DETECTION OF CHANGES IN MINDFULNESS BY MONITORING MEDITATION SESSIONS USING ARTIFICIAL NEURAL NETWORKS AND MULTI AGENT TECHNOLOGY

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Degree of Master of Science in Artificial Intelligence

Department of Computational Mathematics

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Declaration

I declare that this dissertation does not incorporate, without acknowledgment, any material previously submitted for a Degree or a Diploma in any University and to the best of my knowledge and belief, it does not contain any material previously published or written by another person or myself except where due reference is made in the text. I also hereby give consent for my dissertation, if accepted, to be made available for photocopying and for interlibrary loans, and for the title and summary to be made available to outside organization.

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Signature of Supervisor
Date:

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My beloved parents who were always there when I had problems and for helping me to complete this project

Abstract

Meditation has gained lot attraction in modern world. Nevertheless most meditation teachers and practitioners are not fully aware what the expectation is. In most of the meditation centers, the novice meditators follow the wrong way because they cannot track the progress and get proper feedback. It is hard to analyze the success rate and there isn't a way to measure the success. If there is any possibility to monitor the progress of the meditation, then people certainly can improve on their meditation.

In this research, an attempt was made to monitor EEG signals of meditation sessions with ANN technology and multi agent based approach. The proposed solution has the ability to collect the EEG data from expert meditators which has been used to train the artificial neural network. Next the EEG signals of the novice meditator were given as the input to the trained ANN for classification which outputs whether it is successful or unsuccessful. EEG capturing device has been used to collect the EEG data in a non-invasive method. EEG device sends data via Bluetooth. Artifact removal has been done to remove eye related artifacts which are captured by the device. The multi agent system will interpret the EEG signals and provide the recommended meditation technique. Communication and Negotiation among the agents result in more acceptable interpretation by modulating the arguments made by the agents. This multi agent system has been implemented to run of java based jade platform. This experiment used 25 meditators (age ranged between 20 and 65 years). The experiment was done as two stages. First the meditation solution which is trained with expert meditators' data was used to monitor the meditation session of novice. And the number of times which matched was counted. Next the meditators were asked to stay without meditating. It has been proved that meditation session has the ability to provide more attention. The accuracy rate is 72%. The multi agent system is successfully providing the feedback by recommending the meditation technique.

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Chapter 1

Introduction

1.1 Prolegomena

The research related to the brain has gained the focus of modern research world. The hidden complexities of the brain are being explored by scientists around the world including the major researchers from MIT, Princeton University, Harvard, Stanford etc. Recent neuro imaging and EEG studies have uncovered that the meditation has a positive impact on improving brain areas. The alteration in the structure of the brain is defined as neuroplasticity. Further it is mentioned that improving meditation has a direct impact of neuroplasticity. Meditation can be defined as a form of mental training that aims to improve an individual's core physiological capacities[1] [2]. It is evident that mindfulness meditation has positive impact on development of brain function structure as well.

According to literature, the areas of the brain which activates due to meditation and other various mind related methods and their relation to various disorders, memory, attentions are being investigated. Still there isn't a proper way to provide feedback for the novice mediators. Meditators use a log book to write down the incidents related to anger, happiness, and sorrow after the meditation session to track the progress. Interpretation of EEG signals is considered as a challenging task. This research area is still in its infancy. Therefore, lot of research is required to improve the field. A system to interpret EEG signals will be very useful to provide accurate results in order to analyze the progress of the meditation. Such feedback would be beneficial to the meditators. It is hypothesized that the problem of providing feedback to meditators can be solved by monitoring EEG signals of the meditation session by Artificial Neural network and multi agent system.
The aim of this project is to design, develop and evaluate a system to monitor the meditation session and provide feedback.

1.2 Aims and Objectives

- To critical study the problem domain to identify the existing approaches and their advantages and weaknesses.
- Recognizing the suitable technology to develop the meditation feedback solution
- Design and develop a system for solving the problem
- Evaluation of the proposed solution
- Preparation of final documentation

1.3 Background and Motivation

The nature of the brain is considered as the most difficult one to analyze. Understanding how the brain gives rise to the mind represents a great scientific challenge. Although it's in the infant stage, researchers are paying lot of interest in order to identify the nature of the brain. Brain training strategies such as meditation have gained the focus of the modern researchers. In past adult brain was seen as a static organ, but now it is clear that the organization of brain circuitry is constantly changing as a function of experience or learning [3].

According to the research by Tang and others publishes in, Nature reviews neuroscience journal, meditation can be defined as a form of mental training that improves an individual's core psychological capacities [1]. Jon Kabat-Zinn is a researcher at the University of Massachusetts especially known for his work in meditation practices to help people cope with stress, anxiety, pain, and illness. Harvard Medical School cardiologist Herbert Benson, the founder of the Mind/Body Medical Institute at Massachusetts General Hospital has found that even a highly simplified form of meditation produced sustained physiological benefits such as reduced heart, metabolic, and breathing rates [4]. Neuroplasticity is another emerging trend. According to Richard Davidson, neuroplasticity is a term that is used to describe the brain changes that occur due to experience [5]. Further elaborating on it, there are many different methods of neuroplasticity ranging from the new connection growth and the creation of new neurons [6].

In modern world there is a huge tendency for meditation. Manual analysis of EEG waves and FMRI are the main approaches followed by the famous researchers. Taking the FMRI reports regularly is not good for the health. There is no proper safe way to analyze the progress of the meditation session. The meditation teacher has no proper way to provide feedback based on a measurement. Due to this limitation, people question about the improvements about the meditation. If the research succeeds on providing a proper and safe feedback it will definitely have huge demand as well.

1.4 Problem in Brief

Providing proper feedback on the meditation is essential to follow the meditation practices successfully. The meditation teacher has no way to provide feedback based on a measurement. In practical scenarios sometimes novice meditators pretend that they have achieved good levels. We know that brain emit electric pulses continuously. In this research, an attempt was made to provide proper feedback by analyzing EEG using ANN and Multi Agent based system.

1.5 Novel approach for monitoring meditation sessions

A research has been conducted to monitor EEG signals generated from the meditation session using Artificial Neural network and Multi agent system. EEG capturing device is used in a non-invasive approach to collect EEG data. EEG data acquired from the meditation sessions of expert meditators has been used to train the ANN. The inputs of the novice meditator are applied to trained neural network. Status of the meditation session will be the output of the ANN. The most powerful aspect of artificial intelligence, multi agent system has been used to interpret the EEG signals and provide feedback on the meditation session by recommending the meditation technique.

1.6 Structure of the thesis

Rest of the thesis is structured as follows. Chapter 2 critically reviews the current approaches, trends and issues in brain research. Further it explains about the various meditation styles and the current approaches. Chapter 3 discusses about the technology adapted. It explains about multi agent systems, EEG analysis and Artificial neural networks. Chapter 4 explains about the approach of the meditation solution. It explains about the multi agent approach, EEG analysis ANN approach to monitor meditation sessions.

