Phase Synchrony for Human Implicit Intent Differentiation

Ukeob Park, Kalyana C. Veluvolu, and Minho Lee*

School of Electronics Engineering, Kyungpook National University
1370 Sankyuk-Dong, Puk-Gu, Taegu 702-701, South Korea
uepark@ee.knu.ac.kr, {veluvoluk,mholee}@gmail.com

Abstract. This paper focuses on discriminating user's intent to real images based on phase synchrony in EEG. The goal is to differentiate user's navigational intention and informational intention with real world scenario's. In this paper, we first calculate Phase locking Value (PLV) between all electrode pairs in EEG collection montage. We identified several most significant pairs (MSP) to construct brain functional connectivity patterns in different bands, theta band (4~7Hz), alpha (8~13Hz), beta-1 (14~22Hz), beta-2 (23~30Hz). Based on the PLV variation in the selected MSP's, the user intent can be classified. This paper demonstrates the potential of these identified brain electrode pairs in cognitive detection and task classification for future BCI applications.

Keywords: brain-computer interface (BCI), electroencephalographic (EEG), phase synchrony, brain connectivity, intent recognition.

1 Introduction

Brain cognitive fusion technology is an emerging and most promising fusion technology floating in modern society / future of the 21st century. Especially, according to FET2012 January [1], it was written that cognitive science is one of the most important future technology. Information & Communication Technology (ICT) systems should serve as empathic cognitive extensions of their users, being active and instrumental in driving interactions with computers as well as with other humans, hereby learning and adapting with the user. Brain plasticity and behavior is needed in order to interact between human and computer for understanding the impact on Human development [1]. According to the theory of mind [2], human beings have a natural way to represent, predict and interpret the intention expressed explicitly or implicitly by the others. For an efficient human computer interaction system it is necessary for a system to understand the intention of a human. Intention recognition is a relatively new field that is being widely used in web applications [3] and internet security [4]. Many researchers have investigated the decision discrimination in a variety of ways. In particular, upon analyzing the brain science, EEG method is a non-invasive measurement of brain's electrical activity which has a good temporal resolution. Also, to understand

* Corresponding author.

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brain cognition, connectivity plays an important role. Phase synchronization (PS) analysis has been well demonstrated to be a very useful method to infer functional connectivity with multichannel neural signals, e.g., electroencephalography (EEG)[5].

In this paper, we propose the classification of user Navigational / informational intention with phase estimation based on the EEG data. In particular, the paper's goal is to identify the brain connectivity related to user's navigation/information intent thru visual-experiments based on static images that is closest to the practical scenarios. We provide a reference, difference of PLV, for determining the intent of the user (Navigational / Informational intent).

This paper is organized as follows: Methods for PLV and Most significant pair's selection are discussed in Section 2. Section 3 details on the results obtained and Section 4 concludes the paper.

2 Methods

PLV synchronization measures the synchronization level of EEG at every time instant between any two electrode pairs in the range of (0 - 1) [5, 6]. Therefore, the aim of this study is to represent user's change in intent over time as a quantitative representation of PLV.

2.1 Phase Locked Value (PLV)

EEG phase differences are often used to compute "directed coherence" which is a measure of the directional flow of information between two EEG electrode sites [7]. EEG phase difference is also used to estimate conduction velocity and synaptic integration time [8, 9]. Phase locking value (PLV) is a measure for studying the synchronization phenomena in EEG signals. It is similar to cross spectrum but independent of amplitude of the two signals [5]. Making use of PLV, we can measure synchronization between all electrode pairs in EEG collection montage. Synchronization measure PLV formula is as follows [5]:

$$\text{PLV} = \frac{1}{N} \left| \sum_{n=1}^{N} \exp(j\{\Delta\Phi(t,n)\}) \right| \quad (1)$$

Where N is of the total number of trials, $\theta(t,n)$is the phase difference $\Phi_1(t,n) - \Phi_2(t,n)$ between pair of brain nodes, and t is the time of each period. The range of PLV values varies between 0 and 1.PLV = 1, means perfect coupling of electrode pairs and PLV = 0, means not coupled at all.

2.2 Intention Basis for Discrimination

PLV Difference. To identify the network map, we need to identify the PLV difference between the two events (Information intent and Navigation intent). The PLV difference for all electrode pairs in two events provide the measure of how each electrode PLV varies between the two events [11].

