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Individual Optimization of EEG Channel and Frequency Ranges by means of Genetic Algorithm

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Abstract— **It is well established that motor action/imagery provokes an event-related desynchronization (ERD) response at specific brain areas with specific frequency ranges, typically the sensory motor rhythm and beta bands. However, there are individual differences in both brain areas and frequency ranges which can be used to identify ERD. This often results in low classification accuracy of ERD, which makes it difficult to implement of BCI application such as the control of external devices and motor rehabilitation. To overcome this problem, an individually optimized solution may be desirable for enhancing the accuracy of detecting motor action/imagery with ERD rather than a global solution for all BCI users. This paper presents a method based on a genetic algorithm to find individually optimized brain areas and frequency ranges for ERD classification. To optimize these two components, we designed a chromosome consisting of 64-bit elements represented by a binary number and another 9-bit elements using 512 pre-defined frequency ranges (2^9). The average value of the significant level is set for the properties of the objective function for use in a *t*-test, ($p < 0.01$) depending on the random selection from a concurrent population. As a result, contralateral ERD responses in the spatial domain with individually optimized frequency ranges showed a significant difference between resting and motor action. The ERD responses for motor imagery, on the other hand, led to a bilateral pattern with a narrow frequency band compared to motor action. This study provides the possibility of selecting optimized electrode positions and frequency bands which can lead to high levels of ERD classification accuracy.**

I. Introduction

In general, most studies involving a brain-computer interface (BCI) reported a short lasting block/decrease of the frequency power or event-related desynchronization (ERD) in the sensory motor rhythm (SMR) band (8-12 Hz) and in the beta band (13-30 Hz), with a time of only a few seconds as a result of self-paced motor action [1], [2]. Motor imagery, defined as the mental simulation of kinesthetic movement, could generate SMR in the sensorimotor cortex without and physical movement of the body [3]-[5]. The ERD in the SMR and beta band starts bilaterally over the primary motor areas. ERD in the beta band is largely contralateral before dominant hand movement, where it is bilateral before non-dominant hand movement [6]. It has been also well established that the imagination of dominant hand movement results in ERD of the SMR-band power in the contralateral sensorimotor areas [7], [8]. However, individual differences with respect to brain areas and frequency ranges may result in low accuracy as regards motor action/imagery. Therefore, individual optimization may be desirable for enhancing the accuracy when attempting to detect motor action/imagery as opposed to seeking a general solution. The goal of this study was to establish an optimization algorithm that can help individuals obtain their own optimal ERD responses of brain areas and frequency ranges. We demonstrated our developed optimization method using a genetic algorithm by acquiring EEG datasets from four participants.

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II. Methods

A. Subjects

The original sample consisted of four healthy volunteers (only males; mean age 30 ± 1.9 year) who participated in two experimental sessions on the same day. All subjects were right-handed without any medical or psychological disorders. The experiment was approved by the KIST (Korea Institute of Science and Technology) Institutional Review Board, and all subjects gave their written informed consent regarding the study. None of the participants had previous background knowledge or experience with BCIs. All experiments were conducted in the Center for Bionics at KIST.

B. Experimental Protocol and Data Acquisition

The experiment was designed as alternative stimuli by motor action and motor imagery according to a visual and auditory cue. Fig. 1(a). shows the experimental protocol, which was performed fifty times trials per session. All participants underwent four independent sessions. Therefore, 200 trials (epochs), consisting of 100 trials of motor action and the rest for motor imagery were completed during the experimental protocol. Given that we needed to monitor the brain activity patterns of the participants for their overall whole brain areas, multi-channel EEG was recorded from active electrodes placed at the extended international 10-20 system (64 channel) with a head cap designed for the Biosemi™ system (see Fig. 1(b)). The electrode impedance was kept lower than 5 Kohm. The acquired signal was filtered between 0.5 and 100 Hz and sampled at 256 Hz. A 60 Hz notch-filter was used to reject power line noise. After EEG signal acquisition, multi-channel EEG signals were converted to a common average reference (CAR) to offset any common noise components.

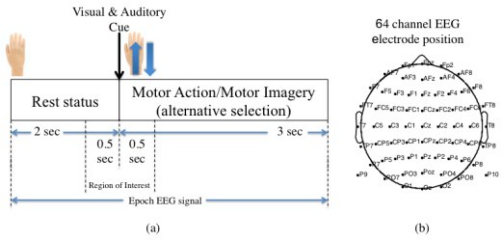


Figure 1. (a) The experimental protocol was as follows: one epoch (5 s) with arm reaching performed repeatedly was referred to as one session (50 trials). After one session ended, participants took a break with their eyes open for 30 s. The session then was repeated four times. The region of interest was 0.5 seconds before and after the visual and auditory cue. (b) Electrode placement.

