A Non-Invasive Pathway for Brain to Brain Direct Communication

B.Tech seminar report submitted in partial fulfilment of the requirements for the the award of the degree of

Bachelor of Technology
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by

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Certificate

This is to certify that the SEMINAR REPORT entitled **A Non-Invasive Pathway for Brain to Brain Direct Communication**, is a bonafide work done by **Tathagata Bandyopadhyay (1305382)** in partial fulfilment for the requirement for the award of the degree of **Bachelor of Technology** in **Computer Science and Engineering**.

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ABSTRACT

Brain computer interfaces (BCI) and Computer Brain interfaces (CBI) are some modern areas of research in the fields of Computer Science and Neurology. A BCI System enables a person to communicate his / her brain signals directly with a computer system, bypassing the normal route through the body's neuro muscular system. On the other side, a computer brain interface can make a computer system directly stimulate some brain activity in the subject's brain, without the help of his / her sensory organs and sensory pathways. With the advent of non-invasive technologies for BCI (eg. Electro Encephalogram or EEG) and non-invasive technologies for CBI (eg. Transcranial Magnetic Stimulation or TMS), it has become possible to establish a direct communication pathway for information exchange between two human brains of two subjects separated by large geographical distance. In this brain to brain communication system, sender's thoughts are read from the EEG signal and the encoded information is sent to the device at receiver's end over the internet. TMS coil placed over the head of the receiver, stimulates his / her different brain areas for the execution of the motor command sent by the sender. Thus, this B2B communication system enables sender and receiver to exchange information without any language, visual or auditory cues.

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1 Introduction

On a summer evening I was sitting alone in my hostle room. After the day's hardwork I was a bit tired and was thinking of my mom. I picked up my mobile phone to call her. And to my utter surprise the phone started ringing and the caller was none but my mom herself. This is just one example. I have experienced similar phenomena several times with many of my near and dear ones. And many of my friends have also shared similar experiences. We call this phenomenon as *telepathy*, "the supposed communication of thoughts or ideas by means other than the known senses", as it is defined in the google dictionary.

Although this telepathy is very amazing and surprising way of communication, it is not in our control. We can not deterministically say when will this happen and when will not. But what if we could device a mechanism through which we can deterministically communicate through our thoughts? This idea of brain to brain(B2B) communication between subjects separated by great geographical distance, has attracted many scientists into brain research.

Various attempts were made till date, with the goal of B2B communication. In [1] Delgado *et al.* describes bidirectional communication between the monkey brain and machine. Chapin *et al.* describes a method of controlling a robot arm from the recorded brain signals from brain of rats who were trained to push a lever to get water [2]. Artificial tactile feedback from the brain controlled external actuator can be generated in rhesus monkeys using intracortical microstimulation (ICMS) of the primary somatosensory cortex [3]. All these above works describes some sort of bidirectional communication between brain and machine. Cortical-spinal communication in monkeys for reconstituting the movent of paralysed limb and hippocampus to hippocampus communication for short term memory transfer in rats are shown in [4] and [5] respectively. Pais *et al.* describes an mechanism to make a rat learn the sensory motor behaviour of another rat through real-time brain to brain interface (BTBI) [6]. More significant work has been done on human subject in [7] and [8] regarding neuro rehabilitation for restoring the motor functions, lost due to paralysis.

All the works discussed so far, use invasive technologies which require some electrodes to be surgically implanted on the brain inside the skull. Despite producing very effective results, invasive brain-machine interfaces (BMI) are less popular in human subjects due to its high cost, complexity and risk. With the advent of non-Invasive Brain-Computer Interface (BCI) (like Electro Encephalogram or EEG) and non-Invasive Computer-Brain Interface (CBI) (like Transcranial Magnetic Stimulation or TMS) systems, scientiests have shifted their focus on the non-Invasive B2B communication. Dewan EM describes a technique using EEG signal to voluntarily control the alpha rythm de-synchronaisation to encode a morse code message [9]. First non-Invasive B2B communication attempt was made in [10] where a human brain is functionally coupled with that of a rat using EEG as BCI system at the human end and Transcranial Focused Ultrasound (FUS) as CBI system at the rat end. The first successful non-Invasive B2B communication in human subjects has been achieved by Grau *et al.* in [11] and it is the topic of discussion of this seminar. This scientific study of Grau *et al.* will be referred as 'the expeiriment' or 'this expeiriment' here after in this document.