Chapter 5 presents our design of the meditation solution. Chapter 6 provides implementation details of the meditation solution. It explains how the meditation sessions are monitored and the feedback given. Chapter 7 reports on evaluation of the new solution by explaining the evaluation strategy, participants, data collection, data representation and data analysis. Chapter 8 concludes the outcome of the research and reports the overall achievements and future work

1.7 Summary

The overall view of the whole project with respect to research problem, objectives, hypothesis and the novel approach for monitoring meditations sessions were explained in this chapter. Structure of the thesis was also presented. Next chapter will be on current approaches trends and issues in brain changes and activations.

Chapter 2

Current approaches, trends and issues in brain research

2.1 Introduction

This chapter explains the background for this project, and identifies the main research questions. Trends of brain research, mindfulness meditation, EEG signal analysis and EEG based brain computer interface devices are discussed in order to define the project's focus, based on lessons learned from previous research efforts.

2.2 Trends in Brain Research

Determining the mental representations mapping onto patterns of neural activity is a key challenge for cognitive neuroscience [7] [8]. It is a fundamental question in cognitive neuroscience and it requires careful examination of information processing in different brain structures; EEG analysis and FMRI data analysis plays a pivotal role in this context[9]. Another emerging trend is neuroplasticity. According to Richard Davidson , neuroplasticity is a term that is used to describe the brain changes that occur due to experience [5]. Further elaborating on it, there are many different methods of neuroplasticity ranging from the new connection growth and the creation of new neurons [6]. Brain training strategies have gained the focus of the researchers. In past adult brain was seen as a static organ, but now it is clear that the organization of brain circuitry is constantly changing as a function of experience or learning [3]. According to Richard Davidson, the attention training with meditation, can improve the ability to sustain attention [10]. A research carried out by Lutz and his team claim that the mental training has the ability to make neural changes which can be clearly seen with the meditators [11] [13].

2.3 Mindfulness meditation

The meditation research is still in infancy level due to various challenges. Most of the findings have not yet been replicated. It is a quality of a young research field. Most of the experiments are not yet elaborated based on theories, the conclusions might have issues[1]. In early days of meditation research, has focused mainly on two types of groups such as practitioners with hundreds or thousands of hours of meditation experience and control group of non-meditators. The expert meditators group was selected from Buddhist monks etc..[12]. According to the research of, the expert meditators had 10,000–54,000 hours of practice in two similar schools of the Tibetan Buddhist tradition. Expert meditators group was compared with age-matched novice meditators with an interest in meditation but no prior experience. Their research proved that expert meditators vs. novices had less brain activation in regions related to discursive thoughts and emotions, and more activations for attention [13]. There are different styles and forms of meditation in almost all cultures and religions. According to Tang and the team, mindfulness meditation originally is from Buddhist meditation traditions [1]. The neuroscience research has looked in to mindfulness practices such as meditation traditions such as vipassana meditation, Dzogchen, Zen, samatha and also mindfulness based approaches such as integrative body-mind training (IBMT) and mindfulness based stress reduction (MBSR) [14]. Within the western psychological context, mindfulness is described as non-judgmental awareness of the present moment [15].

Jon Kabat-Zinn is a scientist especially known for his work in meditation practices, Mindfulness-Based Stress Reduction (MBSR), into medicine and psychology. Vipassana meditation, a traditional Buddhist practice that involves focusing on present-moment sensory awareness with an Equanimeous and non-reactive mental set [16]. This tradition has served as the foundation for contemporary ‘mindfulness’ meditation techniques underlying adaptations of meditative practices such as Mindfulness-Based Stress Reduction(MBSR) and Mindfulness-Based Cognitive Therapy, which are used as the basis for clinical interventions [17].The skills such as attention and cognitive control skills are crucial for the development and maintenance of mindfulness, the intentional and non-judgmental awareness of the fields of experience in the present moment.

Meditation practices can be usefully classified into two main styles such as focused attention (FA) and open monitoring (OM)—depending on how the attentional processes are directed [18]. According to the research carried out by Holzel and others, the left hippocampus is getting changed due to MBSR. Based on the literature available is clear that left hippocampus of the brain plays a major role in this research field [2] [19]. The scientists sought the Dalai Lama's perspective on meditation. According to Richard Davidson, the scientific lives have been deeply affected by the interactions with His Holiness [20].

A voxel based approach to investigate the mindfulness meditation is carried out by Holzel and the team [21]. Further elaborating on the technique, spatial normalization and image segmentation for grey matter is also used. It was shown that meditators had a greater grey matter concentration in the left inferior temporal gyrus and right hippocampus.

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2.4 EEG Signal Analysis

German psychiatrist Hans Berger has made a historical breakthrough by the discovery of electroencephalography (EEG) in 1929. EEG signal analysis plays an important role in order to identify the physiological measures [19]. The gamma activity also plays a key role in this research[11]. According to Richard Davidson, experienced Mindfulness meditators exhibit higher EEG Gamma Activity [11]. Further it is explained that meditation related plastic changes are associated with the sleep. EEG gamma activity during sleep represents a sensitive measure of the plastic effects of meditative training on brain function. The meditators who practice Zen meditation have shown improvements in Alpha and Theta values [11]. Experience meditators have shown high gamma values[22] .

Verifying the identity with brainwave from Texas University shows that EEG identification could be the start of a whole new world of privacy concerns. The EEG signal is a voltage signal that arises from synchronized neural activity, that is, the coordinated firing of millions of neurons in the brain. It can be measured in an invasive approach or a non-invasive approach. The invasive approach places the electrodes inside the brain. The non-invasive approach has the electrodes outside the brain on or near the scalp.

In order to recognize EEG activities supervised classification methods are used. As the classification methods, linear discriminant analysis (LDA), support vector machine (SVM)[23], lazy learning classifiers such as k- nearest neighbor, artificial neural networks (ANNs) are considered to design EEG-based BCI systems. [24]

2.5 EEG based Brain Computer Interface (BCI) Devices

Brain computer interface (BCI) is a communication channel that enables users to control devices and applications [24].The basic operation of a device is to record the bioelectric activity through electrodes in order to differentiate between several mental tasks. An electroencephalogram (EEG) demonstrates direct correlations with user intentions by enabling a direct Brain-Computer Interface (BCI) communication. BCI research has been successfully used not only for helping the disabled, but also as being an additional data input channel for healthy people to be used as an extra channel in game control, augmented reality applications, household device to control, fatigue and stress monitoring and other applications. BCI design represents a new frontier in science and technology that requires multidisciplinary skills from fields such as neuroscience, engineering, computer science, psychology and clinical rehabilitation.

Despite recent developments, there are numerous obstacles to building a usable and effective BCI system. Implementing BCI requires high computational capacity to analyze brain signals in detail and in real-time and such equipment was very expensive. Current Consumer-grade BCI systems are inaccurate and have a low transfer rate. This means that the user may need a long period of time in order to send commands to the device that is being controlled.

