TTIC, 2017, Vol.1, 1-6

BCI requirements for implementing Non-invasive and Invasive Techniques

A. B. Bhattacharya
Department of ECE, Techno India University, West Bengal, Kolkata 700091

Abstract: **The interfaces are the most important part of the hBCI, facilitating a standardized communication between different blocks independently from the chosen platform and software language. Currently, many BCI laboratories have their own techniques to perform data processing. Therefore, common methods to exchange data between different components must be established. A specification which only describes the format of the data to be exchanged between components is not adequate in this case. To achieve true modularity, ways to transmit and exchange data must be defined as well. Three types of viable data exchange methods exist: (I) exchange of data within the same programming language, (II) exchange within the same computer but between different programming languages, and (III) exchange between different computers. We have pointed out the techniques to be implemented for non-invasive and invasive mode of operations, a big challenging problem in coming days to the engineers.**

Index Terms: **Microelectronics, Embedded Systems, Brain Computer Interfacing, Non-invasive and Invasive Technique**

I. INTRODUCTION

Rapid progress in microelectronics and embedded systems have developed and improved many brain signal monitoring techniques [1]. A Brain Computer Interfacing (BCI) must have four requirements. (i) It must record activity directly from the brain (invasively or non-invasively). (ii) It must provide feedback to the user and must do so in actual time. (iii) Signal processing must be performed online. (iv) Finally, the system must rely on the user can choose to perform a mental task whenever wants to achieve a goal with the BCI.

II. SERIAL AND PARALLEL PROCESSING

We first require knowing the basic difference between the serial and parallel processing. An ordinary computer can do one thing at a time and so it does things in a distinct series of operations. This is what we mean by the term serial processing. A typical modern supercomputer can work much more quickly by splitting problems into pieces and working on many pieces immediately. This is meant by parallel processing. Parallel processing is more like what happens in human brains. Every Neuron is connected to over 10,000 to 1, 00,000 other neurons. The number of these connections seems less precise, but it is at least several 125 Trillion connections (10^{14}). The mean total brain volumes found are 1,273.6 cc for men and 1,131.1 cc for women. If we take the volume of the brain as 1000 cc as a low estimate one cubic millimeter becomes 1/1000 of a cubic centimeter and 1/1000000 (10^{-6}) of the entire volume of the brain. Using the high estimate of 10^{15} connections in the brain, we can scale the total number of connections in the brain. It appears that there are 10^{9} connections in a cubic millimeter of the brain [2, 3].

In Figure 1 we have illustrated what is really meant by the terms Serial and parallel processing. In serial processing, a problem is tackled one step at a time by a single processor. It does not matter how fast different parts of the computer are working, such as the input/output or memory, the job still gets done at the speed of the central processor in the middle. On the other hand, in parallel processing, problems are broken up into components. Each of the components is handled by a separate processor. As the processors are working in parallel, the problem is tackled generally more quickly even if the processors work at the same speed as the one in a serial system [4].

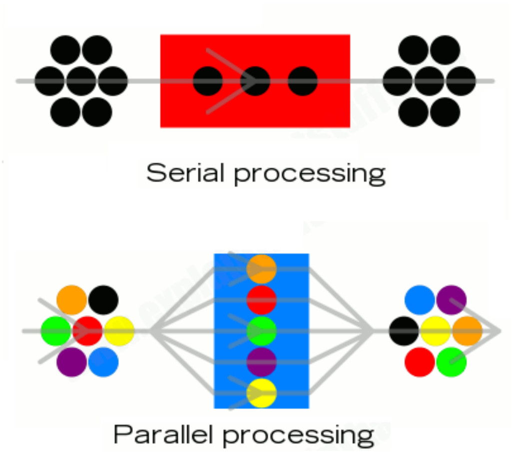


Figure 1 Serial and parallel processing

The neural networks of the brain include nodes, which can be in one or two states. The 'Active states' represent ongoing external events and internal mental processes while 'Quite states' represent stored concepts. Making the quite state nodes to activate is called the information retrieval process. All the basic associations have corresponding basic retrieval requests. The basic association 'A is a part of B' has the two corresponding retrieval requests: 'Retrieve a part of the given item A', and 'Retrieve an item whose given part is B'. This retrieval is termed as basic retrieval [5]. The compound retrieval requests, on the other hand, are of two types, viz., nesting and logical joining. In logical joining, individual requests are joined by the logical relationships AND, OR, NOT and delimiters. Figure 2 shows how the input and the output layers are connected through the hidden layer of the system.

