ISSN: 2278 – 7798
International Journal of Science, Engineering and Technology Research (IJSETR)
Volume 2, Issue 9, September 2013

Comparative Study of Brain Imaging Techniques in BCI System.

Rakesh s Deore
Head of Depabrtment
Dept of Computer Science
S.S.V.P.S's Science College
Dhule

Rahul D Chaudhari
Lecturer
Dept of Computer Science
S.S.V.P.S's Science College
Dhule

Dr.S.C.Mehrotra
Professor
Dept of Computer Science
BAMU
Aurangabad

ABSTRACT

The human brain was the greatest medical and philosophical fascination of the human body. Mankind was no longer content, to know the anatomical makeup of the brain, but we now wanted to understand how this organ performed so many complex functions. This multi-disciplinary collation gave birth to the field of Neuroscience. Its goal was to explore and understand the physiological and psychological behavior of the brain, spinal cord and peripheral nerves that make up this complex integrated information processing and control system. This paper focuses on introduction to the electro-biological brain imaging technique known as Electroencephalography (EEG). It gives a brief introduction to the origins of EEG. Here, we also explain the number of brain imaging techniques and their comparative study.

Keywords

Brain Computer Interface, EEG, MRI, CT, PET, fMRI, EROS

1.1 INTRODUCTION

In a 1875, Richard Caton (1842-1926) was the first person who discovers the existence of electrical currents in the brain. He studied action potentials from the exposed brains of rabbits and monkeys [1]. In 1924, a German neuropsychiatric Hans Berger (1873-1941) used his ordinary radio equipment to amplify the brain's electrical activity measured on the human scalp. This was the first Electroencephalogram (EEG) recording of humans. He showed that weak electric currents generated in the brain can be recorded without opening the skull, and depicted graphically on a strip of paper [2]. The action that he observed changes according to the functional status of the brain, such as during sleep, anesthesia, lack of oxygen and in particular neural diseases such as in epilepsy. He was correct in his assertion that brain activity changes in a consistent and recognizable way when the general situation of the subject changes, as from relaxation to alertness [3]. Berger was the first to use the word "electroencephalogram" to describe the brain electric potentials in humans. He laid the foundations for many of the present applications for EEG. He known as the 'father of EEG'. Now a day Electroencephalogram (EEG) defined as the electrical activity of an alternating type produced by brain structures and recorded from the scalp surface by metal electrodes and conductive media [4]. EEG measured directly from the cortical surface using subdural electrodes called the electrocardiogram (Ecog) while when using a depth probe called electrogram[5]. In this thesis, we will refer only to EEG recorded from the surface of the scalp. In the following subsection, Electroencephalography compared with other brain imaging technologies highlighting its advantages for the purposes of BCI design.

1.2. Brain Imaging Techniques

Imaging is becoming an important tool in both research and clinical care. A range of brain imaging techniques, now provide the visualization of brain structure at different levels. The imaging methods may be invasive or noninvasive. Many non invasive methods allow dynamic processes to be monitored over time. It enables researchers to identify the neural network involved in cognitive processes. Different types of imaging used to reveal brain structure (anatomy), physiology (functions), and biochemical actions of individual cells and of the molecules that compose them. Three main categories referred to as structural, functional and molecular imaging. Some of the imaging techniques listed in the following sections.

1.2.1 X-RAY

The origin of structural imaging was the X-ray, developed in 1895 [7]. X-rays measures the density of tissues. X-rays use photons, a quantum of visible light that possesses energy; the photons are passed through the body and deflected and absorbed to different degrees by the person's tissues. They are recorded as they pass out of the body onto a silver halide film. Dense structures such as bone, which block most of the photons, appear white; structures containing air appear black; and muscle, fat and fluids appear in various shades of gray.

