Decoding of limb trajectories from fMRI signal – a simulation study

Seungkyu Nam(1), Kyung Hwan Kim(2), Dae-Shik Kim(1)

(1) Dept. of Electrical Engineering, Korea Advanced Institute of Science and Technology, South Korea
(2) Dept. of Biomedical Engineering, College of Health Sciences, Yonsei University, South Korea

1. Introduction

Recent brain computer interface (BCI) studies using chronically implanted microelectrode demonstrated that electrophysiological responses from primary motor areas (M1) can be successfully used to control a robotic arm [1]. In order to avoid the invasiveness of electrophysiological recording, more non-invasive approaches such as EEG or fMRI was likewise proposed. However, most non-invasive BCI studies suffer from the fact that they classify brain differential activity states, rather than deciphering the actual neural responses underlying the target behavior. In this study, we found the directional tuning properties, a basic functional property of neural activity in M1, at the voxel level for motor decoding from fMRI signal and we performed a simulation to demonstrate that it is possible to control the robotic arm in real time using multi-voxel patterns.

2. Methods

In order to test the feasibility of motor trajectory decoding using fMRI, we developed a forward model to generate a BOLD signal in M1 for this simulation study.

1. Modeling of the M1

The cells in the M1 are directionally tuned to the direction of arm movement, and the cells with similar preferred directions are organized in columns. Therefore, according to the previous study [2] to model the distribution map of preferred direction in M1, we assumed that a width of directional minicolumns, the basic unit in our model, is 30 um, and a width of the columnar structure clustered with similar preferred directions is 240 um. In addition, we assumed that there are 8 directional tuned minicolumns, and the cluster of minicolumns has same directional sensitivity to the direction of arm movement. See Figure 1.

![Figure 1. Distribution map of preferred direction in M1](image)
2. Forward model of BOLD fMRI signal

Each of minicolumns in M1 is activated according to direction of arm movements, and to represent the neural signal, we used the Poisson spike generation model [3]. Because the fMRI responses are proportional to average firing rates [4], the spike trains of each minicolumns in a voxel are averaged and then convolved with the hemodynamic response function (HRF) to generate the BOLD fMRI signal. The HRF peaks at around 6 seconds. The forward model from neuronal activities to fMRI signals is shown in Figure 2.

![Figure 2. Forward model of BOLD fMRI signal](image)

3. Experiment

The experiment consists of two sessions. First, during the training session, fMRI signals generated by simulated arm movements from the center position toward the eight equidistant targets are analyzed using correlation analysis between multi-voxel spatial patterns in order to find the directional tuning properties at the voxel level. Then, during the test session, the trajectories of continuous arm movements toward random directions are predicted from the fMRI signals using the estimated directional tuning curves.

3. Results

Directional sensitivity, the key element of the motor decoding, can be found at the voxel level analyzed using multi-voxel patterns. Furthermore, the result of motor decoding showed that the trajectories of arm movements can be predicted in two-dimensional space using the motor decoding method based on multi-voxel patterns, and the prediction performance is the best when time delay is 6 seconds. See Figure 3. However, it takes a long time to control the robotic arm in real time. Therefore, the weighted average windowing method was applied to reduce the time delay for real time control system, and the result showed that the prediction performance can be increased when the delay time is faster than 6 seconds using the average windowing method. See Figure 4.
Figure 3. Results of the arm trajectory decoding with 6 seconds delay

Figure 4. (A) Prediction errors according to the delay time. (B) Result of trajectory decoding using average windowing method when the delay time is 3 seconds

4. Conclusions

As a result of this simulation study, we demonstrated the feasibility to control the robotic arm in real time using fMRI-based BCI by finding the directional tuning property at the voxel level. Furthermore, this study provided that if we find the directional sensitivity during motor imagery, it is also possible to read the subject’s intention to move their arm and to control the robotic arm between the thought of the moving the arm and the movement of the robotic arm in real time.

5. Reference