C. *Feature Extraction and Optimization Procedure*

We used a random band power feature over 0.5 s to extract discriminative information under two conditions (resting vs. motor activity and resting vs. motor imagery). Specifically, we used 512 frequency bands (using a FFT filter, e.g., 1-3 Hz, 1-4 Hz, … 18-24 Hz, …, and, 30-33Hz, 31-33 Hz) with sixty-four sites. The extracted features of filtered signals can be obtained by means of averaging power of normalized EEG in all trials[9].

In order to find optimal values for both electrode sites and frequency bands, we developed an optimization method for finding brain areas and frequency ranges related to motor action/imagery (see Fig. 2). An optimization method was constructed based on a genetic algorithm and on a statistical analysis. A designed model structure of these two components, the brain area and the frequency range, was applied to the genetic algorithm as a 73-bit chromosome. The finding of the optimized chromosome with two components was applied to *t*-tests at $p < 0.01$, and this was then applied to every possible combination of electrode selection (brain area) and frequency

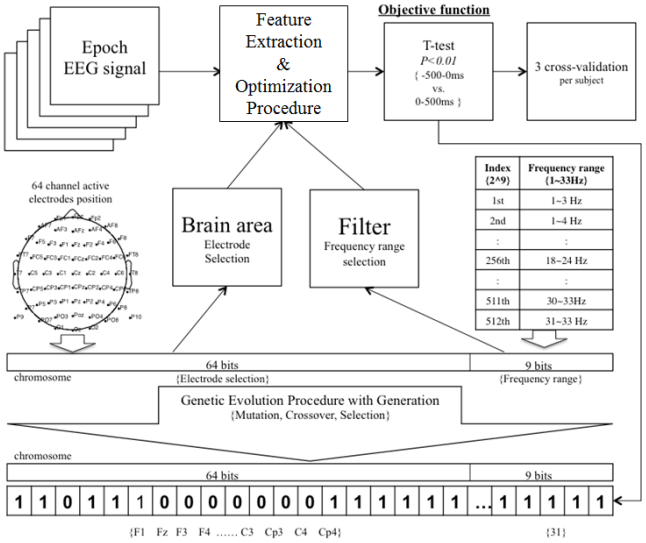


Figure 2. Optimization procedure using a genetic algorithm; 73 bits chromosome (64 channel EEG signal, 2^9 frequency range), population size of 100, generations limited to 100, with a crossover rate of 80 percent using a scattered method and a mutation rate of 0.01. A roulette selection method was used to choose parents - simulating a roulette wheel.

range (band-pass filter setting) between the resting state (-500-0 ms) and motor action/imagery (0-500 ms). The convergence criterion of the objective function with an average p value of 0.0001 was set up to prevent the over-fitting of the optimization procedure of the genetic algorithm.

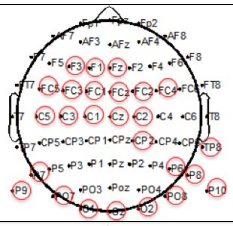
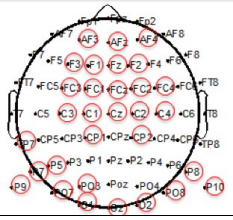
III. Results and Discussion

The results demonstrated that it is possible to optimize brain areas and frequency ranges related to motor action/imagery using a genetic algorithm. Among three independent cross-validation trials, the electrode selection has a rule that is similar to the relative frequency, where the optimal solution was presented more than two-thirds of the time. The left column in Table 1-4 show the spatial response maps for the individually optimized brain areas, where the red circles represent the surviving marks, which show significant differences ($p < 0.01$) between the resting and motor action/imagery states. The right column in Table 1-4 show the ERD response for the individually optimized frequency ranges, where the three selected frequency ranges represent the best ERD response for each cross-validation trial.

Table I shows that the engaged brain areas for motor action presented significant SMR differences ($p < 0.01$) between the resting status (-500-0ms) and motor action (0-500ms) from the frontal, left central, and occipital areas. In the motor imagery trials, they were showed a similar selection of the brain area and the frequency range, but a difference in the left and right hemisphere was not noted.