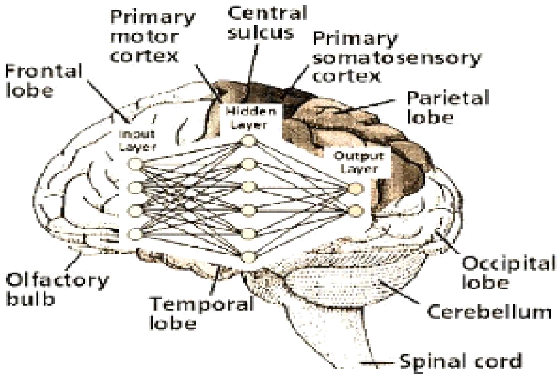


Figure 2 The input and the output layers connected through the hidden layer of the human brain

In practice, computers process information from memory using CPUs and then write the results of that processing back to memory. But such distinction cannot exist in the brain. As neurons process information, they are also changing their synapses, which are they the substrate of memory. As a consequence, retrieval from memory always changes those memories slightly. Multi tasking of human brain is illustrated in Figure 3.

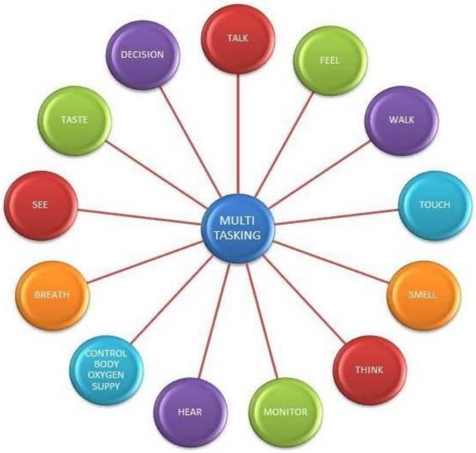


Figure 3 Multi tasking of human brain

A supercomputer, as developed in recent years, is a computer which performs at the highest operational rate. Supercomputers may be used for brain computer interfacing applications to handle very large databases making huge amount of computation at a time. Although advances like multi-core processors and general-purpose graphics processing units have enabled powerful operations in terms of performance. In parallel processing, problems are broken up into components, each of which is handled by an independent processor [6, 7]. As the processors are working in parallel, the problem can be tackled more quickly even if the processors work at the same speed as in the case of a serial system

First human electroencephalogram (EEG) was conducted in 1924 but as technology has concurrently evolved, BCI has gained the potential to transform diagnostic testing for the human brain. BCI market consists of external devices that measure, diagnose and give insight condition of the brain. Some of the companies, in recent years, are attempting to improve to physically connect BCI devices to our brains in a more sophisticated way. The approach of surgically placing sensors on the brain is called invasive BCI technique. This can enable a BCI device to physically manipulate the electrical signaling of the brain rather than just to monitoring it. Invasive BCI technique has strong possibility though it has yet to achieve mainstream consumer applications with external devices that interact with brain activity [8].

III. BRAIN ACTIVITY MONITORING TECHNIQUES

BCI can be performed secretly at the presence of neurons inside the brain cortex on the scalp [9, 10]. The invasive techniques require complicated and clinically risky brain surgery and can only utilize when there are very crucial or significant clinical needs. However, the non-invasive systems can execute without medical complicacy**.**