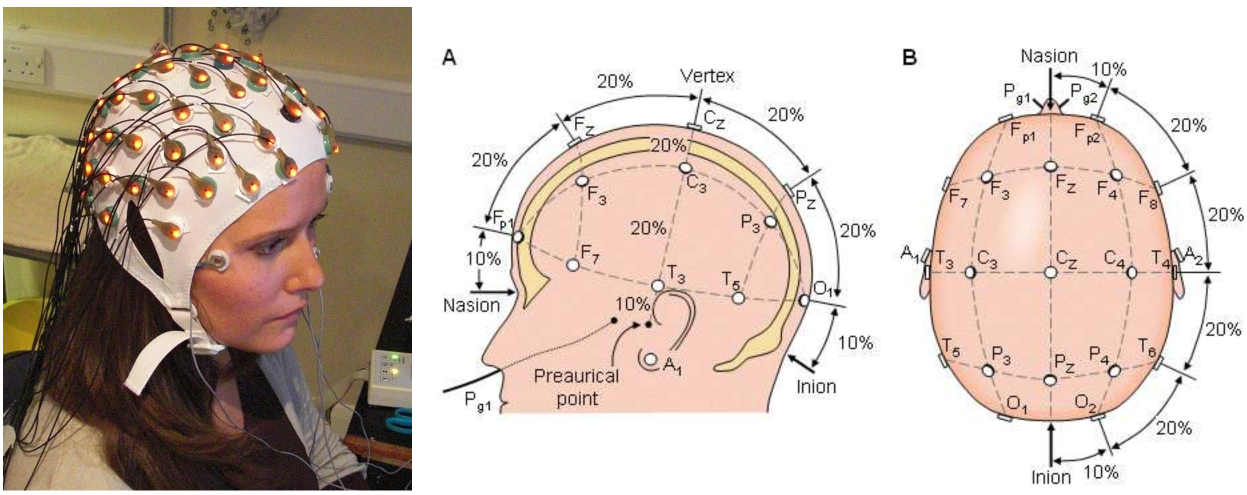
2 Basic Subsystems

Just like any other communication system, the experiment consists of three major subsystems which are (i) Sender, (ii) Receiver and (iii) Communication Medium. Among these, here sender and receiver subsystems are most important as it is required to read the brain signal and encode it in a binary string at the sending end and decode the string and manipulate the brain function at the receiving end. Here sender uses EEG based BCI and receiver uses TMS based CBI. These subsystems are described as follows:

2.1 EEG based BCI

A BCI system reads the brain signals directly from brain and feeds a computer with this signal for processing. Among different BCI systems available today, EEG is wildely used due to its simplicity, non-Invasive nature, portability and cost effectiveness[12].

In EEG electrodes are placed on the scalp in different locations coresponding to different brain regions according to Inernational 10-20 system [13]. Figure 1b shows positioning of different electrodes over the scalp. This electrodes measures the micro-volt potential differences of different regions with respect to the reference electrode placed in the ear lobe [14], [15]. Electrodes are of different types based on the materials with which they are made. Ag/AgCl electrode is the most wildly used due to its good signal capturing quality and reliability. Along with the electrodes, there comes signal acquisition system and amplifier which acquires the signal, amplifies its power and feeds the computer with the amplified signal for processing. Computer attached to the EEG system, uses various digital signal processing (DSP) and machine learning (ML) techniques to extract some meaningful information like motor-imagery left-right hand movement [16] of the subject.



(a) EEG cap with electrodes. Image source [17]

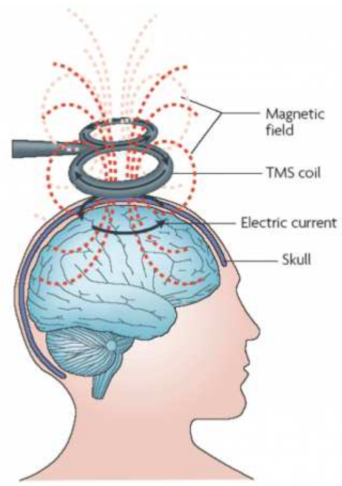
(b) 10-20 electrode positioning. Image source [18]

Figure 1: **EEG cap and electrode positioning.**

2.2 TMS based CBI

A CBI system enables a computer or a machine to stimulate different regions of a brain to artificially invoke different brain functionalities bypassing the natural sensory stimuli. In a very rough sense it can be said, CBI systems are used to write informantion in brain for execution of different functionalities [19], [20]. Different non-Invasive CBI systems are available today, such as: ultra sound stimulation based FUS [21], electrical stimumation based tDCS [22], magnetic stimulation based TMS [23]. A brief description of the TMS is given below as this is used in the CBI subsystem of the experiment.