Multi-electrode, medical grade EEG systems have been used in hospitals and laboratories. But the recent availability of inexpensive, single-channel, dry-electrode

EEG devices make it feasible to take this technology outside of the laboratory into normal day to day activities. The benefits of such devices are affordability and ease of use.

NeuroSky Mindwave Mobile

The Neuro Sky Mind wave is a low cost single-electrode EEG headset, and it has been proven effective in detecting user's mental states. Mind wave Mobile, safely measures and transfers the power spectrum (alpha waves, beta waves, etc.) data via Bluetooth to wirelessly communicate with your computer, iOS, or Android device. This headset can be simply slipped on to be able to see your brainwaves change in real time. This headset is an excellent introduction to the world of brain-computer interface.

Figure 2.1 : NeuroSky Mindwave Mobile

EMOTIV Epoc+

EMOTIV Epoc+ is a 14 channel wireless EEG, designed for contextualized research and advanced brain computer interface (BCI) applications. It provides access to dense array, high quality, raw EEG data using subscription based software, Pure EEG. The EMOTIV Epoc+ features 14 EEG channels plus two reference channels and offers optimal positioning for accurate spatial resolution.

Figure 2.2 : EMOTIV Epoc+

EMOTIV Insight

EMOTIV Insight is a sleek, five channel, wireless EEG headset that records your brainwaves and translates them into meaningful data you can understand. Designed for everyday use, Insight boasts advanced electronics that are fully optimized to produce clean, robust signals anytime, anywhere.

Figure 2.3 : EMOTIV Insight

Multi voxel pattern analysis and various image pre-processing techniques are also used by the researchers [7]. A growing number of studies have shown that substantial information can be obtained from the fMRI signal at a scale that is smaller than traditional neuroimaging analysis techniques. MVPA has been shown to reveal information within brain regions that was lost in previous fMRI analyses, such as sensitivity to orientation[25].

In traditional fMRI analyses researchers analyze such data voxel by voxel, trying to determine whether any voxel shows a significant preference for one or more of the objects. In MVPA, whole pattern across all voxels is analyzed. The full-brain analysis (> 50,000 voxels) increases the probability of finding a significant activation. Functional near-infrared spectroscopy (fNIRS) is an emerging functional neuroimaging technology offering a relatively non-invasive, safe, portable, and low-cost method of indirect and direct monitoring of brain activity.

The major limitation of the mindfulness research is the inconsistency of the results and issues in measuring those results. Self-reporting methods such as logging the behaviors, feelings might not be able to provide proper feedback. Measuring such as heart rate, immunity levels are also considered as measuring techniques. It is not correct to compare the heart rate of two meditators. Therefore, most meditation teachers have the problem of monitoring the meditation process. Davidson and Kabat Zin have initiated research related to EEG analysis to investigate about meditation. If the research related to EEG analysis can be improved to monitor meditation session and provide feedback it would be a great achievement.

2.6 Summary

This chapter explained about the history and current trends in the fields of brain research, mindfulness meditation and brain Computer Interface. Then it critically reviewed those previous and current research works in this field and approaches taken by highlighting issues. It explained about the EEG devices (neurosky mindwave) too.

Chapter 3

Technologies adapted

3.1 Introduction

This chapter presents the major technologies associated with the research. EEG signals of the meditation session are the main input to the system. EEG signals are going through a noise removal process. Artificial Neural Network is used to classify the signals in to successful and unsuccessful meditation session. Multi agent system recommends the meditation technique.

3.2 Multi Agent Systems

In artificial intelligence research, agent-based systems technology has been hailed as a new paradigm for conceptualizing, designing, and implementing software systems. Multi agent systems are design and developed to mimic the real world systems. Most of the real world systems are dynamic, complex and interconnected. Russell and Norving [26] define; agent is anything that perceives its environment through sensors and act upon the environment through actuators.

Environments have an important role when dealing with agents. Agents are sensitive to the environment and its actions have an impact on the environment. This is a key difference between traditional software and Agents. Environments can be categorized to few categories according to their characteristics[26]. If an agent's sensors give it access to the complete state of the environment at each point in time, then we say that the task environment is fully observable. A task environment is effectively fully observable if the sensors detect all aspects that are relevant to the choice of action. Fully observable environments are convenient because the agent need not maintain any internal state to keep track of the world. An environment might be partially observable because of noisy and inaccurate sensors or because parts of the state are simply missing from the sensor data. If the agent has no sensors at all then the environment is unobservable. If the next state of the environment is completely determined by the current state and the action executed by the agent, then we say the environment is deterministic; otherwise, it is stochastic. In sequential environments, on the other hand, the current decision could affect all future decisions. Chess and taxi driving are sequential: in both cases, short-term actions can have long-term consequences. Episodic environments are much simpler than sequential environments because the agent does not need to think ahead.

Unlike traditional artificial intelligence systems the multi agent systems have special features to solve complex problems. G.Rzevski, A.S Karunananda and P. Skobelev are the major researchers in the world for multi agent systems. MAS applications are used in variety of fields such as logistic planning [27], supply chain management, managing complexity in machine translation[28] air craft maintenance etc. A multi-agent system (MAS) is a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver. Communication, Coordination, Negotiation can be defined as the most powerful and important aspects of MAS.

3.2.1 Agent Communication

Agent communication plays a pivotal role in multi agent systems [28]. Agent Communication Languages (ACL) is used for inter-agent communication. It is an attempt to formalize the ways humans use language to achieve everyday tasks like requests, orders, promises, etc. This theory is an attempt to formalize the way humans uses the language to archive the everyday tasks. For example make a request, giving orders, make a promise, etc. ACL is also follows the same theory and establish some standards for the agent communications.

3.2.1.1 ACL Message Structure

A FIPA ACL message contains a set of one or more message parameters. The number of parameters required to generate a ACL message varies based on the situation. The only parameter that is mandatory in the ACL message is the performative parameter; which is used to define the communication type.

3.2.2 Agent Coordination

Multi agent systems need agent coordination to prevent chaos and synchronize individual behaviors of agents. Organizational coordination and contracting can be considered as main techniques for coordination. In organizational coordination agents are placed into certain organizational (e.g., hierarchical) structure along with certain communication patterns. In contracting technique agents use a Contract-Net Protocol (CNP) to establish contract relationships with other agents. Agents can act as both managers and contractors.

3.2.3 Agent Negotiation

Negotiation supports resolving conflicts. Negotiation can be cooperative or competitive. Communication process becomes a negotiation due to bargaining among agents. Contracting agents will lead to bargain (negotiate) between the manager and the bidders. Then that communication process will become a negotiation process. For example, an agent can use a strategy of constraint relaxation to submit bids that become increasingly more attractive to the manager. Negotiation process can either be cooperative or competitive based on the situation. In either case agent can be success or fail in the negotiation process.

3.3 Electroencephalography (EEG)

The role of brain has always fascinated human beings. A German scientist named Hans Berger discovered electroencephalography (EEG) about 80 years ago. After this, new methods for exploring it have been found and we can categorize them into two main groups such as Invasive and non-invasive. An invasive approach requires physical implants of electrodes in humans or animals, making it possible to measure single neurons or very local field potentials.

