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NON-INVASIVE BRAIN TO BRAIN INTERFACE

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***ABSTRACT*- Technologies of the current era provide the ability to interface and communicate directly from one human brain to another. This can be done by using Transcranial magnetic stimulation (TMS), Brain to Brain Interfaces (BBIs), EEG (electroencephalograph) and the Internet. Computer commands are generated using the brain-to-computer interface (BCI) and these commands are translated to generate brain functions and a form of magnetic stimulation by using computer-to-brain interface (CBI). So a way was discovered to establish a good working link between the brains, thus creating a brain to brain interface. This new innovation can further be applied for people with disabilities or for emergency landing of aircrafts by controlling the hand motions.**

Keywords— BBI, BCI,CBI, EEG, TMS, Brain-to-Brain coupling, electrodes, FEM, rTMS, transcranial, IGBT

1. INTRODUCTION

The direct communication between two individual brains is one of the fascinating research topics for the convenience of our lives. Brain-to-brain interface (BBI) refers to the hardware and software environment that detects and transfers thoughts between two people, this is possible by the following techniques.

Brain-to-computer interface (BCI) refers to the hardware and software environment that detects and translates brain activity to control computers or stored-program architecture devices without involving muscles or the peripheral nervous system. To characterize a specific function of the brain, invasive means such as implantable cortical microelectrode arrays that directly detect the electrical field potentials/spikes from the somatomotor areas have been used, for example, to provide BCI control options for quadriplegic patients. Other than these BCI methods which require a surgery to implant electrodes to the brain surface, non-invasive functional imaging modalities such as electroencephalogram (EEG) and stimulation modality such as Trans cranial magnetic stimulation coil (TMS) are used now.

It is notable that the flow of information used in the current implementation of BCI is unidirectional, in the sense that the control commands originating from the brain are directed to operate a computer. To establish the bidirectional interface between the brain and the computer, the creation of a computer to- brain interface, namely CBI, was sought after, whereby the computer-generated commands can be used to modulate the function of the specific brain area via its direct stimulation/suppression, all without engaging the peripheral nervous system and sensory pathways. The bidirectional interface between the brain and the computer would ultimately lead to the development of a 'Brain-to-Brain Interface' (BBI), in which neural activities from individual brains are linked and mediated by computers direct electrical stimulation of the motor cortex, achieved by surgically-implanted electrodes, was used to elicit animal limb motion necessary for navigating through complex spatial environments.

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Deep brain stimulation (DBS) or epicortical stimulation can also be adopted for human application, but would require invasive surgical procedures. Transcranial magnetic stimulation (TMS) confers the non-invasive means of Neuro-modulation; however, lacks penetration depth and spatial specificity due to its electromagnetically inductive nature [1]. A thought-process (intention to stimulate a human brain) originating from a human participant is detected in forms of EEG human brain which elicits the subsequent hand movement.

2. HISTORY

Electrical signals produced by brain activity were first recorded from the cortical surface in animals by Richard Caton in 1875 (Caton, 1875) and from the human scalp by Hans Berger in 1929 (Berger, 1929). Hans Berger, who discovered the human EEG, speculated in his first comprehensive review of his experiments with the ‘‘Elektrenkephalogramm’’ (1929) about the possibility of reading thoughts from the EEG traces by using sophisticated mathematical analyses. In the 75 years since Berger’s first report, electroencephalographic (EEG) activity has been used mainly for clinical diagnosis and for exploring brain function. In between many scientists proceeded the work [2].

Studies with brain-machine interfaces had convinced the researchers that the brain was much more plastic than they thought. In those experiments, the brain was able to adapt easily to accept input from devices outside the body and even learn how to process invisible infrared light generated by an artificial sensor. So, the question they asked was, if the brain could assimilate signals from artificial sensors, could it also assimilate information input from sensors from a different body.

Researchers have electronically linked the brains of pairs of rats for the first time, enabling them to communicate directly to solve simple behavioral puzzles. As the ultimate test of their system, they even brain-linked two animals thousands of miles apart—one in Durham, North Carolina and one in Natal, Brazil. To test this hypothesis, in one set of experiments, the researchers first trained pairs of rats to solve a simple problem, where the rats had to press the correct lever when an indicator light above the lever switched on, to obtain a sip of water. They next connected the two animals' brains via arrays of microelectrodes—each roughly one hundredth the diameter of a human hair—inserted into the area of the cortex that processes touch information. One animal of the dyad was designated as the "encoder" animal. This animal received a visual cue that informed it which lever to press in exchange for a food pellet. Once this “encoder” rat pressed the right lever, a sample of its brain activity that coded its behavioral decision was translated into a pattern of electrical stimulation that was delivered directly into the brain of the second animal of the dyad, known as the "decoder" animal. The decoder rat had the same types of levers in its chamber, but it did not receive any visual cue indicating which lever it should press to obtain a reward. Therefore, to press the correct lever and receive the reward it craved, the decoder rat would have to rely on the cue transmitted from the encoder via the brain-to-brain machine interface [3].