TMS is one of the effective non-invasive techniques of brain stimulation which works on the principle of elecro-magnetic induction generated by an insulated coil positioned over the scalp. When focoused on the particular region, the magnetic pulses pass through the skull and stimulate the nerve cells of that particular region of the brain. Figure 2a shows a schematic diagram of the TMS system.



(a) TMS diagram

(b) TMS is being applied on a patient

Figure 2: **Transcranial Magnetic Stimulation.** Image source [24]

2.2.1 Different uses of TMS

As TMS is a very effective non-invasive brain stimulator with minimal side effects, it has found many uses in medication of different brain diseases. Some of the uses [25] of TMS are listed below:

- Antidepressant [26]
- Treatment of movement disorder [27]
- Treatment of neuropsychiatric disorders [28]
- Epilepsy medication [29]
- **Phosphene perception** [30], [31]

Among these uses, *phosphene perception* is exploited in this experiment at the CBI end. A brief description of phosphene perception is explained below.

2.2.2 Generation of Phosphene Perception with TMS

Phosphene perception refers to a sensation of ring or spot of light produced by some stimulation of nerve cells of the retina or some direct stimulation of the visual cortex of the brain other than the use of light stimuli. Phosphene stimuli are broadly of three types: (i) Mechanical, (ii) Electrical and (iii) Magnetic. Mechanical stimuli refers to the pressure applied on the eye balls. Both eletrical and magnetic stimuli are directly applied to visual cortex region of the brain and used by Transcranial Direct Current Stimulation (tCDS) and TMS respectively. In this experiment phosphene perception was created by TMS. Some particular orientation of the coil and position in the right visual occipital cortex can be found which produces phosphenes with heighest intensity. These positions are called *phosphene hotspot*. These positions can slightly vary subject to subject.

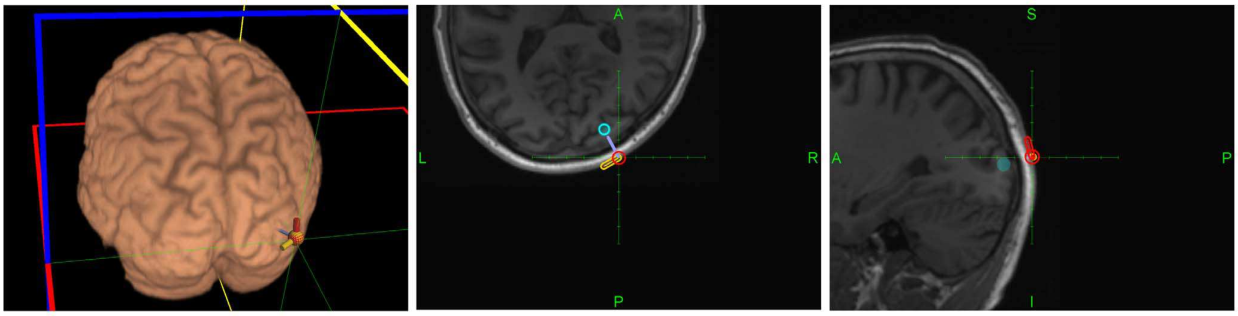


Figure 3: **Location of phosphene hotspot.** Orange colour shows phosphene producing and red colour shows phosphene not producing orientation of the TMS coil. Image source [11].

3 The Experiment

In this section the experiment done by Grau *et al.* will be discussed in brief. The three major parts of the experiment is explained below.

3.1 Equipments

3.1.1 Human Subjects

Four healthy human subjects of age 28-50 years were chosen for the experiment with their written consent. One of them (Subject 1) is assigned to the BCI subsystem for transmission of the brain data. Rest three (Subject 2, Subject 3, Subject 4) were assigned to the CBI system for reception of the data in their brain.

3.1.2 BCI Subsystem

For recording of the brain activity of the sender a wireless (500 S/s, 24 bit) EEG recording system (Starstim tCS/EEG system, by Neuroelectrics, http://www.neuroelectrics.com) was used. To get the binary information from the EEG signal BCI 2000 platform [32, p. 264] was used.

3.1.3 CBI Subsystem

CBI Subsystem used biphasic TMS pulses. For achieving high precision of relocation and reorientation of the TMS target, a neuro-navigated [33], [34] robotized TMS system (Axilum Robotics TMS-Robot, http://www.axilumrobotics.com, piloted by Localite 2.8 Neuronavigation system using the MagVenture MagPro R30 TMS Stimulator with a butterfly coil of type Cool-B65-RO) was used.

