Simultaneous EEG-fMRI Data Acquisition during Cognitive Task

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***Abstract*- Functional Magnetic Resonance Imaging (fMRI) has very high spatial resolution as compared to the Electroencephalography (EEG) which on other hand has very high temporal resolution. The pros and cons of the EEG and fMRI are complementary to each other. Simultaneous EEG-fMRI data recording solve the problem to get high spatial and temporal resolution at the same time to study the brain dynamics in efficient manner. EEG-fMRI integration is a new approach to study human brain activity. Recent developments in MRI compatible EEG equipment made this integration more easy and attractive in cognitive neuroscience. The simultaneous EEG-fMRI data acquisition gives us the better information for all activated areas of the brain to understand the cognitive processes. We developed data acquisition setup for simultaneous EEG-fMRI for cognitive tasks. Also data recording has been done for two healthy participants as a pilot study which will be further continued on other healthy participants as well as on patients. The EEG and fMRI data is pre-processed and artefacts are removed. This combined EEG-fMRI data can be further used in multimodal data integration or data fusion which can give the better results and understanding of the cognitive processes of human brain as compared to analysing EEG and fMRI data separately.**

Keywords—fMRI, EEG, Simultaneous EEG-fMRI, Working memory, Cognitive neuroscience, Multimodal neuroimaging

I. Introduction

Different Neuroimaging modalities are used these days to investigate the functional activities of human brain dynamics. Most commonly used modalities are like EEG, fMRI, PET, MEG (Magnetoencephlography) etc. Magnetic Resonance Imaging (MRI) is commonly used for obtaining the structural images of the organs including the brain as well. It can also provide the physio-chemical state of the tissues, perfusion and vascularization as well. In 1990,there was emergence of the Functional Magnetic Resonance Imaging (fMRI) which has capability to measure the hemodynamic response inferring to the neural activity of the brain[1]. fMRI has excellent spatial resolution covering the whole brain based on the voxels of size of few millimeters. It has gained popularity in the cognitive neuroscience research due to this characteristic. However, it is well known that fMRI is not capable of measuring the fast temporal rapidly varying neuronal event because hemodynamic response evolves in seconds instead of milliseconds[2].The data acquisition of fMRI is very slow to acquire the images/slices of the full brain and takes seconds to do that. Electroencephalography (EEG) on the other hand directly measures the neural activity on the scalp noninvasively with the temporal resolution in milliseconds. EEG widely used in medical community to diagnose epilepsy, brain disorder etc. [3-5]. In the last decade, researchers made efforts to integrate the complementary advantages of EEG/MEG and fMRI. Later on, EEG proved to be the better candidate for integration with fMRI because it can be used with fMRI to acquire simultaneous EEG-fMRI data.

In the past few years, Multimodal integrating techniques are getting popularity. Multimodal approaches mostly depend upon the assumption of the common neural activities among different recorded signals [1, 6, 7]. Normal EEG equipment cannot be used in the high static and gradient magnetic field environment of fMRI scanner. Therefore, in some studies parallel data acquisition is carried out in separate sessions of EEG and fMRI with same experiment. In one study, parametric approach was used to combine EEG-fMRI in which correlation between P300 of ERP and hemodynamic response using fMRI was found [8]. The parametric approach is only being valid to those studies where memory or learning is not the primary goal of investigation of the human brain. The experimental paradigm where the memory or cognition is the primary concern, parallel data acquisition or in other words separate session data recording for EEG and fMRI is not fruitful. Hence, simultaneous EEG-fMRI is right candidate for this kind of application like memory or learning. Now this could become possible due to development of MRI compatible equipment. EEG measurements inside the fMRI scanner are challenging tasks and many technical issues are there to resolve it completely before start of any data acquisition. First, nonmagnetic wires and electrodes are required e.g. gold electrodes which could be expensive option and other one is silver electrodes i-e Ag/AgCl. These electrodes can be used separately or in the form of head caps which could reduce the time. There should be no loops and wires during data acquisition as it would produce heating and artefact which directly affects the EEG signal quality[9].