In Table II, the engaged brain areas for motor action presented significant beta differences ($p < 0.01$) between the resting status (-500-0ms) and the motor action (0-500ms) from the frontal, central, and right occipital areas. In the motor imagery trials, they showed different selected patterns for the

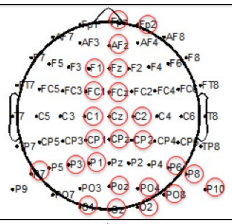
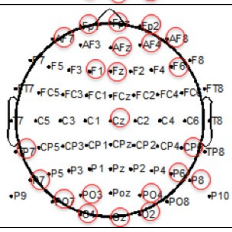
TABLE I. Selected Electrodes and Frequency Ranges Through the Genetic Algorithm with Respect to Motor Action/Imagery (N = 200 trials); {Subject 1}

Selected Electrodes {Average selection rate>=2/3}	**Selected Frequency Range (Independent Cases)**
Motor Action[a] 	9 – 15 Hz 8 – 14 Hz 8 – 13 Hz
Motor Imagery[b] 	9 – 12 Hz 8 – 14 Hz 9 – 13 Hz

a. Motor action: 27 electrodes (F1, F3, FC5, FC3, FC1, C1, C3, C5, P7, P9, PO7, O1, Iz, Oz, Fz, FC4, FC2, FCz, Cz, C2, TP8, CP2, P6, P8, P10, PO8, and O2).

b. Motor imagery: 32 electrodes (AF3, F1, F3, FC3, FC1, C1, C3, TP7, CP1, P5, P7, P9, PO7, PO3,O1, Iz, Oz, AF4, AFz, Fz, F2, FC4, FC2, FCz, Cz, C2, C4, CP2, P8, P10, PO8, and O2).

TABLE II. SELECTED ELECTRODES AND FREQUENCY RANGES THROUGH THE GENETIC ALGORITHM WITH RESPECT TO MOTOR ACTION/IMAGERY (N = 200 TRIALS); {SUBJECT 2}

Selected Electrodes {Average selection rate>=2/3}	Selected Frequency Range (Independent Cases)
Motor Action[a] 	19 – 32 Hz 21 – 29 Hz 9 – 32 Hz
Motor Imagery[b] 	2 – 13 Hz 9 – 31 Hz 2 – 29 Hz

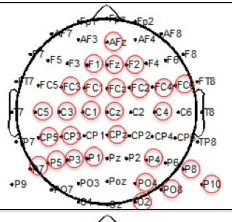
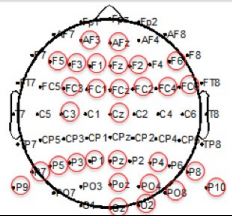
a. Motor action: 26 electrodes (F1, FC1, C1, CP3, CP1, P1, P3, P7, O1, Oz, POz, CPz, Fpz, Fp2, AFz, Fz, FCz, Cz, C2, CP2, P6, P8, P10, PO8, PO4, and O2).

b. Motor imagery: 22 electrodes (Fp1, AF7, F1, TP7, P7, PO7, PO3, O1, Oz, Fpz, Fp2, AF8, AF4, AFz, Fz, F6, Cz, CP6, P6, P8, PO4, and O2).

brain area (frontal, occipital without sensory motor areas {except for Cz}) and frequency range (a broader band including theta and alpha). In addition more frontal areas and a broader EEG band were engaged in motor imagery as compared to the motor action state.

The results for Subject 3 are unusual in terms of the ERD response of the motor action/imagery in such a low frequency range (theta). The dominant hand movement, i.e., that of the right hand, generated a contralateral ERD pattern. However, the selected electrodes for the motor imagery in Table 3 did not show a similar distribution as compared to the motor action, as only the best chromosome among the last generation

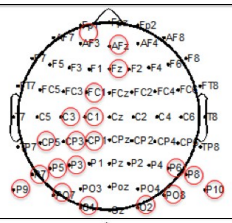
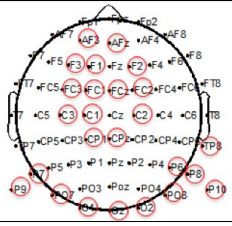
TABLE III. SELECTED ELECTRODES AND FREQUENCY RANGES THROUGH THE GENETIC ALGORITHM WITH RESPECT TO MOTOR ACTION/IMAGERY (N = 200 TRIALS); {SUBJECT 3}

Selected Electrodes {Average selection rate>=2/3}	Selected Frequency Range (Independent Cases)
Motor Action[a] 	18 – 32 Hz 14 – 33 Hz 3 – 9 Hz
Motor Imagery[b] 	3 – 8 Hz 2 – 8 Hz 3 – 9 Hz

a. Motor action: 29 electrodes (F1, FC3, FC1, C1, C3, C5, CP5, CP3, P1, P3, P5, P7, O1, CPz, AFz, Fz, F2, FC6, FC4, FC2, FCz, Cz, C4, P4, P8, P10, PO8, PO4, and O2)

b. Motor imagery: 35 electrodes (AF3, F1, F3, F5, FC3, FC1, C1, C3, P1, P3, P5, P7, P9, PO7, PO3, O1, Iz, Oz, POz, Pz, AFz, Fz, F2, F6, FC6, FC4, FC2, FCz, Cz, P4, P8, P10, PO8, PO4, and O2)