1.1.2 Computer Assisted Tomography

Computerization transformed the x-ray in the 1970s[8], with the development of Computer Assisted Tomography (CT), and its two main developers received the Nobel Prize in Medicine or Physiology in 1979 [9,10,11]. This technology uses special x-ray equipment to obtain three-dimensional anatomical images of bone, soft tissues and air in the entire body, including the head. CT imaging was the first technique to show clear evidence, during life, of decreases in the amount of brain tissue in older compared to younger people. Because CT can be done quickly, it is especially useful in emergency trauma situations, showing any abnormalities in brain structure including brain swelling, or bleeding arising from ruptured aneurysms, hemorrhagic stroke (a ruptured blood vessel), and head injury.

1.1.3 Magnetic Resonance Imaging (MRI)

MRI is a non-invasive method of mapping the internal structure and certain aspects of function within the body [11]. It is based on the principle of nuclear magnetic resonance and uses radiofrequency waves to probe tissue structure and function without requiring exposure to ionizing radiation. The two researchers who made MRI clinically feasible in the 1980s by building on initial discoveries of the 1930s won the Nobel Prize in Physiology or Medicine in 2003. The MR Image is constructed by placing the patient inside a large magnet, which induces a relatively strong External magnetic field. This causes the nuclei of many atoms in the body, including Hydrogen, to align them with the magnetic field and later application of RF signal, Energy is released from the body, detected and used to construct the MR image by Computer [11].

1.1.3 Positron Emission Tomography

PET measures physiological functioning in the brain. It provided the first opportunity to explore the parts of the brain that were activated in undertaking specific tasks; now it is primarily used to study neurotransmitters, actions of pharmaceutical drugs, and the expression of specific genes in the brain. PET is based on the principle that changes in regional cerebral flow and metabolism in brain regions are coupled to changes in neural activity in those regions.

1.1.4 Single Photon Emission Computed Tomography (SPECT)

SPECT measures physiological functioning in the brain and is similar to PET (Please see Positron Emission Tomography). SPECT uses commercially available stable low level radioisotopes and is therefore less expensive, more convenient for clinical use, is widely used clinically.

1.1.5 Tran cranial magnetic stimulation (TMS)

It is a non-invasive technique that is used to map cortical functions in the brain, such as identifying motor or speech areas. With TMS, a large electromagnetic coil is placed on the scalp, near the forehead. An electromagnet is then used to create a rapidly changing magnetic field, inducing weak electric currents. Unlike the mapping function, a repetitive form of TMS, called rTMS, is used therapeutically to treat depression.

1.1.6 Ultrasound

It uses sound waves to determine the locations of surfaces within tissues, and differentiates surfaces from fluids. It does so by measuring the time that occurs between the production of an ultrasonic pulse to the production of the echo created when the surface reflects the pulse.

Modern medicine applies a variety of imaging techniques to analyze the functioning of the human body. The group of electro-biological measurements consists of electrocardiography (ECG, heart), electromyography (EMG, muscle contraction), electrogastrography (EGG, stomach), electro oculography (EOG, eye dipole field) and electroencephalography (EEG, brain). EEG involves the recording of scalp electrical activity generated by brain structures. It is just one of the many brain imaging technologies that have been developed in the pursuit of the ability to visualize brain condition and understand brain function.

In the following subsection, Electroencephalography is compared with other brain imaging technologies, highlighting its advantages for the purposes of BCI design.