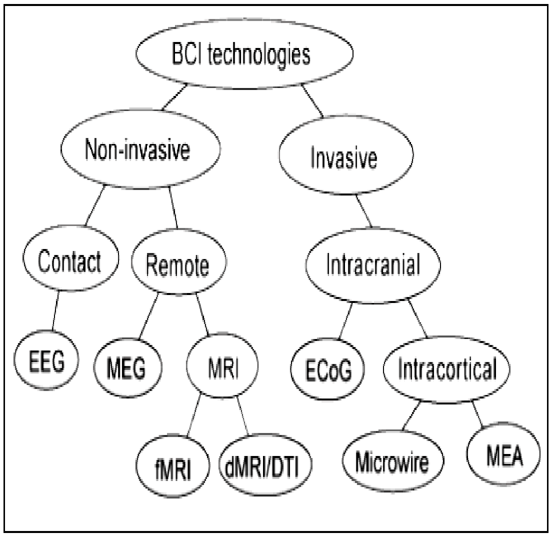


Figure 4 Classification of recent technologies for brain activity monitoring

Figure 4 shows a general classification of different technologies recently available for brain activity monitoring: EEG (Electroencephalography); MEG (Magneto encephalography); MRI (Magnetic Resonance Imaging); f MRI (Functional MRI); d MRI (Diffusion MRI); DTI (Diffusion Tensor Imaging); ECoG (Electrocorticography); MEA (Multiple Electrode Array).

The typical electrode locations for several BCI technologies are schematically shown in Figure 5 and disadvantages and signals of some growing technologies are illustrate in Figure 6.

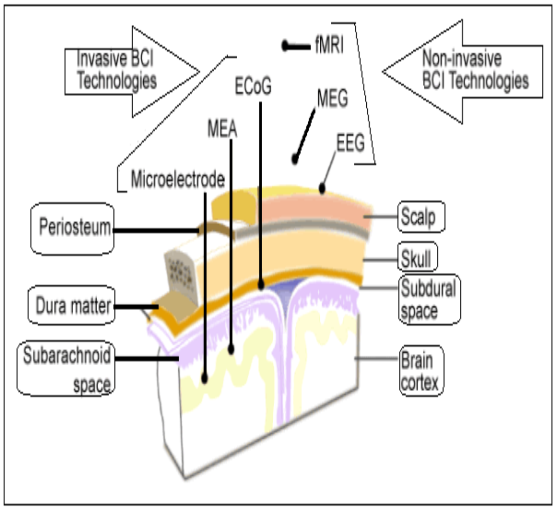
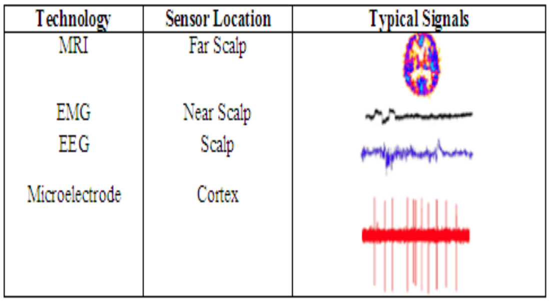


Figure 5 Install location of Electrode in various brain sensing technologies



Technology	Sensor Location	Typical Signals
MRI	Far Scalp	
EMG	Near Scalp	
EEG	Scalp	
Microelectrode	Cortex	

Figure 6 Different BCI technologies and sensor location Signals

Microelectrode or microware is a very popular invasive electrode for monitoring cortical neuron activities. The technique has developed to perform in dual purposes: (i) sensing and (ii) stimulation. These electrodes are more specific as they penetrate the pia matter and the cortex for higher spatial resolution. They can record the activity of a single neuron by recording the potential spikes or actions of the neuron. These spikes are recorded by placing the electrode within the field generated by the neuron. Recording from one neuron is called single unit activity (SUA) and recording from multiple brain neurons are called as multi-unit activity (MUA) [19]. Microelectrode array (MEA) and microwire electrodes are requiring the activities into the cortex made by microscale and nanoscale technology. The signal can be used to record neuronal population. Using the spike amplitude, it can determine a single neuronal activity. Electrode design is an important component of microelectrode sensing technique.

Invasive electrodes including multi-electrodes contain microwires in a planar silicon probes and platforms with micro-electrode array (MEA), called "Michigan Electrode" and "Utah Electrode". The fabrication process involves the use of IC (integrated circuit) technology to create dense arrays of thin film electrodes. The multi-electrode cortical probe invented in 1966 at Stanford University. It was difficult to produce such electrodes until the microelectromechanical systems (MEMS) technology and silicon-on-insulator (SOI) wafer technologies were developed [11].