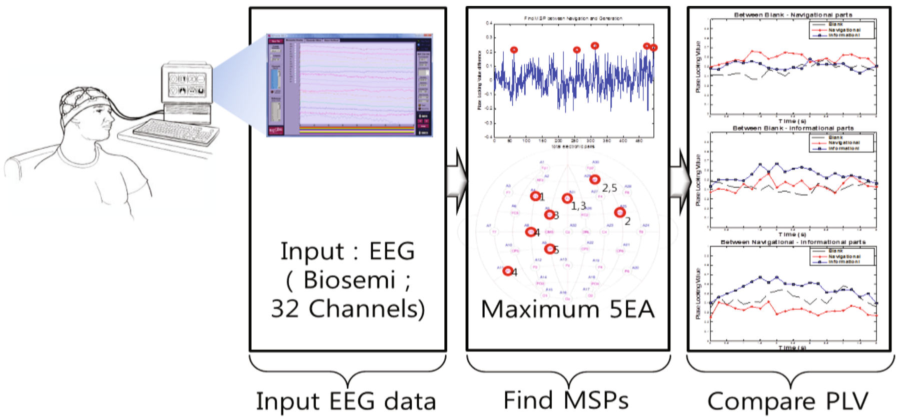

Fig. 1. Totally analysis process

In Fig. 2, the experiment timing scheme is shown. Thee PLV determined during informational and navigational intent periods is used to obtain the PLV difference for all electrode pairs. The difference PLV between navigational and informational periods is the key for classification in this paper.

The Most Significant Pairs (MSP). The MSP represents the most reactive electrode pairs (electrode pairs/locations) of brain compared between the two events (information intent /navigation intent and rest). This is shown in Fig.1. After determining the PLV of total electrode pair of each informational part and navigational part, we define the most significant pair (MSP), the electrode pair that has the most PLV difference between these two events. The formula for the MSP can be as follows.

$$\mathrm{MSP-I} = \underset{e}{argmax}\{PLV_{information} - PLV_{rest}\} \quad (2)$$

$$\mathrm{MSP-N} = \underset{e}{argmax}\{PLV_{navigation} - PLV_{rest}\} \quad (3)$$

Where MSP-I and MSP-N corresponds to MSP's identified for information intent and navigation intent. In Eq. (2) and (3), e represents electrode pairs. It is possible to identify both the brain connectivity and the most reactive electrode pairs based on PLV from Eq.(2) and (3). Recently, the work in [11] identified 5 most significant pairs for classification of motor imagery tasks. In this work, we follow similar procedure for identification of 5 MSP's. One may also choose more number of MSP's (say 10 MSP's or 20 MSP's).

2.3 Experimental Setup and Data Collection

Ten healthy subjects participated in the study. EEG data from 32 channels were recorded with biosemi (www.biosemi.com) amplifier. The timing scheme of the experiment is shown in Fig. 2. Subjects had to perform the following tasks during each trial.

Navigational intent.: To focus on the image present on the screen.

Informational intent.: To search for the specific object in the displayed image.

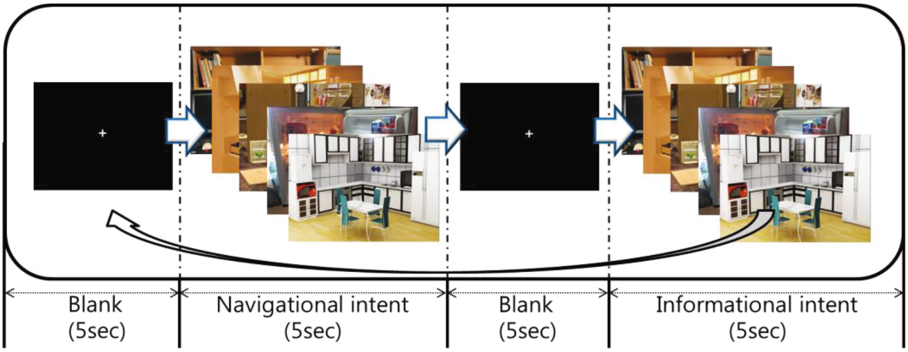

Fig. 2. Procedure of the block diagram for the synchronization of Phase estimation

One session consisted of 5 trials and in each trial, different navigation/informational intent images that were close to a real-life scenario were shown to the subject as shown in Fig. 2 [10]. 5 sessions were conducted and hence a total of 25 trials/subject. Blank images shown between the intent was to prevent the mixing of intents. Random images in each sequence were presented to avoid the induction of intent in subjects due to the iterative nature of the experiment.

3 Results

We selected 5 MSP − N and 5MSP − Iidentified in theta band to classify navigational and informational intents, $MSP - N$ and $MSP - I$ are identified using (2) and these pairs are subject-intent specific. Fig. 3 shows the results obtained with three subjects. Identified reactive pairs 5 $MSP - N$ and 5 $MSP - I$ are shown in the Fig. 3. The average PLV of 5 $MSP - N$ and 5 $MSP - I$ during both the events for three subjects are also illustrated.

One can easily observe the $MSP - N$ having higher PLV level compared to $MSP - I$ during navigational intent duration and vice versa during informational intent duration. The difference in PLV level of navigational intent and informational intent is crucial for the intent classification. The difference in PLV level of identified MSP's can be calculated using the following equation set:

$$DPLVN = \langle PLV_N^{MSP-N} \rangle - \langle PLV_N^{MSP-I} \rangle \quad (4)$$

$$DPLVI = \langle PLV_I^{MSP-N} \rangle - \langle PLV_I^{MSP-I} \rangle \quad (5)$$

Where $DPLVN$ is the difference in PLV level of 5 electrode pairs $MSP-N$ to $MSP-I$ during navigational period and $DPLVI$ is the difference in PLV level of $MSP-N$ to $MSP-I$ during informational intent duration, $\langle\ \rangle$ being the mean operator.