Brain Imaging Techniques	Measurement Properties	Advantages	Disadvantages
EEG	Macroscopic Brain Electrophysiology	1) Non Invasive 2) Inexpensive 3) Ease of Acquisition	1) Poor spatial resolution 2) Trial to trial variation 3) Volumetric smearing effects of skull
ECOG	Electro physiology of extra-cellular current	1) High temporal resolution 2) Good spatial resolution 3) Equipment inexpensive	1) Highly invasive 2) Requires surgery, 3) craniotomy required 4) Procedurally expensive
MEG	Cortical Magnetic Fields associated with the electrical activity	1) Completely non-invasive 2) Spatial resolution up to 3mm 3) Good temporal resolution	1) Extremely expensive equipment 2) Difficult to acquire 3) Rrequires magnetic isolation room 4) Not practical for real-time analysis
CT	X-Ray brightness intensity maps in relation to brain tissue density. Superseded by MRI technology	1) Excellent spatial resolution.	1) Only anatomical information. 2) none on cognitive function . 3) Extremely expensive 4) X-Ray radiation hazard
SPECT	Tracking of radioactive tracers in blood stream. The measurement of blood flow, oxygen and glucose reflects the amount of brain activity.	1) Do not require on-site cyclotron to produce SPECT tracers, unlike PET Less technical and medical staff required than PET	1) Measures blood flow instead of electrophysiology 2) Poor time and spatial resolution Ionizing radiation hazard 3) Procedurally expensive 4) More limited than PET tracers
PET	Tracking of gamma radiation from decaying radioactive tracers in blood stream. Measures the regional cerebral metabolism and blood flow that reflect the amount of brain activity.	1) More versatile than SPECT 2) More spatial resolution than SPECT. 3) particularly for deeper brain structures. 4) Able to identify which brain receptors are being activated by abused drugs, neurotransm -itters, and	1) Measures metabolism of oxygen and sugar rather than electrophysiology 2) Ionizing radiation hazard 3) Poor time resolution (~2 mins) 4) Measurements cannot be repeated, annual maximum dosage

		potential treatment compounds	is one examination 5) Equipment extremely expensive. 6) Highly qualified staff required
MRI	Radio waves pass through a large magnetic field (~1.5T). A computer monitors the variations in the radio waves due to the electro-magnetic activity in the brain to generate a picture.	1) High anatomical detail (spatial resolution) 2) Non-invasive	1) Only anatomical information, none on cognitive functionality 2) Poor temporal resolution 3) Expensive equipment and procedure
fMRI	Magnetic fields and radio waves exploit the magnetic properties of blood to track its flow. It involves monitoring the Blood Oxygenation . Level Dependence (BOLD) in response to a function or stimulus.	1) Good spatial resolution 2) Non-invasive	1) Depends on hemodynamic response of blood which introduces an inherent lag 2) Trades off some spatial resolution from MRI to improve temporal resolution. 3) Expensive equipment and procedure 4) Temporal resolution (~1s) not as good as EEG
EROS	Changes occur in optical parameters (scattering and absorption) of cortical tissue when active	1) Good temporal resolution 2) Non-invasive 3) Good spatial resolution 4) Non-ionizing radiation 5) Relatively low cost	1) Penetration only several centimeters 2) Studying the cortical activity rather than the sub-cortical 3) Infancy of its development

Though the EEG has a poor spatial resolution, it has excellent temporal resolution of less than a millisecond. It is also relatively inexpensive and simple to acquire. So it is the only practical non-invasive brain imaging modality for repeated real-time brain behavioral analysis. For this reason, the EEG is used as the input brain imaging modality for BCI design.

1.3 EEG Acquisition Method

In the scalp recorded EEG the neuronal electrical activity is recorded non-invasively, typically using small metal plate electrodes. Recordings can be made using either reference electrodes or bipolar linkages. While the number of the electrodes used varies from study to study, they are typically placed at specific scalp locations. The voltages, of the order of microvolts (µV), must be carefully recorded to avoid interference and digitized so that it can be stored and viewed on a computer. The amplitude of the recorded potential depends on the intensity of the electrical source, on its distance from the recording electrodes, its special orientation, and on the electrical properties of the structures between the source and the recording electrode. The greatest contributions to the scalp recorded signals result from potential changes which (a) occur near the recording electrodes,(b) are generated by cortical dipole layers that are orientated towards the recording electrode at a 90 angle to the scalp surface, (c) are generated in a large area of tissue, and (d) rise and fall at rapid speed [14].

This section will briefly highlight the equipment, methods and standards involved in acquiring a scalp recorded EEG. It serves as a review of the key issues related to acquisition.