The main challenge is the strong static magnetic field and gradient switching magnetic field. These fields produce significant deteriorating effects on the EEG signals recorded. The main artefacts due to MRI scanner are: Gradient artefacts

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due to the fast switching magnetic fields during image acquisition and Ballistocardiogram (BCG) artefacts due to cardiac related motion inside the scanner. Heart beat is also important factor which add on to produce BCG artefacts [10]. The amplitudes of these artefacts are very large as compared to the standard EEG signal. GA artefacts seem very complex and give perception of non-removal at first sight but GA artefacts are easy to remove as compared with BCGs. The template based method to remove the gradient artefacts is commonly and successfully used in most of the cases. To remove BCG is a challenging task as it is originated from physiological activities inside the human body. Allen's approach of artefact subtraction is known as AAS[11].This method subtracts the artefact template which is calculated by averaging of the several periods of EEG signals. Independent component Analysis (ICA) based on data driven approach is also used to remove the artefacts. However, removal of BCG artefacts using ICA is a challenging task as ICA assumes fixed electrode topographies while BCG artefacts generated from multiple sources having varying electrode topographies. Therefore, ICA decomposition of the EEG data which is recorded inside scanner produces several BCG activated components. There is a chance that neuronal activated component mixed with BCG artefacts is removed by subtraction. It can distort the actual neuronal activity of interest [10]. Principle component analysis (PCA) can also be used to remove BCG artefacts. PCA produces principal components including BCG activity in EEG signal and it is termed as Optimal Basis Set (OBS)[12].

Multimodal data analysis requires dedicated methods. The two approaches commonly followed in practice. One is the data driven and other one is model driven methods. Furthermore, data driven approach is easy to implement and involves less complexities as compared to the model driven approach. For data driven, no a prior information is requires and it is easy to interpret. On other hand, model driven approach requires the accurate model to get the better results and it is difficult to implement. For example, in case of EEG-fMRI, it is not easy to develop the realistic model of the EEG and hemodynamic inferring the neural activities. Therefore, parameter estimation of the model is mostly based on the probabilistic estimations[13]. From past few years, researchers are focusing to combine the EEG-fMRI simultaneously to get high spatiotemporal resolution of the brain imaging by showing different kind of events e.g. Auditory odd ball , visual stimulus and cognitive tasks. The human brain remains most of the time active in performing different executive functions and also involve in learning and memory process. Cognitive process in human brain includes attention, memory, logic and reasoning, audio and visual processing. Memory can be divided into two categories: one is short term or working memory and other one is long term memory[14]. For our research, we have chosen visual working memory test as our cognitive task

In this paper, we developed the simultaneous EEG-fMRI data acquisition setup to be used for cognitive tasks. MRI compatible equipment is successfully integrated with MRI scanner by resolving all issues related to the synchronization, safety and experiment paradigm. For pilot study, we are able to record the simultaneous EEG-fMRI data .The data is pre-processed to remove the artefacts like gradients and BCG.

II. Methods

The simultaneous EEG-fMRI data acquisition is used to get better information during cognitive task . This research is approved by Human Ethics Committee, Universiti Sains Malaysia, Health Campus, Kelentan. For pilot study, one healthy participant of age 23, male is selected and consent form is signed by him .

A. EEG-fMRI Data Acquisition Setup

EEG data is recorded using MR compatible 128 channels EEG cap (Electrical Geodesics Inc. , USA). Figure 1 shows the 128 channel MR compatible EEG cap.