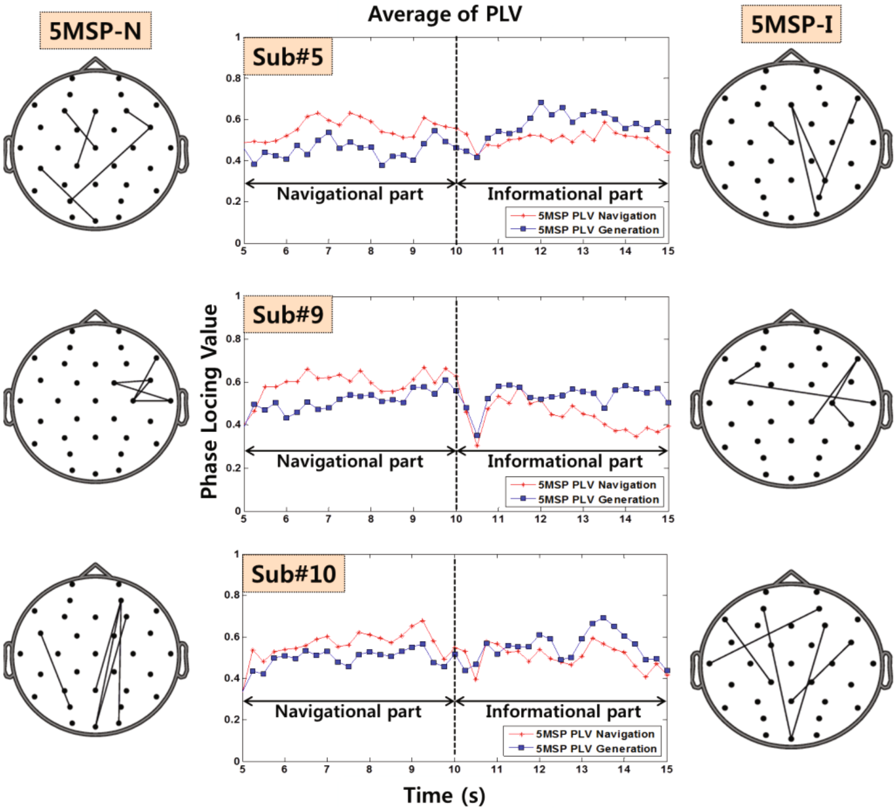

Fig. 3. Comparison of $MSP-N$ and $MSP-I$ in θ band during navigational intent and informational intent

$DPLVN$ is positive during navigational intent, it shows that the PLV level of $MSP-N$ is high compared to $MSP-I$ and vice-versa during the informational intent. This relative difference change can be identified in all the subjects. The average PLV of 5 $MSP-I$ and 5 $MSP-N$ for all subjects in all the selected bands during navigational intent and informational intent are shown in bar plots (Fig. 4). Table 1 is filled by values of Fig. 4.and difference means the difference of PLV level in Eq. (4) and (5). The relative change can be clearly identified in all the frequency bands. Thus, it is clear that the proposed method can clearly differentiate between both the events.

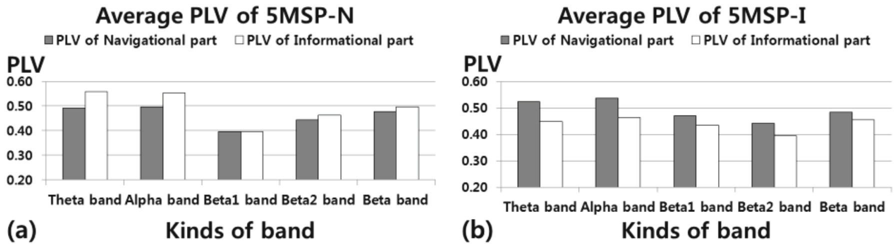

Fig. 4. Average PLV of 5 $MSP - I$ and 5 $MSP - N$ during a) navigational intent b) informational intent

Table 1. Average PLV-N/I of 5MSP and difference of PLV-N/I at each band

Kinds of band	**Navigation period**			**Information period**		
	PLV-N	PLV-I	Difference	PLV-N	PLV-I	Difference
θ band	0.52	0.45	0.0749	0.49	0.56	0.0667
α band	0.54	0.46	0.0719	0.50	0.55	0.0570
β1 band	0.47	0.44	0.0346	0.40	0.40	-0.0001
β2 band	0.44	0.40	0.0463	0.44	0.46	0.0195
β band	0.48	0.45	0.0284	0.48	0.50	0.0185

4 Conclusions

In this paper, we proposed a method to differentiate the user's intent given a real picture based on the phase synchrony of EEG. We identified most significant PLV varying pairs between user's navigational and information generating period. These significant pairs demonstrate the variation in functional connectivity and the applicability of this method for BCI applications.

Our future research will focus on determining the user's intent based on multimodal biometric data using the same proposed method. We finally plan to apply these methods for human-robot interaction systems.

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