectiveness of the proposed algorithm. Finally, In Section "Comparison with previous studies" we have compared our proposed algorithm with some previous studies and Section "Conclusion and Future work" gives the conclusion of this paper.

Literature review

In last four decades, the research activities on brain-computer interfacing grow rapidly by overcoming several challenges. In the paper (Allison et al., 2012), the author has described a new type of BCI where the subject has controlled vertical cursor movement using Event-related De-synchronization (ERD) activity and horizontal movement using Steady-state visually evoked potential (SSVEP) activity. Decision tree-based classification is applied on EEG signal for classifying the 2-D cursor movement of motor imagery BCI data (Aydemir & Kayikcioglu, 2014). In our previous work (Chakladar & Chakraborty, 2017), We have implemented a multi-threaded, computational cost-effective algorithm ("FindTarget") for cursor movement in 2D environment. In the paper (Fabiani, McFarland, Wolpaw, & Pfurtscheller, 2004), the author implements a function by which disabled people can control the cursor in three directions. The degree of freedom of cursor movement has increased. It has been shown that 2-D cursor movement control and target selection can also implement in hybrid EEG based BCI system. Besides unsupervised clustering approach, supervised classification approach is also useful for effective EEG based classification in brain-computer interfaces (Jayaram, Alamgir, Altun, Scholkopf, & Grosse-Wentrup, 2016). In paper (Kashyap & Bhattacharya, 2017), the author has described a new concept called "vicinity" for grouping the spatially distributed data points in the dense region. Motor imagery and P300 potential have used to control the horizontal and vertical movement of the cursor. In paper (Li, Ma, & Ogihara, 2004), the author has partitioned the data into the correct cluster and applies an internal index on that partition. A new EEG-based BCI system has been developed by grouping mu/beta rhythm during motor imagery and P300 potential. This study uses two independent signals to control the 2D cursor-control and the hybrid system also allows the subjects to move the cursor to arbitrary positions (Li et al., 2010). Hybrid feature classification has been done using SVM for target selection in the paper (Chakladar & Chakraborty, 2018; Long, Li, Yu, & Gu, 2012). Multi-target based Noninvasive BCI has discussed in the paper (McFarland, Krusienski, Sarnacki, & Wolpaw, 2008), where the author has used two sets of sensorimotor-rhythm for horizontal and vertical movement of the cursor and try to choose the appropriate target on the screen. EEG based BCI has been implemented for totally paralyzed people using digital signal processing technology (McFarland, Lefkowicz, & Wolpaw, 1997). This work includes multi-dimensional movement control and sequential target selection with non-invasive BCI technology. In paper (McFarland, Sarnacki, & Wolpaw, 2010), the author has described the three different movements of scalp-recorded EEG activity to reach the targets. All these activities aim to incorporate intelligent brain control system. In the paper (McFarland & Wolpaw, 2003), the author has described the speed, accuracy, and relationship between them of EEG based BCI and also implemented a controller using which the author demonstrated the gain during cursor movement for the different position of a large number of targets. Cursor movement using invasive BCI has useful applications in robotic arm control (Wolpaw & McFarland, 2004). A paper (Xing-Yu, Jing, Zhang, & Bei, 2013), investigated novel EEG patterns and feasible methods to elicit more discriminative brain activities.

Proposed work

In BCI system, scalp voltage of people are captured from EEG channels and then the signal is amplified, digitized, spatially filtered so that people can control the μ or β rhythm amplitude to move the cursor which is appeared on the computer screen (Wolpaw, McFarland, & Vaughan, 2000). In multi-target based BCI system, multiple targets are distributed into several clusters and the brain signal captured from different electrodes interpreted as a cursor. The cursor is assigned to any cluster based on the similarity measure (Euclidean distance) with the set of targets. Once the cluster is formed then cursor movement within that cluster has been performed. To implement the cursor movement towards multiple targets we have used three different