EEG is an electrophysiological monitoring method to record electrical activity of the brain. It is typically noninvasive, with the electrodes placed along the scalp, although invasive electrodes are sometimes used in specific applications. EEG measures voltage fluctuations resulting from ionic current within the neurons of the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a period of time, as recorded from multiple electrodes placed on the scalp. Brain waves are associated with specific brain functions and states of mind .Main EEG frequency bands and their basic information are listed below [29].

Band	Frequency Range	
α	8 - 13 Hz in frequency	Alertness, peacefulness
β	14 - 30 Hz in frequency	thinking, focus, sustained attention
θ	4 - 7 Hz in frequency	creativity, insight
δ	0.5 - 3 Hz in frequency	sleep, repair, complex problem solving
γ	31 - 50 Hz in frequency	Long term meditators

Table 3.1 Frequency bands and basic information

3.4 Brain Mapping

Neuroscientists have made great progress in recent years toward understanding how the brain works [30]. Europe’s Human Brain Project will attempt to create a computational simulation of the human brain, while the U.S. BRAIN Initiative will try to create a wide-ranging picture of brain activity. U.S. BRAIN Initiative is, a large neuroscience program announced by President Obama. The brain generates electrical signals when neurons fire. Therefore, electrical signals are considered as brain waves. Brain waves are associated with specific brain functions and states of mind. EEG brain map helps identify where the brain has specific problems. For neurofeedback, it provides a guide to where to train. Each area of the brain plays an important functional role. If one or more areas of the brain are running too slowly or too fast, it causes problems such as attention, emotional control or behavior difficulties [31]. If electrical activity is outside normal limits in a specific part of the brain, it indicates that area may contribute to the presented problem.

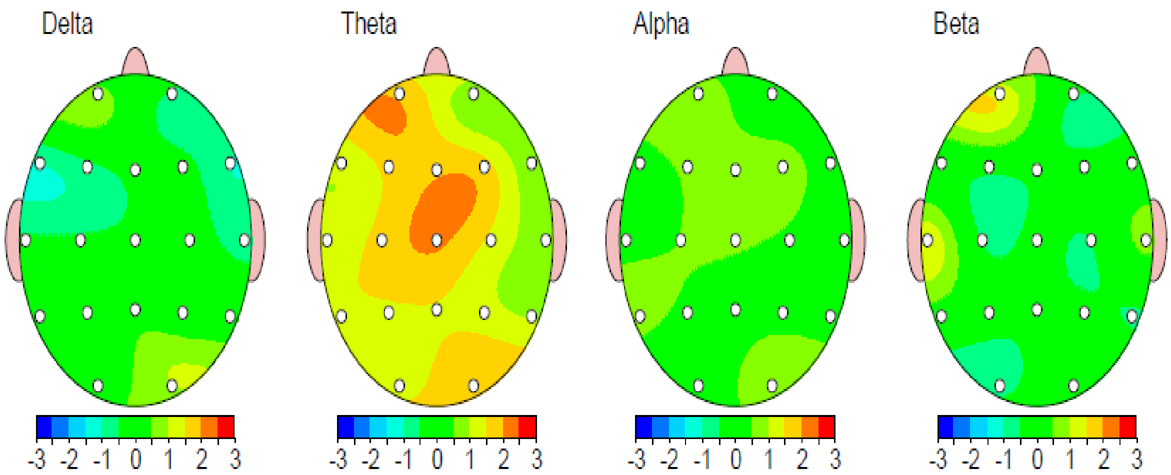


Figure 3.1: EEG Brain map

Mapping process gives us the ability to observe dynamic changes in the brain when the brain is engaged in for instance cognitive tasks showing brain areas that are not effectively involving or processing information as the task demands

3.5 Artificial Neural Network (ANN)

Artificial neural networks (ANNs) are a family of models inspired by biological neural networks (the central nervous systems of animals, in particular the brain) and are used to estimate or approximate functions that can depend on a large number of inputs and are generally unknown. Artificial neural networks are generally presented as systems of interconnected "neurons" which exchange messages between each other. The connections have numeric weights that can be tuned based on experience, making neural nets adaptive to inputs and capable of learning.

- To understand how the brain actually works
- To solve practical problems by using learning algorithms inspired by the brain