Another experiment was conducted by scientists that allowed humans to control animals by thoughts. In this experiment, rat was used. The scientists controlled the movement of rat’s tail using their mind [1].

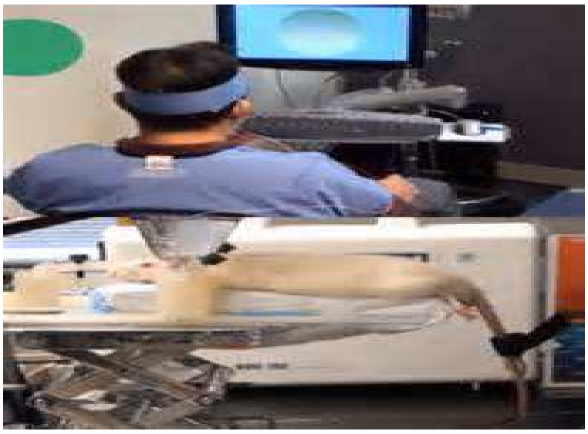

Figure 1: BBI between a human brain and that of a rat (Courtesy www.medgadget.com)

3. EXPERIMENT

Using the finding of the experiments on BBI on rats and the other findings of BCI and CBI an experiment was conducted. Person A wearing a cap with electrodes hooked up to an electroencephalography machine, which reads electrical activity in the brain. Person B in the campus was wearing a swim cap marked with the stimulation site for the transcranial magnetic stimulation coil that was placed directly over his left motor cortex, which controls hand movement. Person A looked at a computer screen and played a simple video game with his mind. When he was supposed to fire a cannon at a target, he imagined moving his right hand (being careful not to actually move his hand), causing a cursor to hit the "fire" button. Almost instantaneously, Person B, who wore noise-cancelling ear buds and wasn't looking at a computer screen, involuntarily moved his right index finger to push the space bar on the keyboard in front of him, as if firing the cannon. Person B compared the feeling of his hand moving involuntarily to that of a nervous tic. This was basically a one-way flow of information from his brain to the other person. The next step has a more equitable two-way conversation directly between the two brains [8].

Figure 2: BBI experiment conducted by researchers on two human brains (Courtesy www.washington.edu.news)

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4. SYSTEM OVERVIEW

4.1 Working principle

The technologies used by the researchers for recording and stimulating the brain are both well-known. Electroencephalography, or EEG, is routinely used by clinicians and researchers to record brain activity noninvasively from the scalp. The Internet was a way to connect computers, and now it can be a way to connect brains. Transcranial magnetic stimulation is a non-invasive way of delivering stimulation to the brain to elicit a response. Its effect depends on where the coil is placed; in this case, it was placed directly over the brain region that controls a person’s right hand. By activating these neurons, stimulation convinced the brain that it needed to move the right hand.

4.2 Components used in brain-to-brain communication

4.2.1 ***Brain computer interface:*** A brain–computer interface (BCI), sometimes called a direct neural interface or a brain–machine interface (BMI), is direct communication pathway between the brain and an external device. BCIs are often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions.

4.2.2 ***Electrodes:*** An electrode is an electrical conductor used to make contact with a non-metallic part of a circuit (e.g. a semiconductor, an electrolyte or a vacuum). Electrode locations and names are specified by the International 10–20 system for most clinical and research applications (except when high-density arrays are used). This system ensures that the naming of electrodes is consistent across laboratories. In most clinical applications, 19 recording electrodes (plus ground and system reference) are used. A smaller number of electrodes are typically used when