3.1.4 Communication Link

Sender (BCI) and receiver (CBI) subsystems were linked through internet connection and the encoded bit strings were automatically sent via email.

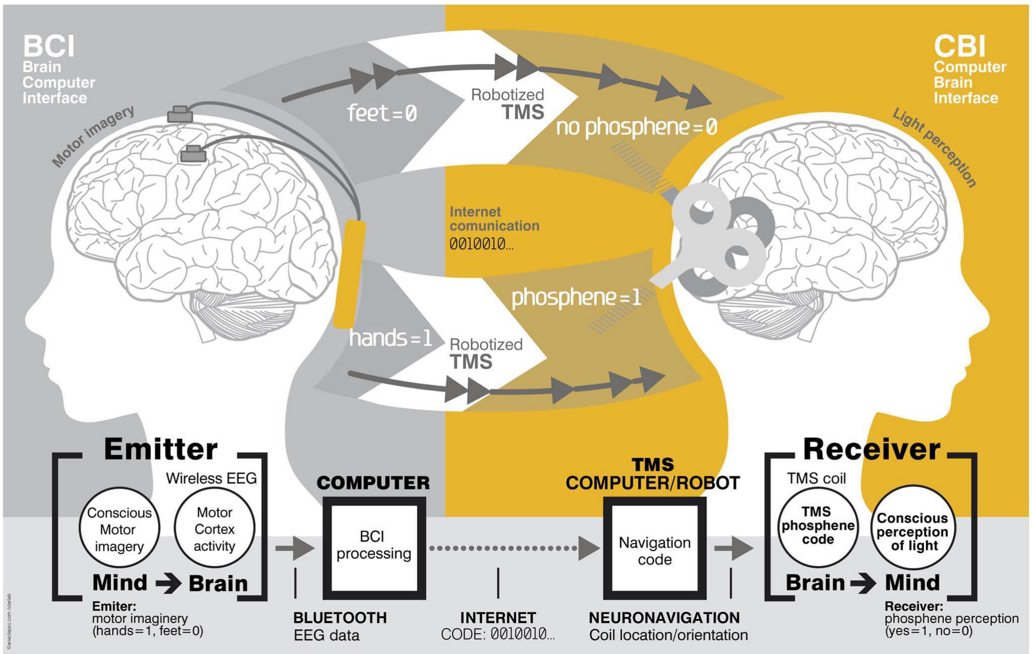


Figure 4: **Diagrammatic Overview of the system.** Image source [11].

3.2 Method

As the experiment consisted of two major subsystems at the two end, experimental method also had two consitituting parts, one for each end.

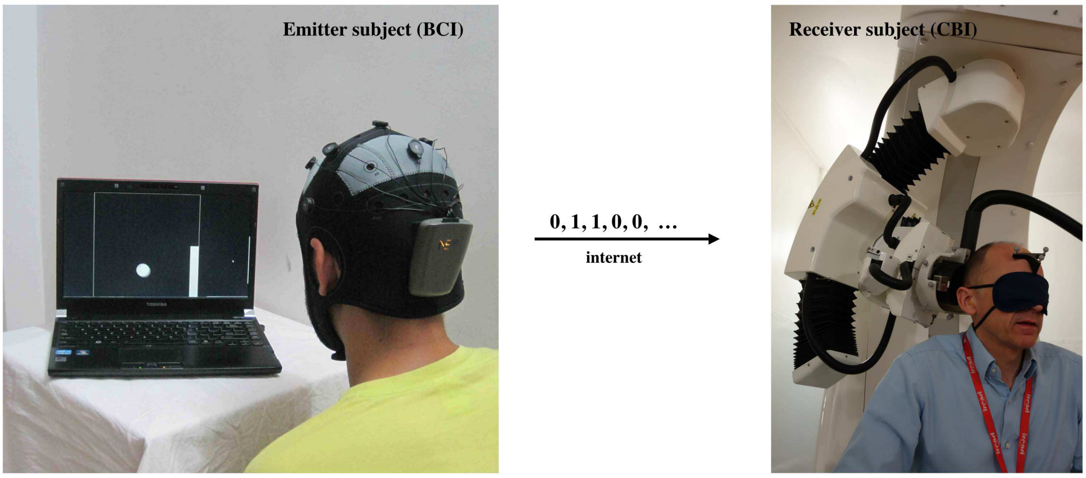


Figure 5: **Emitter and Receiver Subjects.** Image source [11].