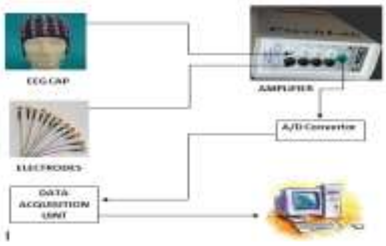
1.3.1. EEG Equipments

The basic EEG recording system consists of electrodes with conductive media, amplifiers with filters, an analog-to-digital (A/D) converter and finally a recording device to store the data. Electrodes, in conjunction with the electrode gel, sense the signal from the scalp surface; amplifiers bring the microvolt and often nano volt signals into a range where they can be digitized accurately; and the A/D converter changes signals from analog to digital form that can be finally stored or viewed on a computer. Table 2-3 provides a summary of the necessary EEG acquisition equipment and the typical specifications or products.

EEG Acquisition Components	Typical Specifications or Products
Electrodes	1) Electrode cap with conductive jelly
Amplifiers	1) Amp Gain between 100-100K 2) Input Impedance >100MΩ 3) Common-mode rejection ratio >100dB 4) High pass filter with cut-off in range 0.1 to 0.7 5) Low pass filter with cut-off below half the sampling rate 6) Notch filter at mains frequency(50 / 60 Hz) . 7) Analog-to-Digital Converter
Analog to Digital Converter	1) At least a 12 bit A/D converter with accuracy lower than overall noise (0.3-2µV) .
Storage/Visualization Unit	1) Sufficient fast pc for presentation, processing and Storage.

1.3.2 Electrodes

An electrode is a small conductive plate that picks up the electrical activity of the medium that it is in contact with. In the case of EEG, electrodes provide the interface between the skin and the recording apparatus by transforming the ionic current on the skin to the electrical current in the electrode. Conductive electrolyte media ensures a good electrical contact by lowering the contact impedance at the electrode-skin interface.



1.3.3 Electrode Placement System

The 10/20 system or International 10/20 system is internationally recognized method to describe the location of scalp electrodes [x-10]. The system is based on the relationship between the locations of an electrode and the underlying area of cerebral cortex. The Number 10 and 20 refers to the fact that the distances between adjacent electrodes are either 10% or 20% of total front back or right left distance of the skull. Each site has letter to identify the lobe and a number to identify the hemisphere location.

Electrode	Lobe
F	Frontal
T	Temporal
C	Central
P	Parietal
O	Occipital

No central lobe exists, the 'C' letter is used for identification purpose only. The 'Z' (Zero) refers to an electrode placed on the mid line. Even numbers (2,4,6,8) refer to an electrode positions on right hemisphere. Odd numbers (1,3,5,7) refer to electrode positions on the left hemisphere.

1.4. EEG signal properties

This section performs an introduction to the analysis and characteristics of scalp recorded EEG signals from both a clinical and signal processing point of view.. An individual's brain wave patterns are unique. In some cases, it is possible to distinguish a person according to their characteristic brain activity, e.g. location of alpha peak [29]. Subjects who regard themselves as rational types or as holistic/intuitive types may demonstrate certain higher activity in their frontal left and frontal right regions respectively. An EEG signal consists of many components with different characteristics. A large amount of data received from even one single EEG channel presents a difficulty for interpretation The EEG recorded brain waves originate from a multitude of different neural communities from various regions of the brain. These neural communities produce electrical contributions or components that can differ by a number of characteristics such as topographic location, firing rate (frequency), amplitude, latency etc.

1.4.1 Morphology

It explains the shape of wave. Morphology is the primary EEG descriptor in epileptic studies. Brain patterns form wave shapes that are commonly sinusoidal. A complex can be made up of a combination of sharp and slow waves and tend to last longer than 0.25s therefore do not repeat over rates of 4Hz.

1.4.2 Repetition

It defines the type of waveform occurrence. Spindles are group of rhythmic repetitive waves that gradually increase and then decrease in amplitude.

1.4.3 Frequency

It explains how often a repetitive wave occurs. Frequency bands are alpha, beta, delta, and theta.

1.4.4 Amplitude

Amplitude is measured in micro volts (μV) peak-to-peak or from the calibrated zero reference.