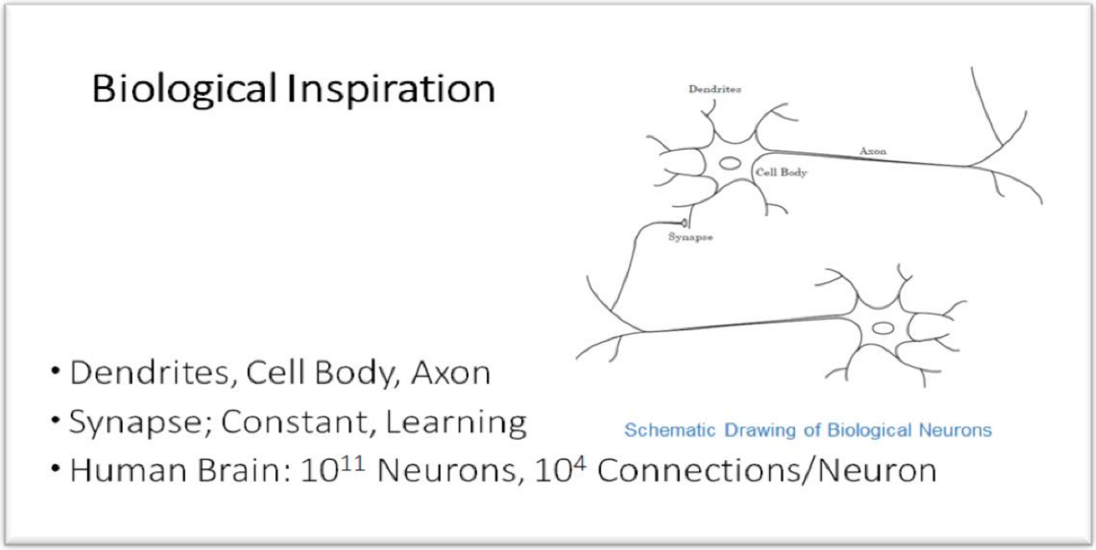


Figure 3.2: Biological Inspiration

3.5.1 Neural network applications

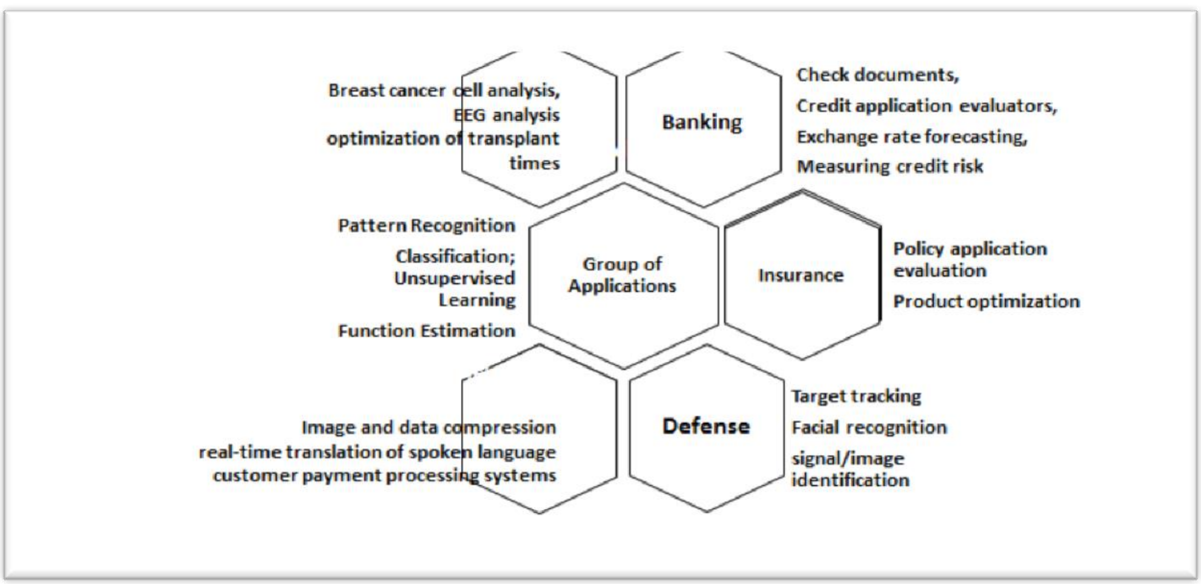


Figure 3.3 : ANN applications

3.5.2 Supervised learning

This is the machine learning task of inferring a function from labeled training data. The training data consist of a set of training examples. In supervised learning, each example is a pair consisting of an input object (typically a vector) and a desired output value (also called the supervisory signal)[32].

3.5.3 Unsupervised learning

This is the type of machine learning algorithm used to draw inferences from datasets consisting of input data without labeled responses. The most common unsupervised learning method is cluster analysis, which is used for exploratory data analysis to find hidden patterns or grouping in data.

3.5.4 Single-Neuron Perceptron

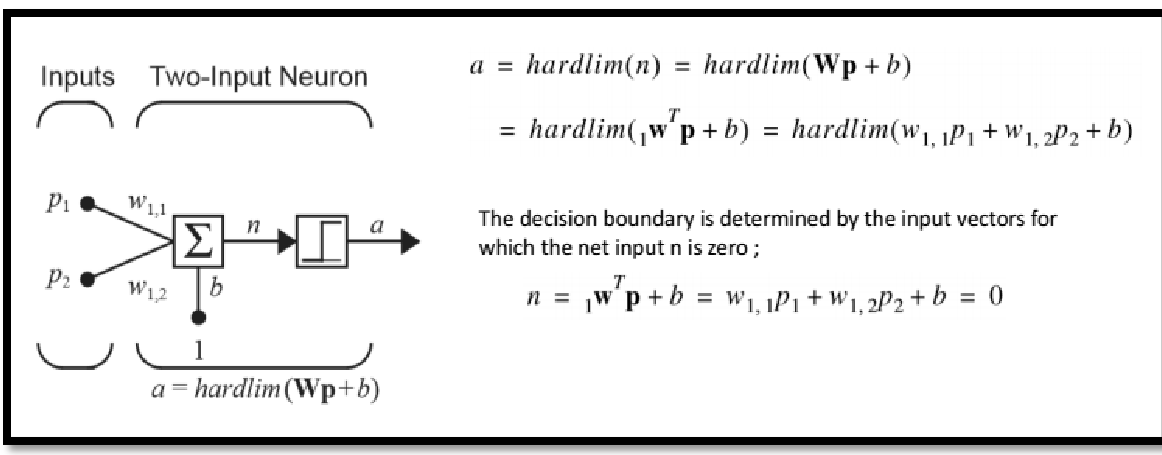


Figure 3.4: Single neuron perceptron

3.5.5 Multilayer Perceptron

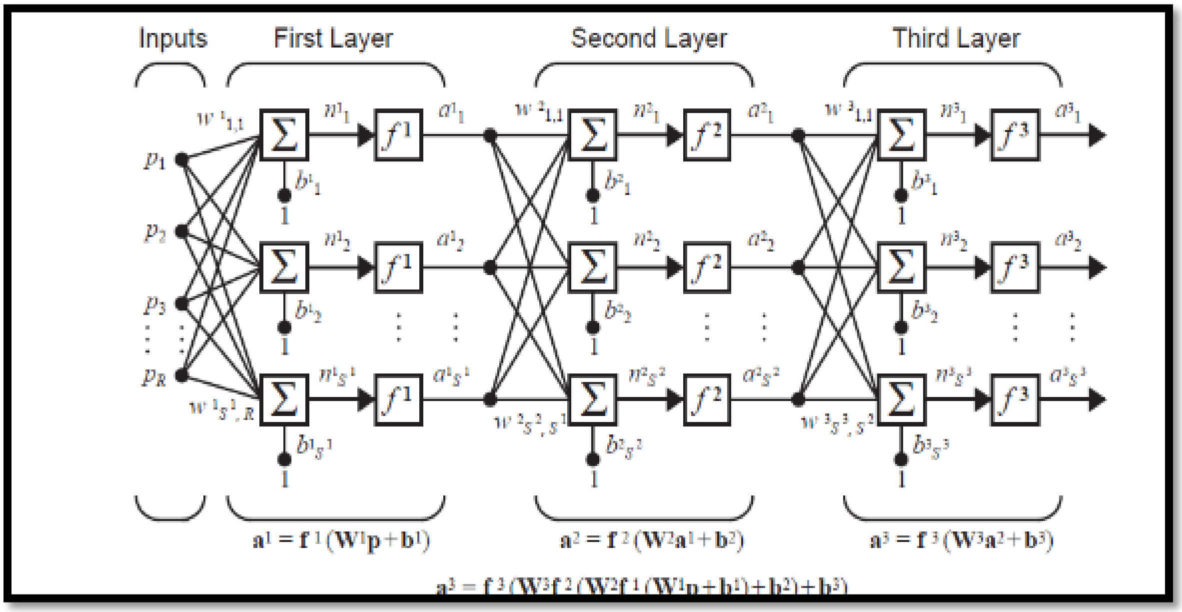


Figure 3.4: Multilayer perceptron

A multilayer perceptron (MLP) is a feedforward artificial neural network model that maps sets of input data onto a set of appropriate outputs. An MLP consists of multiple layers of nodes in a directed graph, with each layer fully connected to the next one.

3.6 Summary

This chapter presented the technologies adapted for the meditation solution. Multi agent systems were discussed in this chapter. Agent communication, coordination and negotiation were explained under the multi agent systems. Basic kinds of agent programs are also discussed in this chapter. Electroencephalography (EEG) and Artificial Neural Network (ANN) are also discussed in this chapter.