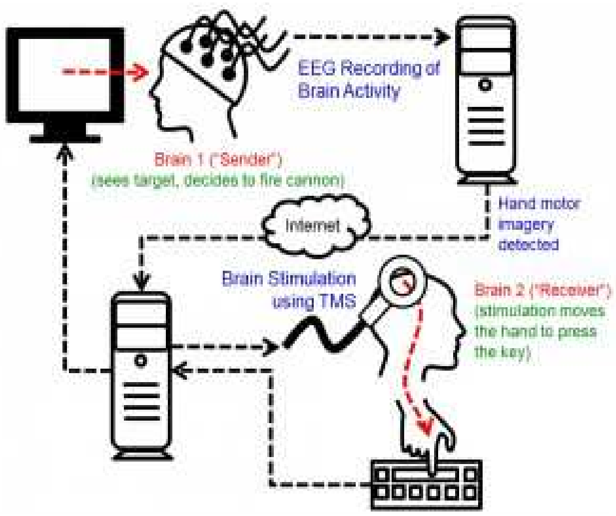

Figure 4: Block Diagram

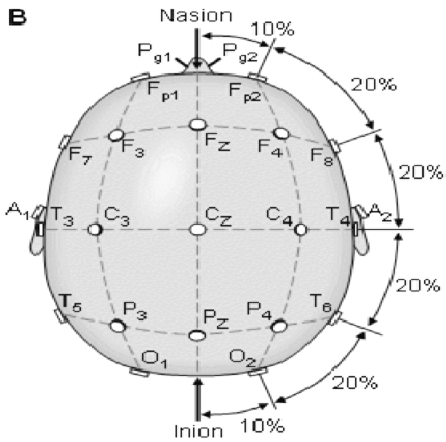

Figure 5: International 10-20 system for the position of electrodes on the brain [2]

recording EEG from neonates. Additional electrodes can be added to the standard set-up when a clinical or research application demands increased spatial resolution for a particular area of the brain. High-density arrays (typically via cap or net) can contain up to 256 electrodes more-or-less evenly spaced around the scalp.

4.2.3 ***EEG:*** Electroencephalography is the recording of electrical activity along the scalp. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain. Electroencephalography (EEG) is the most studied potential non-invasive interface, mainly due to its fine temporal resolution, ease of use, low set up cost. But as well as the technology's susceptibility to noise, another substantial barrier to using EEG as a brain–computer interface is the extensive training required before users can use the technology.

4.2.4 ***LED lamp:*** A light-emitting-diode lamp is a solid-state lamp that uses light-emitting diodes (LEDs) as the source of light portability and since the light output of individual light-emitting diodes is small compared to incandescent and compact fluorescent lamps, multiple diodes are used together. LED lamps can be made interchangeable with other types. Most LED lamps must also include internal circuits to operate from standard AC voltage. LED lamps offer long life and high efficiency, but initial costs are higher than that of fluorescent lamps.

4.2.5 ***Internet:*** In this system the transmission of the signals to another person through the Internet.

4.2.6 ***Personal computer:*** PC is used to pick up the stream of binary digits and also it can decipher whether a zero or one was transmitted [2].

5. BRAIN-TO-BRAIN COUPLING

The premise of brain-to-brain coupling is that the perceptual system of one brain can be coupled to the motor system of another. Different objects in the environment emit different forms of energy (mechanical, chemical, electromagnetic), and receptors convert these signals into electrical impulses that the brain can use to infer information about the state of the world and generate appropriate behaviors. Thus, stimulus-to-brain coupling is fundamental to the ability to retrieve information about the world to

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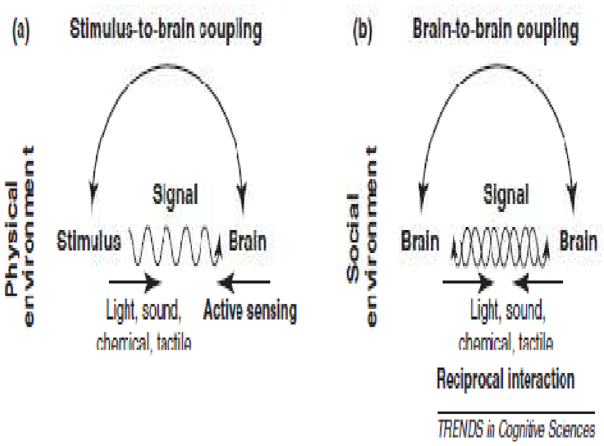

Figure 6: To illustrate a) stimulus to brain coupling b) brain to brain coupling [4]

guide actions. Brain-to-brain coupling also relies on stimulus-to-brain coupling as a vehicle for conveying information. However, in brain-to-brain coupling, the signal is generated by another brain and body that resemble one's own, rather than by inanimate objects in the physical environment (Figure 6b). Brain-to-brain coupling is analogous to a wireless communication system in which two brains are coupled via the transmission of a physical signal (light, sound, pressure or chemical compound) through the shared physical environment. The coordination of behavior between the sender and receiver enables specific mechanisms for brain-to-brain coupling unavailable during interactions with the inanimate world. One example of such coupling is the presence of synchronous spatiotemporal patterns of brain activities that are correlated with the degree of understanding during verbal communications between a speaker and a listener. The presented BBI method may be used to augment this mutual coupling of the brains, and may have a positive impact on human social behavior [4].