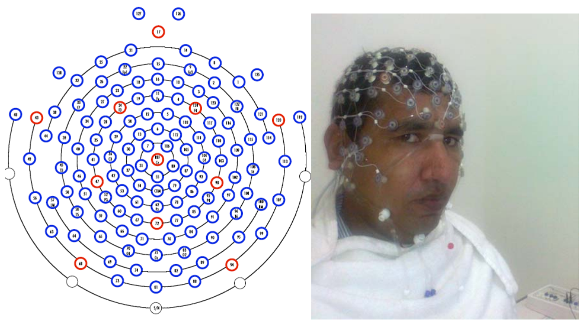

Figure 1. (a)128 Channel HydroCel Geodesic Sensor Net (b) 128 channel MR compatible cap

fMRI imaging data recorded with 3 Tesla fMRI machine available at Hospital Universiti Sains Malaysia. The combine setup look like as shown in Figure 2.

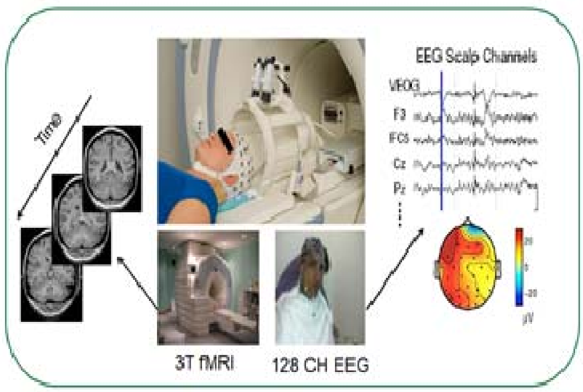

Figure 2. Data Acquisition Setup for EEG-fMRI

B. Synchronization between EEG and fMRI

The most challenging task to acquire the simultaneously EEG and fMRI data is synchronization of the two systems with the experimental cognitive task. It means that when cognitive task experiment starts the EEG and fMRI recording data simultaneously. This requires the hardware and software modification in the systems. The MR Trigger pulse is required to run the experiment and EEG recording. This can be done by receiving the pulse and this trigger pulse can initiate the experiment. We modified the hardware and software for synchronization and used TR pulse to start the experiment simultaneously.

C. Cognitive Task Paradigm

The Cognitive task is based upon the standard working memory paradigm [15-17]. Four pictures are shown to the participant for 2s and after a retention interval, one probe picture is displayed to the participant. For each probe picture, the participant has to respond that this probe picture is appeared before or not by pressing the response button. After Inter trial interval (ITI), a new set of stimulus is appeared as shown in Figure 3.

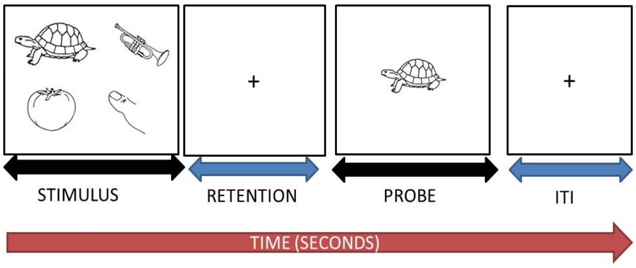

Figure 3. Cognitive task (Visual Working Memory)

D. EEG –fMRI Data Acquisition

For fMRI data acquisition, 3.0 Tesla Philips MRI scanner is used for fMRI data recording located at Hospital Universiti Sains Malaysia. The data is recorded in the DICOM format. The repetition time is chosen to 2s with TE=35ms. The matrix size is 64X64.The gradient Echo Planner Imaging (EPI) is used as a pulse sequence for fMRI scanner [15, 18] . MR compatible EEG equipment (128 Channels) is used for acquiring the EEG data along with the fMRI. The sampling frequency is 250 samples/sec. The average reference is used here. The cognitive task paradigm is run during the simultaneous EEG-fMRI data acquisition. The experiment consists of 50 trials and participant has to respond during the cognitive task by pressing the button of the response box.

III. Data Analysis and Results

E. EEG Preprocessing

EEG is contaminated with Ballistocardiogram (BCG) or pulse artifacts and Gradient artifacts (GA). Additional artifacts are known as the helium pump artifacts which can be removed by turning off the helium pump during the data acquisition[19].Firstly, the gradient artifacts are removed using the subtraction template method[10, 12].