TABLE IV. SELECTED ELECTRODES AND FREQUENCY RANGES THROUGH THE GENETIC ALGORITHM WITH RESPECT TO MOTOR ACTION/IMAGERY (N = 200 TRIALS); {SUBJECT 3}

Selected Electrodes {Average selection rate>=2/3}	Selected Frequency Range (Independent Cases)
Motor Action[a] 	8 – 22 Hz 7 – 21 Hz 18 – 22 Hz
Motor Imagery[b] 	8 – 12 Hz 7 – 12 Hz 7 – 12 Hz

a. Motor action: 21 electrodes (Fp1, FC1, C1, C3, CP5, CP3, CP1, P3, P5, P7, P9, PO7, O1, Iz, AFz, Fz, P6, P8, P10, PO8, andO2)

b. Motor imagery: 26 electrodes (AF3, F1, F3, FC3, FC1, C1, C3, CP1, P7, P9, PO7, O1, Iz, Oz, CPz, AFz, F2, FC2, FCz, C2, TP8, P6, P8, P10, PO8, and O2)

of offspring by the genetic algorithm can survive. The other solution was discarded, although all criteria were satisfied with their ERD patterns.

A contralateral ERD pattern in the spatial domain was selected as the best representative chromosome from both the motor action and the imagery trials, as shown in Table 4. However, the ERD spatial pattern of between the motor action and the motor imagery showed a difference in that the ERD response pertaining to motor imagery was less lateralized with the SMR frequency range.

IV. CONCLUSION

The proposed method can help individuals obtain the optimal ERD patterns of motor action/imagery by selecting the best chromosome with an engaged brain area and frequency range. To confirm the effect of the proposed method, we performed three cross-validation trials for all sessions while the participants were acting/imaging right hand movements according to our experimental protocol before and after the motor action/imagery. The analysis results from the individual optimization sessions showed a consistent outcome (chromosome) in both brain areas (selected electrode related to motor action/imagery) and frequency ranges (representing the ERD pattern), demonstrating that the proposed method can be used as a tool for creating an individually optimized system in BCI applications. Furthermore, we expect that this method will be useful not only for BCI applications but also for neuro-rehabilitation systems for stroke patients with different types of brain lesions.

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REFERENCES

[1] G. Pfurtscheller and A. Aranibar, "Evaluation of event-related desynchronization (ERD) preceding and following voluntary self-paced movement," Electroencephalogr Clin Neurophysiol, vol. 46, pp. 138-46, Feb 1979.

[2] G. Pfurtscheller, "Central beta rhythm during sensorimotor activities in man," Electroencephalogr Clin Neurophysiol, vol. 51, pp. 253-64, Mar 1981.

[3] J. Decety and D. H. Ingvar, "Brain structures participating in mental simulation of motor behavior: a neuropsychological interpretation," Acta Psychol (Amst), vol. 73, pp. 13-34, Feb 1990.

[4] M. Jeannerod and V. Frak, "Mental imaging of motor activity in humans," Curr Opin Neurobiol, vol. 9, pp. 735-9, Dec 1999.

[5] H. J. Hwang, K. Kwon, and C. H. Im, "Neurofeedback-based motor imagery training for brain-computer interface (BCI)," Journal of Neuroscience Methods, vol. 179, pp. 150-156, Apr 30 2009.

[6] O. Bai, Z. Mari, S. Vorbach, and M. Hallett, "Asymmetric spatiotemporal patterns of event-related desynchronization preceding voluntary sequential finger movements: a high-resolution EEG study," Clinical Neurophysiology, vol. 116, pp. 1213-1221, May 2005.

[7] M. Lotze, P. Montoya, M. Erb, E. Hulsmann, H. Flor, U. Klose, N. Birbaumer, and W. Grodd, "Activation of cortical and cerebellar motor areas during executed and imagined hand movements: an fMRI study," J Cogn Neurosci, vol. 11, pp. 491-501, Sep 1999.

[8] G. Pfurtscheller and C. Neuper, "Motor imagery and direct brain-computer communication," Proceedings of the IEEE, vol. 89, pp. 1123-1134, Jul 2001.

[9] G. Pfurtscheller, S. Lopes, “Event-related EEG/MEG synchronization and desynchronization: basic principles,” Clinical Neurophysiology, vol. 110, pp. 1842-1857, Feb 1999.