3.2.1 BCI Side

To capture the EEG signals an EEG cap with eight Ag/AgCl electrode was used. Electrodes F3, F4, T7, C3, Cz, C4, T8 and Fz were placed at their respective positions according to 10-20 system, on the scalp of the subject 1. All the electrodes had a common ground placed in the right ear lobe. Electrodes C3, Cz and C4 corresponds to motor imagery activities. So, these electrodes of interest (C3, Cz and C4) were filtered out with the use of a spatial filter to minimize the effect of their neighbouring electrodes. The subject was asked to encode bit value 1 and 0 by performing motor-imagery of hand and feet respectively. A BCI 2000 platform was used to convert the EEG signal into binary information by classifying the motor-imagery activity.

Emitter subject was cued by a video game like visualization (Figure 5) of the bit values. Each bit was represented either by a target bar like structure in the downright part of the screen (bit value 0) or in the upright part (bit value 1). The vertical positioning of a ball appearing on the screen from left with a constant horizontal speed, was controlled by the motor-imagery task performed by the subject, according to the encoding scheme as discussed earlier. Successful bit encoding was visualized as hitting of the target by the ball. An automated program was used to send these BCI encoded bits to the CBI Subsystem via email.

3.2.2 CBI Side

At the receiver side, for each of the receiver subject, the precise position of the TMS Phosphene hotspot were identified with the help of a neuro-navigated Robotized TMS system and verbal communication of the subjects about their phosphene perception. For this position of the TMS coil phosphene perception was generated in the subjects due to the magnetic stimulation thus encoding bit value 1 (*active condition*). Bit value 0 (*silent condition*) was encoded using the different orientation of the coil which did not produce phosphene. Each of the receiver subjects, went through a familiarization period when they were supplied with several TMS pulses to the chosen right occipital cortex site using various rotations of the coil and the intensity of the TMS pulses, that optimally discriminated active from silent orientation, was identified .

A number of measures had been taken to nullify the possibility of the receiver subjects getting Peripherial Nervous System (PNS) input cues (tactile, auditory or visual) related to the coil movement. These measures were:

- **To avoid the contact related cues**, rotation based encoding strategy was adopted. Equal contact force with the scalp in all conditions was maintained with the help of a force sensor attached to the coil. Cables were placed in such a way that it did not touch subject's shoulder or back in any of the position of coil rotation.

- **To avoid the auditory cues**, subjects were asked to wear earplugs. The coil rotation mechanism was designed such a way such that it produced equal level of noise in any bit transmission and any orientation of the coil.

- **To avoid visual cues**, subjects were made to wear eye mask.

The effectiveness of these measures were assesed by carrying out series of control studies using *d-prime* statistic [35], [11].

3.3 Result

The first attempt of this experiment was done offline (i.e, BCI and CBI transmission was done in different time buffering the data received from BCI Subsystem) from Barcelona to Strasbourg. It resulted in 15% transmission error rate with 5% in the BCI segment and 11% in the CBI segment.

The final experiment was done online betwween Thiruvananthapuram, India (BCI side) and Strasbourg, France (CBI Side) on two different days with subject 3 and subject 2 in the receiver end. There was a program written to parse the incoming mails to navigate the TMS system over the receiver's scalp and deliver the TMS pulses. BCI emitter encoded 140 bits which were sent via email, using an automated program, to the CBI subsystem. In the first experiment the transmission error rates were of 6%, 5% and 11% for the BCI, CBI and the combined B2B components respectively, and in the second, error rates were of 2%, 1% and 4% respectively.

Bit rate for BCI and CBI was 3 and 2 bits per minute. The B2B link provided a bit rate of 2 bits per minute.

4 Application and Future Scope

The experiment was a significant first step towards an alternate way of inter personal communication. This also paves the path towards possibility of non-invasive direct tramission of emotions and feelings or the possibility of sense synthesis in human ie. interface of different arbitrary sensors in the human brain. Some advancement of this technology might let us think and communicate collectively. This brain to brain communication can also be the way of non-verbal communication with other species [36].

5 Limitation

This excellent research work has some limitations too. Slow bit rate, high cost of the systems (especially TMS system) and non portability are some of the major issues. Other than that some ethical issues might be raised like the threat of stealing of someone's personal thoughts and thereby compromising with the data privacy.

6 Conclusion

This experiment was the first to demonstrate the brain to brain communication in human. This was different from previous experiments in three senses such as:

- It used human subject in both the end
- It used completely non-Invasive technology
- It was consciously driven

Above three points made this experiment unique from the others. Despite having different limitations and scopes of improvements, this experiment has become a pioneer in showing a complete alternate way of interpersonal communication in human.

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