F. fMRI Preprocessing

The fMRI data can be easily preprocessed in terms of temporal realignment, co registration, segmentation etc using the statistical parameter mapping tool.

G. Results

The acquired data is shown in Figure 4 and it contains all the artifacts as discussed in the introduction section during the simultaneous EEG-fMRI data acquisition. The right side of the figure 4 shows the gradient artifact which is very large in magnitude as compared to the normal EEG data. The left side of the figure 4 shows the normal BCG artifacts.

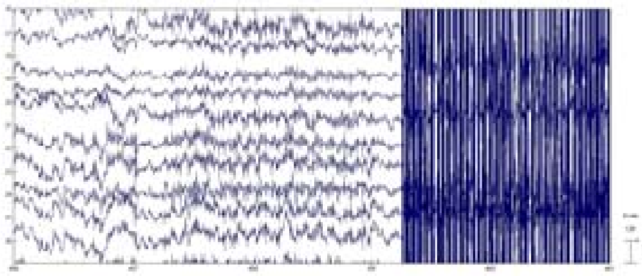

Figure 4. EEG signals with Artifacts

Figure 5 shows the clean EEG and all the artifacts are removed now by using template subtraction method as discussed in introduction section.

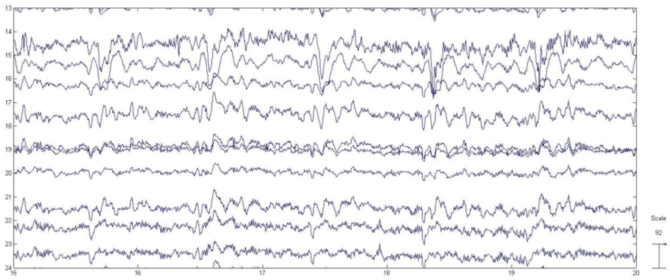

Figure 5. Clean EEG Signal after artifact removal

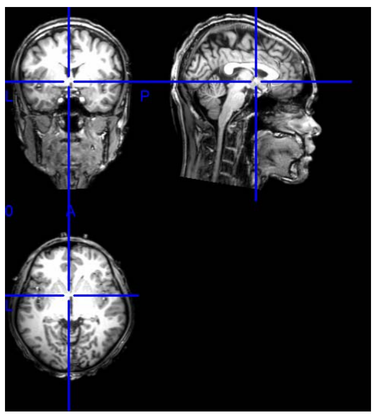

Figure 6. Anatomical Image

Figure 6 shows the acquired T1 weighted anatomical image and it is used to map the fMRI images .Figure 7 shows the acquired fMRI image during the cognitive task.

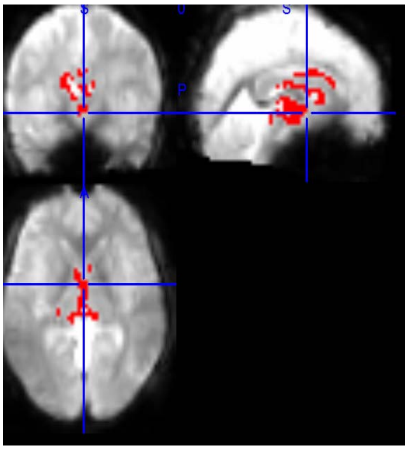

Figure 7. Acquired Functional MRI Images

IV. CONCLUSIONS

The Simultaneous EEG-fMRI gives the better spatiotemporal information as compared to the individual modality of the human brain. The combine recording involves many technical challenges and safety related issues inside the MRI scanner environment. The MRI compatible EEG equipment solves the problems to design the data acquisition setup according to the requirement. In our case, we developed the simultaneous EEG-fMRI setup to record the combine data for cognitive task. We successfully recorded the simultaneous EEG-fMRI data during cognitive task and it is preprocessed to remove the artifacts. In future, this data acquisition setup will be used on normal as well as patients to know more deeply about brain functions and dysfunction effectively.

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