Chapter 4

Approach of Developing Meditation Feedback Solution

4.1 Introduction

In previous chapters we defined the research problem as the inability to provide effective feedback on the meditation. And also we discussed about the ANN and multi agent system which could be used to solve the problem. In this project EEG data from expert meditators will be used to train the artificial neural network and the EEG signals of the novice meditator will be given as the input to the trained ANN for classification. The multi agent system will interpret the EEG signals and provide the recommended meditation technique.

This chapter will elaborate on the hypothesis and how the technologies are adapted for the solution. Further this chapter will explain about the users, inputs, outputs, process, technology that implements the solution.

4.2 Hypothesis

The hypothesis of the research is that the problem of providing feedback to meditators can be solved by monitoring EEG signals of the meditation session by Artificial Neural network and multi agent system.

4.3 Inputs to System

The system will receive EEG wave signals generated by the brain. This is generated by the EEG headset with the signal node. The EEG recording can provide clues about the physical and mental state of the subject. In order to collect the EEG signals a brain signal a specialized brain headset will be used. Eg: Neurosky head set with Think Gear module. ThinkGear is the technology inside every NeuroSky product or partner product that enables a device to interface with the wearers' brainwaves. The Connector (TGC) runs as a background process on your computer and is responsible for directing headset data from the serial port to an open network socket. It includes the thinkgear module and EEG sensor that touches the forehead.

4.4 Output from the System

Recommended Meditation Technique is the output of the multi agent system. E.g.: Anapanasathi meditation, Vipassana meditation etc. Status of the meditation session (Successful, Unsuccessful) is the output of the ANN.

4.5 Process

The research was divided in to the sections such as EEG signal data acquisition and processing, feature extraction, classification and multi agent system. , EEG signals captured by the NeuroSky Mindwave device are transmitted via Bluetooth. EEG data acquired from the meditation sessions has been fed to the ANN. Feature extraction has been done in order to extract useful information from the signal. Features can be considered as characteristics of a signal that are able to distinguish between different emotions. The Artificial Neural Network will be trained with the EEG signals of the expert meditators. The inputs of the novice meditator are applied to the trained artificial neural network. The EEG meditation data will be saved in the solution. A file based approach is used for this purpose. The sensors not only record brain activity from neural activities but also other artifacts. Therefore, artifact removal has been done to clean the data. The main damage is caused by the eye related artifacts. The signal level strength of neuro sky mobile falls between 0-200. If the signal strength is greater than 50, it can be accepted.

The most powerful aspect of artificial intelligence, multi agent system will be used to interpret the EEG signals and provide necessary recommendation based on the EEG data. This system mimics the way how several experts use their knowledge and ability to examine the changes to find the improvements. Top level diagram of the proposed system is depicted below.

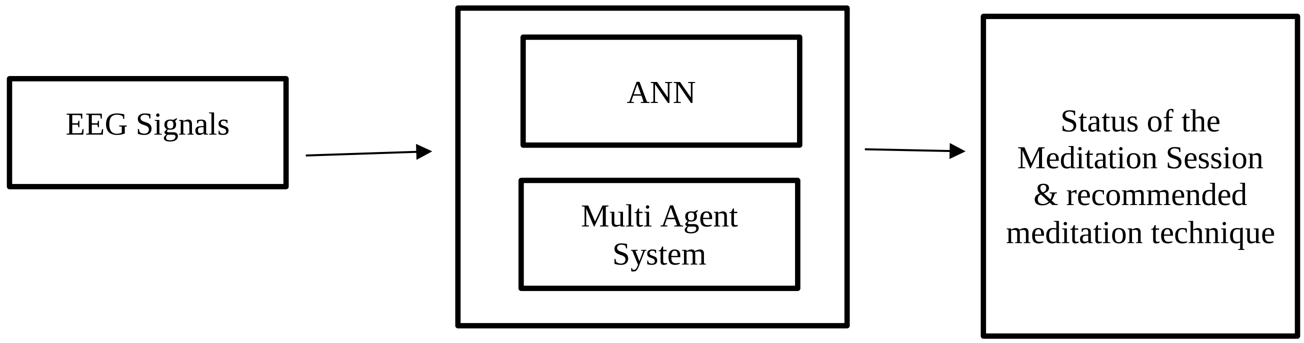


Figure 4.1: Proposed System

4.6 Features

The proposed system should be able to analyze the EEG signals of the novice meditator and provide feedback on the meditation session. The system should be for day to day use and should not cause health risks. And also it should provide real time feedback on the meditation session and also provide the recommended meditation technique. The user should be able to see the information related to EEG signals such as average, maximum value etc...

4.7 Users

This solution can be used in many scenarios. Mainly this solution will be useful for the mediators to receive feedback for meditation sessions. The meditation teachers can use this solution to check the progress of a novice meditator. And also the expert meditators or the teachers have the ability to record their own EEG signal from the meditation session to train the system. Next they can check with the input of their novice meditators' EEG data to check the progress. This solution will be useful to psychologists in order to analyze the changes due to their treatment with mindfulness meditation related to the attention and concentration disorders.

4.8 Summary

In this chapter we discussed about the approach to solve the problem of monitoring the progress of a meditation session for effective feedback. System Inputs, outputs, hypothesis, and process to develop the meditation feedback solution were presented in this chapter. The meditation solution can be used in various scenarios. Mainly the meditation solution will be useful for the mediators to receive feedback for meditation sessions. Finally this chapter explained about the features and users of the meditation feedback solution in a detailed manner.

Chapter 5

Analysis and Design of Meditation Feedback Solution

5.1 Introduction

The method used for the designing of this project will be discussed on this chapter which details about designing of the meditation feedback solution. This chapter provides a detailed explanation of all methods used in the analysis and experiments as well as the justifications behind using those methods.

The research was divided in to the sections such as EEG signal data acquisition and processing, feature extraction, classification and multi agent system. The high level architecture is depicted below.