1.4.5 Distribution

It is the occurrence of electrical activity recorded by electrodes positioned over different parts of the head.

1.4.6 Reactivity

It refers to changes that can be produced in some normal and abnormal patterns by various functions.For the purposes of BCI system design, there exist various EEG signal properties that discriminate brain function and hence can be used as an input mechanism to offer control or communication. EEG signal properties for BCI systems can be categorized into one of the following groups:

1. Rhythmic brain activity
2. Event-related potentials (ERPs)
3. Event-related resynchronization (ERD) and event-related synchronization (ERS).

1.5 Conclusion

EEG is limited by the vast number of electrically active neuronal elements, the complex electrical and spatial geometry of the brain and head, and the disconcerting trial-to-trial variability of brain function [57]. The layers of cerebrospinal fluid, skull and scalp between the electrodes and the brain itself, act as an electrical shield severely attenuating and volume smearing the electrical contributions of neuron communities to EEG recordings. This presents a difficult challenge to localize and decipher the contributions of neuron communities to the EEG recorded micro potentials. Despite EEG's poor spatial resolution, its excellent temporal resolution of less than one millisecond and ease of acquisition makes it the only practical brain imaging modality for real-time BCI systems. Despite the Herculean challenges for utilising EEG as the input modality to a BCI, recent advances in signal processing techniques make it more feasible than ever before.

2. REFERENCES.

[1] K P Tripathi (2011).A Study of Interactivity in Human Computer Interaction, International Journal of Computer Applcations (0975-8887) Vol 16-No 6.,Feb 2011.

[2] Jodi Forlizzi, John Zimmerman, Vince Mancuso, and Sonya Kwak (2007), How Interface Agents Affect Interaction Between Humans and Computers.

[3] Dhirem Parmar. Human Computer Inetraction,IIT Kharkpur.

[4] Alexiei Dingli. Human Computer Inetraction.

[5] Majlinda Fetaji,Suzana Loskoska,Bekim Fetaji,Mirlinda Ebibi. Investigating Human Computer Interaction issues in Designing Efficient Virtual Learning Environments.

[6] Brian R. Gaines(1988) A Conceptual Framework for Person-Computer Interaction in Distributed Systems IEEE Transactions on Systems, Man & Cybernetics, 18(4), 532-541, 1988.

[7] Sean Bechhofer ,Human Computer Interaction.

[8] Efraim Turban, Jay E. Aronson (2003). Decision Support Systems and Intelligent Systems, 6th edition. Pearson Education, New Delhi.

[9] Newell, A. and Simon, H.A., Human Problem Solving, Prentice-Hall, Englewood Cliffs, NJ, 1972.

[10] Licklider, J. C. R. (1960). Man-computer symbiosis. Institute of Radio Engineers Transactions on Human Factors Electronics, HFE-I, 4-11.

[11] Englebart, D. C. (1962). Augmenting human intellect: A conceptual framework. No. AFOSR-3223) Stanford Research Institute (SRI) Menlo Park, CA English, W. K., Englebart,

[12] Bush, Vannevar [1945]. As We May Think. Atlantic Monthly, 176(1), pages 101–108. http://www.theatlantic.com/doc/194507/bush.

[13] Nyce, James M. and Paul Kahn [1991]. From Memex to Hypertext: Vannevar Bush and the Mind'sMachine. Academic Press. ISBN 0125232705 (com, uk).

[14] Bush, Vannevar [1945]. As We May Think. LIFE Magazine, 19(11), pages 112–124.

[15] Bush, Vannevar [1996]. As We May Think. interactions, 3(2), pages 35–46. ISSN 1072-5520. doi:10.1145/227181.227186.

[16] Sutherland, Ivan E. [1963]. Sketchpad: A Man-Machined Graphical Communication System. PhD dissertation, MIT. http://hdl.handle.net/1721.1/14979. Original version scanned by MIT

[17] Sutherland, Ivan E. [1963]. Sketchpad: A Man-Machined Graphical Communication System. PhD dissertation, MIT. http://www.cl.cam.ac.uk/techreports/UCAM-CL-TR-574.pdf. Archival version with preface by Alan Blackwell and Kerry Roddenphone.