6. TMS FOR DEEP BRAIN STIMULATION

Transcranial magnetic stimulation (TMS) is a non-invasive method to cause depolarization or hyperpolarization in the neurons of the brain. TMS uses electromagnetic induction to induce weak electric currents using a rapidly changing magnetic field; this can cause activity in specific or general parts of the brain with minimal discomfort, allowing for study of

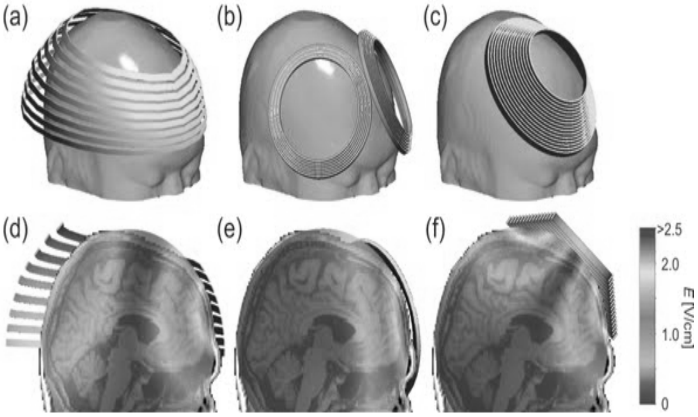

Figure 7: TMS coils for brain stimulation [7]

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the brain's functioning and interconnections [5]. Transcranial magnetic stimulation (TMS) devices allow adjustment of the magnetic stimulus parameters over a wide range. Pulse shaping is accomplished through the use of high power insulated-gate bipolar transistors (IGBTs), high energy storage capacitors, and requisite snubber and control circuits. rTMS (repetitive TMS) produces briefer magnetic pulses than conventional TMS, which could reduce unpleasant scalp sensation. rTMS can generate high frequency trains of unipolar pulses which may have more potent therapeutic effect [6].

The design of TMS coils determines the electric field pattern that is induced in the brain. Depending on the stimulation target, designs with various degrees of focality and field penetration depth could be desirable. We are interested in coil designs for deep brain TMS, which are particularly challenging due to the rapid decay of electric field away from the coil.. In the process of coil development, finite element modeling (FEM) of electromagnetic fields is used which allows fast optimization designs before a hardware prototype, is constructed.TMS is used for transcranial brain stimulation in the presence of implanted stimulation systems. To stimulate deep brain regions, a very high intensity would be needed. Such intensity cannot be reached by standard magnetic stimulators using the regular figure-of-eight or brain regions effectively would stimulate cortical regions and facial nerves over the level that may lead to facial pain, facial and cervical muscle contractions, and other undesirable side effects [5]. The double-cone coil has a somewhat similar shape as the figure-of-eight coil except that the two rings create an angle (95 deg) between them and their diameter is usually larger. This coil, which is able to create greater electrical field intensity, is considered to be the best tool for stimulation of deeper brain regions compared with other coils [5]. Electrical field intensity in the tissue and the rate of decrease of electrical field as function of distance from the coil, depend strongly on the orientation of coil elements relative to tissue surface. Studies with volume conductors having flat and geometries have demonstrated that coil elements perpendicular to the surface, induce accumulation of surface charge which leads to complete cancellation of the perpendicular components of the induced field at all points within the tissue. In addition, the electrical field in any other direction is considerably reduced. Therefore, when designing a coil for deep brain stimulation, an effort should be made to minimize the overall length of coil elements that are not tangential to brain tissue surface. Physiologic studies of peripheral nerves revealed that optimal activation occurs when the field is oriented in the same direction as the nerve fiber Hence, to stimulate deep brain regions, it is necessary to use coils in such an orientation that they will produce a considerable field in a direction tangential to the surface, which should also be the preferable direction to activate the neurons under consideration. Another requirement is that the field in the deep region will be as large as possible compared with the field at the cortex [7].

