Advancing Motor Imagery based BCI and its Applications

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The motor imagery (MI) based BCI uses cortical activations resulting from MI tasks to create a direct communication link between human brain and computing devices. Its major advantage is that it can facilitate a self-paced natural communication channel between the user and assistive systems as well as has potential to support motor recovery in post-stroke paralysis. However, several factors such as non-stationary brainwaves, and time-varying electrode characteristics and mental states, may degrade its performance significantly [1]. Additionally, some subjects are not so good in performing MI, categorised as having BCI aphasia but do improve with practice. Also, in motor recovery applications, initial moderate performance of novice stroke sufferers may cause frustration and impede recovery. To account for these performance degrading effects, recently we have undertaken investigations in primarily in three main areas: signal processing, multi-sensor integration, and applications involving brain-actuated wheelchair/mobile robot control and BCI-supported stroke rehabilitation.

Signal processing and multi-sensor integration

As a result of non-linear dynamics, EEG signal distribution is known to be non-Gaussian during motor imagery. A higher order statistics, the bispectrum, should theoretically be zero for Gaussian distribution and non-zero only if the distribution is non-Gaussian. The bispectrum method has been used to extract features of nonlinear interactions over several frequency components from MI-related EEG signals. A BCI designed using the bispectrum features along with an LDA classifier [2] has been found to provide enhanced feature separability and robustness against noise. Simultaneous recording of EEG and ECG signals were made while six healthy subjects performed effortful MI tasks. A hybrid BCI designed by integrating features extracted from both EEG and ECG [3], provided significant enhancement in performance compared to the case when either of the features were used alone.

Applications

An MI BCI has been applied for providing neurofeedback to five chronic hemiplegic stroke sufferers undertaking MI practices as part of a rehabilitation protocol involving both MI and physical practices of a rehabilitation task of 30 minutes duration each [1]. All five patients achieved improvement in at least one of the two rehabilitation outcomes, Action Research Arm Test (ARAT) and grip strength (GS) and these two were found sufficient to monitor incremental functional gains during the intervention for all patients. The improvements approached a minimal clinically important difference (MCID) for the ARAT. However the task classification accuracy (CA) rate improvements obtained with 11 to 12 sessions of practice over a six week period, were not statistically significant. Nevertheless, the cortical activations in terms of event related de-synchronisation/synchronisation (ERD/ERS) were found to be correlated with changes in rehabilitation outcomes. However, for only two participants, the ERD change was statistically significant between the first and the last session. It was felt that for significant enhancement in CA rates, the study should run much longer, i.e. at least 20 or more sessions. Overall, however, the crucial observation is the fact that the moderate BCI classification performance did not impede the positive rehabilitation trends. Therefore the study concluded that the BCI supported MI practice is a feasible intervention.

Challenges and Way Forward

Human beings use multiple mediums for communication, e.g. speech, hand gesture, changes in face and voice level. Multiple brain areas are involved in processing any perception-action [1]. Enhanced performance through multi-modal and distributed hybrid BCI design, unsupervised adaptation, better brain modelling, and robust decoder design, environment monitoring, and intelligent electrode assembly, may go a long way in making the MI BCI more practical. Systems need to be designed so that even with lower accuracy, its use is practical, e.g. BCI may act only at the executive level and delegate the task. In terms of motor recovery, further work and extensive controlled trials are required to be undertaken to ascertain most appropriate content, dose and frequency of MI/physical practices. Also there is a need to investigate whether MI/physical practices through imitation learning in a team can provide enhanced recovery. Mental state monitoring maybe needed to assess the fatigue and accordingly decide appropriate exercise doses.

Acknowledgements

This research has been supported by grants from InvestNI and Northern Ireland Development Fund, Leverhulme Visiting Fellowship, Ulster University Research Council Support Fund, and UK India Education and Research Initiative (UKIERI).

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