[18] Kay, Alan [1987]. Doing with Images Makes Symbols (Part 1). University Video Communications (UVC), San Jose, California, USA.

[19] Fitch, John [1964]. Computer Sketchpad. WGBH Science Reporter. http://www.wgbh.org/article?item_id=3360989.

[20] Wikipedia [2009]. The Mother of All Demos. http://en.wikipedia.org/wiki/ he_Mother_of_All_Demos.

[21] Engelbart, Douglas C. [1962]. Augmenting Human Intellect: A Conceptual Framework. Afosr3233 summary report, Stanford Research Institute.

[22] English, William K., Douglas C. Engelbart, and Melvyn L. Berman [1967]. Display-Selection Techniques for Text Manipulation. Transactions on Human Factors in Electronics, 8(1), pages 5–15. ISSN 0096-249X.

[23] Engelbart, Douglas C. [1970]. X-Y Position Indicator for a Display System. US Patent 3541541 , Stanford Research Institute. Filed 21 Jun 1967, issued 17 Nov 1970.

[24] Engelbart, Douglas C. [2008]. Bootstrap Institute. http://bootstrap.org.

[25] Hegland, Frode and Fleur Klijnsma [2008]. Invisible Revolution: The Doug Engelbart Story.

[26] Hegland, Frode and Fleur Klijnsma [2008]. Invisible Revolution: The Doug Engelbart Story. http://invisiblerevolution.net/.

[27] Kay, Alan [1987]. Doing with Images Makes Symbols (Part 1). University Video Communications(UVC), San Jose, California, USA.

[28] J. Y. Chai, P. Hong and M. X. Zhou(2004). Aprobabilistic approach to reference resolution in multimodal user interfaces, Proceedings of the 9th International Conference on Intelligent User Interfaces, Funchal, Madeira, Portugal, pp 70-77 .

[29] E.A. Bretz(2002). When work is fun and games, IEEE Spectrum, 39(12), pp 50-50 .

[30] ExtremeTech, "Canesta says "Virtual Keyboard" is reality",

[31] M.T. Maybury and W. Wahlster(1998). Readings in Intelligent User Interfaces, Morgan Kaufmann Press, San.

[32] G. Riva, F. Vatalaro, F. Davide and M. Alaniz(2005). Ambient Intelligence: The Evolution of Technology, Communication and Cognition towards the Future of -HCI, IOS Press, Fairfax .

[33] M. Pantic and L.J.M. Rothkrantz (2000). Automatic analysis of facial expressions: the state of the art, IEEE Transactions on PAMI, 22(12), pp 1424-1445 .

[34] J.K. Aggarwal and Q. Cai(1999). Human motion analysis: a review, Computer Vision and Image Understanding, 73(3), pp 428-440 .

[35] S. Kettebekov and R. Sharma(2000), "Understanding gestures in multimodal human computer interaction", International Journal on Artificial Intelligence Tools, 9(2)

[36] Y. Wu and T. Huang.(1999). Vision-based gesture recognition: a review, in A.Braffort, R. Gherbi, S. Gibet, J. Richardson and D. Teil (eds), Gesture-Based Communication in Human-Computer Interaction, volume 1739 of Lecture Notes in Artificial Intelligence, Springer-Verlag, Berlin/Heidelberg (1999).

[37] Various Authors(2007) Adaptive, intelligent and emotional user interfaces, Part II of HCI Intelligent Multimodal Interaction Environments, 12th International Conference,HCI International (Proceedings Part III), Springer Berlin, Heidelberg .

[38] T. Kirishima, K. Sato and K. Chihara(2005). Real-time gesture recognition by learning and selective control of visual interest points, IEEE Transactions on PAMI, 27(3), pp351- 364 .