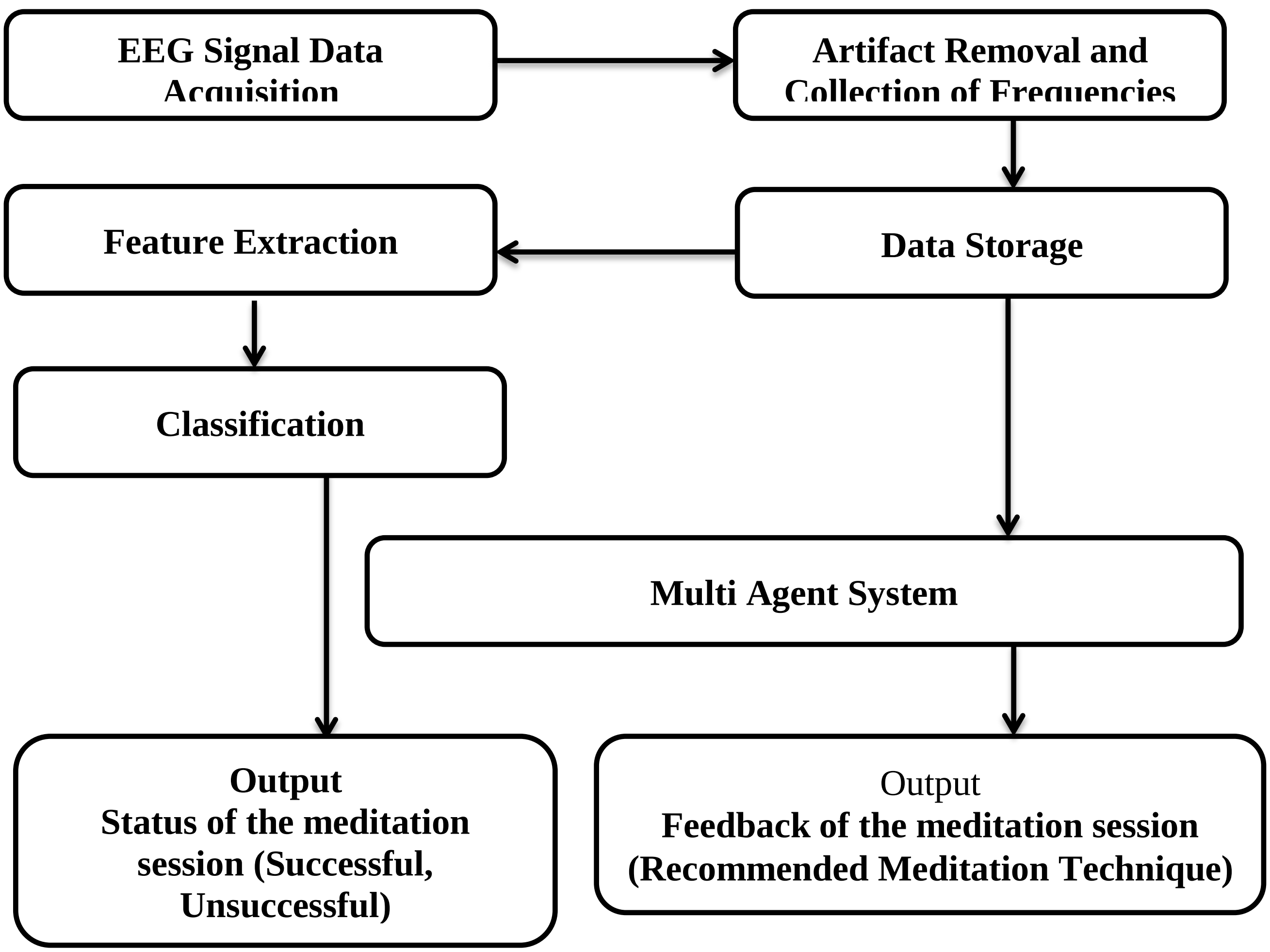


Figure 5.1: Top Level Design of the System

5.2 EEG Signal Data Acquisition

In data acquisition, EEG (NeuroSky Mindwave) device is used for acquiring data through several experiments. It is cheap and has one sensor. These details are sent via Bluetooth. The data can be captured using any programming language and make use of them. Life cycle of a neuro sky mind wave mobile consists of several stages such as establishing the socket connection, Authorization (Authorization of the client by the server), Configuration of server (performed any time) ,Receipt of headset data (repeating),Stopping the socket connection Measures derived from brain electrical activity have excellent temporal resolution in the millisecond domain. EEG recordings have distinct advantages and disadvantages when used to make inferences about cognition.

5.3 Artifact Removal

In brain wave analysis should be done carefully and need to acquire correct clean data. Therefore, it is essential to remove unnecessary artifacts. The artifact removal process will be applied to clean the data. These sensors not only recorded brain activity from neural activities but also other artifacts. The main damage is caused by the eye related artifacts.

5.4 Feature Extraction and Selection

Feature extraction is the process of extracting useful information from the signal. Features are characteristics of a signal that are able to distinguish between different emotions. The following features that will be used in the study

- delta;
- theta;
- lowAlpha;
- highAlpha;
- lowBeta;
- highBeta;
- lowGamma;
- highGamma;

5.5 Multi Agent System

The results will be analyzed by the multi agent system. MAS have the ability to generate very powerful emergent behavior. Agents are complicated computer programs that act autonomously on behalf of their users. There will be many agents in a system to provide better results. It's a loosely coupled network of software agents that interact to solve problems that are beyond the individual capacities or knowledge of each problem solver. MAS applications are used in variety of fields such as logistic planning , supply chain management, air craft maintenance etc … Communication, Coordination, Negotiation can be defined as the most powerful and important aspects of MAS.

5.6 Agent platforms

There are various agent platforms. JADE (Java Agent Development Framework) is a software framework fully implemented in Java language. It is according to the Foundation for Intelligent Physical Agents-FIPA. Agents use common language, an Agent Communication Language, or ACL. Much work has been done in developing ACLs that are declarative, syntactically simple, and readable by people.

5.7 Summary

In this chapter we have discussed about the EEG data acquisition and artifact removal. EEG (NeuroSky Mindwave) device has been used for acquiring data. EEG data from expert meditators are used to train the ANN. Trained ANN is used to provide feedback to the novice meditators. JADE (Java Agent Development Framework) was selected to develop the multi agent system. The multi agent system will play a major role to recommend the suitable meditation technique.

Chapter 6

Implementation of Meditation Feedback Solution

6.1 Introduction

This chapter discusses how the Meditation solution is implemented. In chapter 5, we discussed about the design of the meditation solution and this chapter will further explain the implementation details of each module such as technologies, algorithms which are mentioned in the design.

According to the design of the meditation solution this system has two main components. The EEG analysis component with traditional ANN based system and the powerful multi agent system.

In the ANN component there were following modules.

1. EEG signal data acquisition
2. Artefact Removal and collection of frequencies
3. Data storage
4. Feature extraction
5. Classification
6. ANN output

6.2 EEG signal data acquisition

A non-invasive approach is used for this solution to acquire data. Neurosky mindwave headset is used. It is an affordable headset which is used for research. The neurosky mind wave head set consists of one sensor. The sensor is rest on to forehead of the person. And the brain signals are emitted from the forehead. Neurosky mind wave mobile supports .Net API as well as Java. In this research java is used.