Hesed coil was designed to stimulate effectively deeper brain regions without increasing the electrical field intensity in the superficial cortical regions. Numeric simulations and phantom measurements of the total electrical field produced by the Hesed

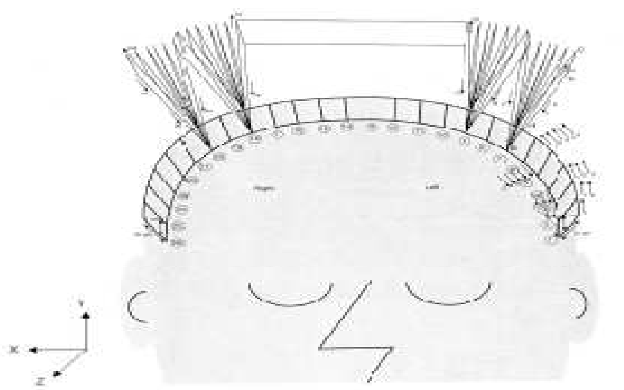

Figure 9: The Hesed coil shape when applied over the human head [8]

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coil inside a homogeneous spherical volume conductor and compare these with results from a circular coil in different orientations and from the double-cone coil. The drop of the electrical field in the brain as a function of the distance from the new coil is much slower compared with previous coils. Such a coil can stimulate deeper regions such as the nucleus accumbens and the fibers connecting the medial prefrontal or cingulate cortex with the nucleus accumbens the coil design when applied on the human head. The coil contains several strips attached to the head, all connected serially, and having wires that induce stimulation in the desired direction. This desired direction is the anteroposterior direction. For each strip there is a return path wire, having current component at the opposite direction (z direction), which is located 5 cm above the head. These return paths are located at the top edges of four fans, to remove the currents flowing through them away from the deep regions of the head. The specific design of the fans is meant to reduce the inductance of the coil. The fans are connected to the frame near strips 7, 9, 18, and 20 (see Figure 9). These loci were chosen to remove the return paths as much as possible from the deep brain region to be activated most effectively. The only wires with currents that have radial components are those connecting the strips that are attached to the head with their return paths, along the sides of the fans. An optimized coil would have a flexible frame allowing all elements of the coil that are touching the head to be tangential to the head surface The Hesed coil may be used to stimulate a variety of deep brain regions. In this case transcranial magnetic stimulation coil was placed directly over the patient's left motor cortex, which controls hand movement [7].

7. ADVANTAGES

7.1 Help people with severe debilitating muscle wasting diseases, or with the so-called 'locked-in' syndrome, to communicate.
7.2 Help in direct brain communication in completely paralyzed patients.
7.3 Help to those who suffer from disorders like ALS (Amyotrophic lateral sclerosis), Brainstem stroke, brain or spinal cord injury [2].

8. LIMITATIONS

8.1 ***Liability*: **Most people would agree that, under normal circumstances, we are fully responsible for our actions. However, if our intent was affected by a brain–computer interface, incorrect actions may be produced simply by incorrect detection of correct intent.
8.2 ***Privacy***: The capacity to induce information into the brain may provide us with the ability to base our actions on a better assessment of the environment. Because this information is provided by a computer, it could be accessed and modified by third parties, which may allow them to influence our actions.
8.3 In terms of the speed, accuracy and robustness of the technology, there is long way to go [2].

9. APPLICATIONS

9.1 Communication and control: BBIs provide options for communication and control for people with devastating neuromuscular disorders (such as amyotrophic lateral sclerosis, or ALS, brainstem stroke, cerebral palsy, and spinal cord injury).

***9.2 Military defence system*:** DARPA (Defence Advanced Research Projects Agency) has been interested in Brain-Machine-Interfaces for a number of years for military applications like wiring fighter pilots directly to their planes to allow autonomous flight from the safety of the ground [2].

10. FUTURE ENHANCEMENTS

More experiments have to be conducted to transmit more complex information from one brain to the other. Years from now the technology could be used, for example, by someone on the ground to help a flight attendant or passenger land an airplane if the pilot becomes incapacitated. Or a person with disabilities could communicate his or her wish, say, for food or water. The brain signals from one person to another would work even if they didn't speak the same language [8].

11. CONCLUSION

Coupled brains can create new phenomena, including verbal and nonverbal communication systems and that could not have emerged in species that lack brain-to-brain coupling. Brain-to Brain Interface will help people who suffer with "Locked –In" syndrome, and can also be used in our military defense system. One person can chat, that is brain-to-brain at speed of thoughts with the person miles away. The technology will cut down the verbal communication in coming era. A broadband connection, however, would be essential.

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