[39] R. Ruddaraju, A. Haro, K. Nagel, Q. Tran, I. Essa, G. Abowd and E. Mynatt(2003). Perceptual user interfaces using vision-based eye tracking, Proceedings of the 5th International Conference on Multimodal Interfaces, Vancouver, pp 227-233.

[40] A.T. Duchowski(2002).A breadth-first survey of eye tracking applications, Behavior Research Methods, Instruments, and Computers, 34(4), pp 455-470 .

[41] M.N. Huhns and M.P. Singh (eds)(1998). Readings in Agents, Morgan Kaufmann, San Francisco (1998).

[42] P. Rubin, E. Vatikiotis-Bateson and C. Benoit (eds.)(1998).Special issue on audio-visual speech processing, Speech Communication, 26, pp 1-2 .

[43] J.P. Campbell Jr.(1997).Speaker recognition: a tutorial, Proceedings of IEEE, 85(9), pp 1437-1462 .

[44] P.Y. Oudeyer(2003). The production and recognition of emotions in speech: features and algorithms, International Journal of Human-Computer Studies, 59(1-2), pp 157-183.

[45] C.M. Karat, J. Vergo and D. Nahamoo(2003), Conversational interface technologies, in J.A. Jacko and A. Sears (eds), The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Application, Lawrence Erlbaum Associates, Mahwah .

[46] L.S. Chen(2000). Joint Processing of Audio-Visual Information for the Recognition of Emotional Expressions in Human-Computer Interaction, PhD thesis, UIUC.

[47] M. Schröder, D. Heylen and I. Poggi(2006). Perception of non-verbal emotional listener feedback.Proceedings of Speech Prosody 2006, Dresden, Germany, pp 43-46

[48] M.J. Lyons, M. Haehnel and N. Tetsutani(2003).Designing, playing, and performing,with a vision-based mouth interface", Proceedings of the 2003 Conference on New Interfaces for Nusical Expression, Montreal, pp 116-121 (2003).

[49] D. Göger, K. Weiss, C. Burghart and H. Wörn, "Sensitive skin for a humanoid robot", Human-Centered Robotic Systems (HCRS'06), Munich, (2006).

[50] O. Khatib, O. Brock, K.S. Chang, D. Ruspini, L. Sentis and S. Viji(2004), "Human-centered robotics and interactive haptic simulation", International Journal of Robotics Research, 23(2), pp 167-178.

[51] L.E. Sibert and R.J.K. Jacob (2000). Evaluation of eye gaze interaction, Conference of Human Factors in Computing Systems, pp 281-288 (2000).

[52] B.A. Myers,(1998).A brief history of human-computer interaction technology, ACM interactions, 5(2), pp 44-54 .

[53] B. Shneiderman (1998). Designing the User Interface: Strategies for Effective Human-Computer Interaction (3rd edition), Addison Wesley Longman, Reading.

[54] A Murata(1991).An experimental evaluation of mouse, joystick, joycard, lightpen ,trackball and touchscreen for Pointing - Basic Study on Human Interface Design,

[55] Proceedings of the Fourth International Conference on Human-Computer Interaction 1991, pp 123-127 (1991).

[56] L.R. Rabiner(1993). Fundamentals of Speech Recognition, Prentice Hall, Englewood

[57] H. Iwata(2003), "Haptic interfaces", in J.A. Jacko and A. Sears (eds), The Human Computer Interaction.

[58] H. Iwata(2003), "Haptic interfaces", in J.A. Jacko and A. Sears (eds), The Human Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Application, Lawrence Erlbaum Associates, Mahwah.

[59] W. Barfield and T. Caudell(2001), Fundamentals of Wearable Computers and Augmented Reality, Lawrence Erlbaum Associates, Mahwah .

[60] M.D. Yacoub(2002), Wireless Technology: Protocols, Standards, and Techniques, CRC Press, London.

[61] C. Burghart, O. Schorr, S. Yigit, N. Hata, K. Chinzei, A. Timofeev, R. Kikinis, H. Wörn and U.Rembold(2001).A multi-agent system architecture for man-machine interaction.