IV. INVASIVE BCI MONITORING TECHNIQUES

Implantable, intracranial cortical neuronal devices are the example of some highly invasive monitoring device. Those implantable medical devices are attaching to the outside or inside of the skull including electronic signal processing elements connected to one or more electrodes which penetrates the skull for recording the neural actions in brain or motivate brain neurons in a safe and predictable manner. Neuronal actions can be recorded in local field potential (LFP), used in ECoG, or neuronal action potentials which used in Multiple Electrode Array (MEA). MEA is mainly used to simultaneously probe, a dense region of cortical surface from multiple sites. These approaches have their roots in the pioneering studies conducted by Fetz and colleagues in the 1960s and 1970s. ECoG has an ability to stimulate individual neuron with deep brain stimulation (DBS), is a mechanical neuronal electrode setup that penetrates deep inside the cortex, where the electrodes used for stimulation, can also used in monitoring of neuronal activities. ECoG electrodes penetrate the skull, but do not penetrate pia mater (innermost layer of the meninges), while the microelectrodes and MEA penetrate pia mater [11]. Single unit for neuronal action potential recording are intra-cortical, requiring activity of dura matter and brain cortical tissue and consider as highly invasive device.

V. NON-INVASIVE BCI MONITORING TECHNOLOGIES

Technologies that can non-invasively monitor brain signals are EEG, fMEG, and MRI. Among these non-invasive sensing techniques, EEG and MEG have excellent temporal resolution, while MEG and MRI have higher spatial resolution. MEG captures magnetic signals generated from neuronal firings, while EEG captures noisy electric signals directly. In contrast, fMRI is an indirect measurement of activities since it captures increased blood flow in the cortex that relates to increased brain activities. Both MEG and MRI require high sensitive magnetic sensors. EEG sensors are miniature and lightweight and can be convenient worn for continuous sensing at home or outdoors for long duration. In contrast, Electromyogram (EMG) signals are produced by skeletal muscles and can be primarily associated with facial expressions, as well as physiological and mental states like sleep and medical abnormalities. The sensor position allows proximal detection of certain muscle activities like eye muscle movement can be detected with sensors placed on the forehead. Non-invasive human scalp EEG (Electroencephalography) used for recording of asynchronous activation of the massive amounts of neuron firings in the brain cortex. EEG signals are typically in the ten to hundred μV ranges and classified as delta rhythm (0.1-3.5 Hz), theta rhythm (4-7.5 Hz), alpha rhythm (8-13 Hz), beta rhythm (14-30 Hz), and gamma rhythm (>30 Hz). EEG analysis has been applied for neuroscience, cognitive science and psychology through studies that show various brain lobes are responsible for specific cognitive activities. For instance, the frontal lobe is highly associated with problem solving, mental flexibility, judgment, creativity, foresightedness, and deficiencies; whereas the temporal lobe is primarily responsible for auditory sensation, perception, language comprehension, long-term memory and sexual behavior. EEG data can be analyzed for mental states and neuronal activities of neurological disorder patients. In case of epilepsy (neurological disorder patients) activities can be captured in EEG. The data shows increased level of uncontrolled activity of brain signals which is characterized by increases in Gamma rhythms. EEG sensors can monitor brain electrical activities for long duration[9, 11].

MEG (Megnatoencephalography) technique records magnetic response of the axon current flow using very highly sensitive magnetic coils placed on the scalp. Based on Maxwell Theory, the current flow in neurons produces tiny magnetic fields around them. MEG, in particular, primarily records activity of sulcus, in comparison to gyrus, as the current flow is perpendicular to the sensing coils. MEG sensors generally employ special type of magnetic sensors, such as SQUID. These passive sensors can record weak magnetic field around 10-14 Tesla. Despite the advantage of high spatial and temporal resolution, MEG has not yet been widely adopted as a cognitive neuroimaging technique due to the large, expensive, and inconvenient helmet with SQUID sensors that provide itself non-portable and highly sensitive to movement. Magnetic Resonance Imaging (MRI) is a relatively new technology that was developed 20 years ago to non-invasively measure patterns of brain activities. MRI technique relies on the resonance of bodily fluid, primarily blood, to orient and resonate to the direction of applied high magnetic field (7–11 Tesla). The magnetic field strength of such equipment is 5 orders of magnitude higher than the Earth’s surface magnetic field (25-65 micro Tesla). This technique is suitable for human brain activity monitoring where invasive methods are not required. Common two types of MRI technologies for brain signal monitoring are (i) functional MRI (fMRI) and (ii) diffusion MRI (dMRI) or Diffusion Tensor Imaging (DTI). Among newer technologies for remote sensing of brain activities, near infra-red (NIR) sensing is promising.

The signal flow can be explained in the following way: signals [either from EEG, other biosignals like electromyogram (EMG), or from assistive devices] are acquired via different hardware and hardware interfaces (USB port, data acquisition cards) and provided for further use. The BCI output can be blocked if artifacts are found in the EEG, in which case the joystick is used instead. Decisions can be based on static or dynamic rules [11]. The final control signal then goes on to the shared control block. This module also receives information from the environment and helps to control the application in the most appropriate way. Design sketch of the hBCI is shown in Figure 7.

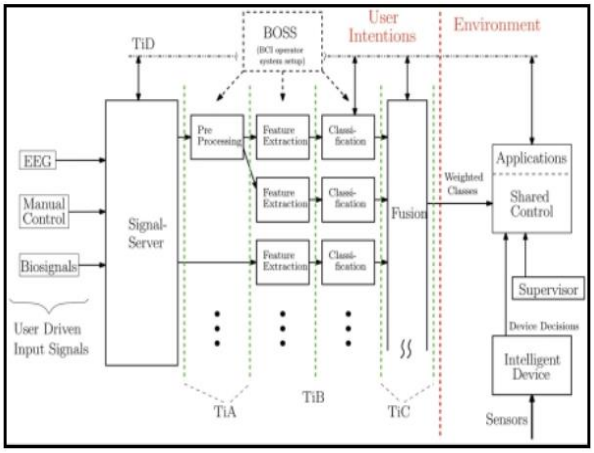


Figure 7 Design sketch of the hBCI

Raw control signals from the user (EEG, assistive devices, other biosignals) are collected by the Signal Server which provides those signals in a standardized way to whatever client may connect to it. This connection is realized.

VII. CONCLUSIONS

The main question here is how the subject might control a complex application by means of an uncertain channel such as a BCI. An answer to this fundamental issue is the well-known shared control approach. The cooperation between a human and an intelligent device allows the subject to focus their attention on a final target and ignore low-level details related to the execution of an action. For instance, in the case of a BCI-based telepresence robot the introduction of the shared control helps the user to reach the target in less time with a lower number of commands. In this case the role of shared control is to take care of the low-

Acknowledgement: The author likes to express his sincere thanks to the authority of Techno India University, West Bengal, for giving him full freedom and enough facility to continue his research work and developing research teams and environment.

REFERENCES

1. "Encephalo- Etymology". Online Etymology Dictionary. Retrieved October 24, 2015.

2.Bigos, K.L.; Hariri, A.; Weinberger, D. (2015). Neuroimaging Genetics: Principles and Practices. Oxford University Press. p. 157. ISBN 0199920222.

3. Davey, G. (2011). Applied Psychology. John Wiley & Sons. p. 153. ISBN 1444331213.

4. Kolb, B.; Whishaw, I. (2009). Fundamentals of Human Neuropsychology. Macmillan. pp. 73–75. ISBN 0716795868. Retrieved January 25, 2017.

5. Netter, F (2014). Atlas of Human Anatomy Including Student Consult Interactive Ancillaries and Guides (6th ed.). Philadelphia, Penn.: W B Saunders Co. p. 114. ISBN 978-1-4557-0418-7.

6. Pavel, Fiala; Jiří, Valenta (January 1, 2013). "Central Nervous System". Karolinum Press. p. 79.

7. Laterra, J.; Keep, R.; Betz, L.A.; et al. (1999). "Blood–Cerebrospinal Fluid Barrier". Basic Neurochemistry: Molecular, Cellular and Medical Aspects (6th ed.). Philadelphia: Lippincott-Raven.

8. Sadler, T. (2010). Langman's medical embryology (11th ed.). Philadelphia: Lippincott Williams & Wilkins. p. 293. ISBN 978-07817-9069-7.

9. Hellier, J. (2014). The Brain, the Nervous System, and Their Diseases [3 volumes]. ABC-CLIO. pp. 300–303. ISBN 1610693388.

10. Cowin, S.C.; Doty, S.B. (2007). Tissue Mechanics. Springer Science & Business Media. p. 4. ISBN 0387499857. Retrieved March 3, 2017.

11. Bhattacharya, A. B. and Sen, P., Brain Computer Interface Technology and its Modern Applications, Lambert Academic Publishing, Germany, 2018