Data collection is the step one. The EEG data is collected from 33 expert meditators. It includes monks too. The expert meditator was given the option to practice or perform the meditation and EEG data was recorded. The sessions were around 20 minutes. The data acquisition part is depicted below

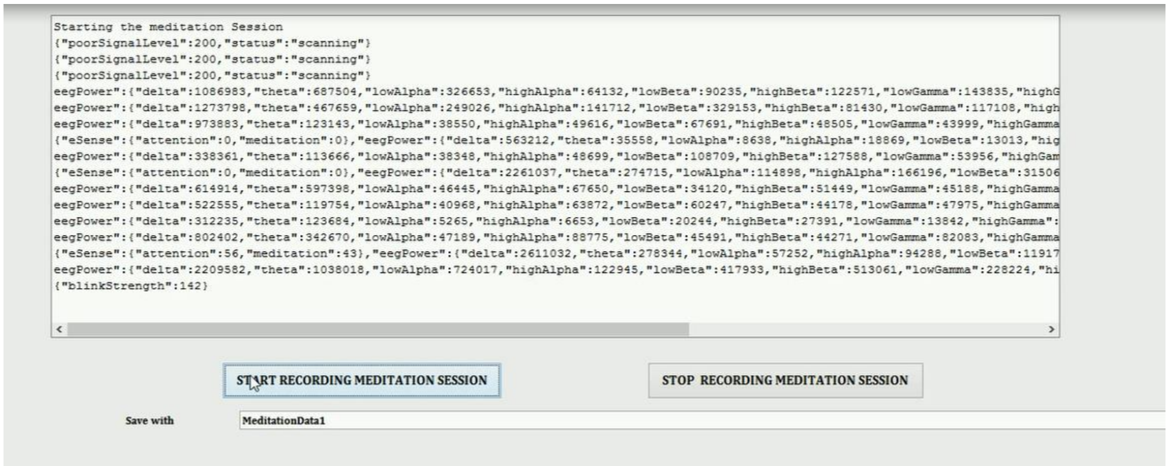


Figure 6.1: Data Acquisition

Figure 6.2: Data Acquisition

6.3 Artifact Removal and collection of frequencies

In order to do the research well it is important to get clean data. The sensors will record noise as well. Those artifacts should be removed. Eye related artifacts have the ability to have a bad impact on the research results. The signal level strength of neuro sky mobile falls between 0-200. If the signal strength is greater than 50, it can be accepted.

6.4 Data storage

The EEG meditation data will be saved in the solution. A file based approach is used as the data storage mechanism of the meditation feedback solution.

6.5 Feature extraction

Feature extraction plays an important role. Here, we extract thee necessary data for the ANN component. When RAW data is coming FFT is used to convert this in to frequency domain. Once FFT is applied it is possible to get following bands from the EEG signal. NeuroSky headset internally does this processing and output the band details once per second.

- delta;
- theta;
- lowAlpha;
- highAlpha;
- lowBeta;
- highBeta;
- lowGamma;
- highGamma;

6.6 Designing and Training Artificial Neural Network

This part plays a key role in the meditation solution. As per the above mentioned details we have already identified the necessary features for the ANN. Those features include EEG signals and now we can use them as input to the ANN.

The Output layer will have a single neuron. After setting up the ANN, the hidden layer and the neurons will be adjusted based on experiments. Following will be the inputs for the ANN. Delta, theta, lowAlpha, highAlpha, lowBeta, highBeta, lowGamma, highGamma. After experiments following values and selected.

Input Layer	8 neurons
Hidden Layer	10 Neurons
Output Layer	1 neuron
Momentum	0.1
Learning rate	0.3
Algorithm	Backpropagation

Table 6.1 ANN Configuration

Each data file with EEG signals of expert meditators are fed to the artificial neural network and supervised training session is carried out.

There were around 30 expert meditators with many sessions. After the training is done meditationsolution.dat file is created and it will be used for future tasks. Few screenshots of the development progress are depicted below.

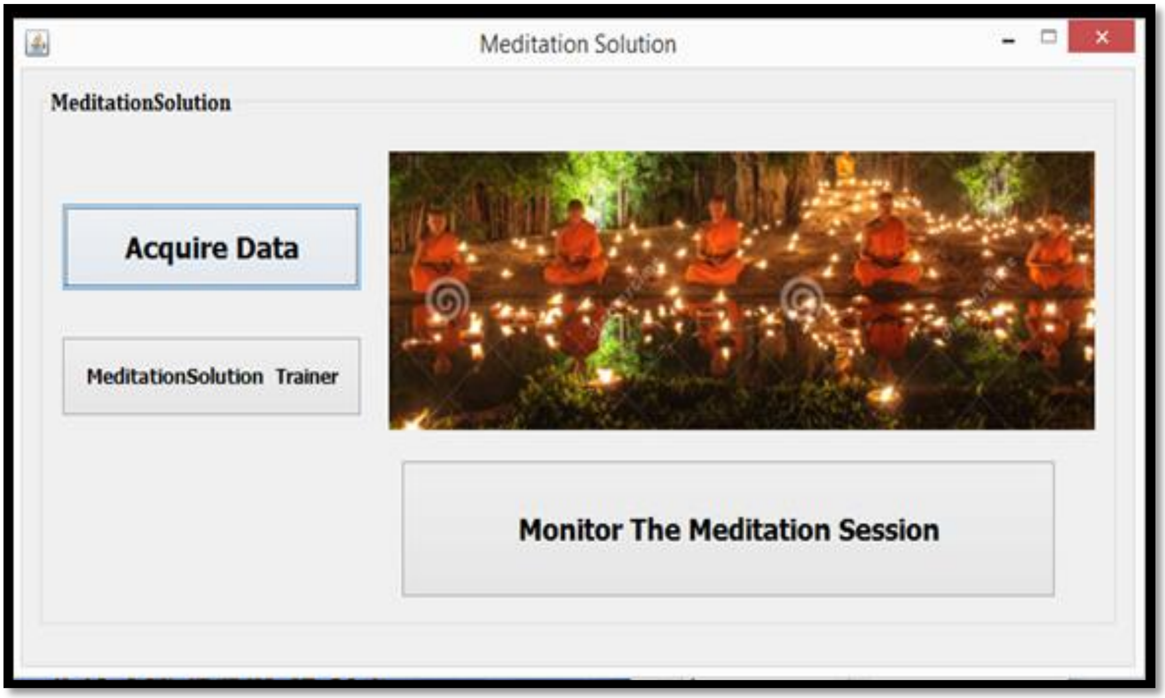


Figure 6.3: Meditation Solution main UI

Figure 6.4: Monitoring meditation progress

6.7 Development of the multi agent system

As mentioned in the design chapter, the traditional artificial intelligence approaches such as ANN does not have the ability provide powerful features of a multi agent system. In a multi agent system is it important to identify the agents. The main agents of the system are listed below.

6.8 The rationale of selecting agents

There agents were selected by the facts from the literature review, expert advice.

Agents of the System

1. Alpha agent - Alpha agent get activated when alpha signals are available from the sensors
2. Attention agent - Attention agent will be activated when the attention values are available via the sensor
3. Meditation agent - Meditation agent will be activated when the attention values are available via the sensor
4. Artefact removal agent - Artifact removal agent will come into action when the eye related artifacts are found
5. Theta agent - Theta agent will be activated when the theta values are available via the sensor
6. Low gamma agent - Low gamma agent will be activated when the low gamma values are available via the sensor
7. Management Agent
8. Decision Agent

6.9 Main Tasks of each agent

Alpha agent

- Read alpha values
- Calculate the average
- Calculate the maximum alpha value
- Calculate the minimum alpha values
- Involve in communication etc ..

Attention agent

- Read attention values
- Calculate the average
- Calculate the maximum attention value
- Calculate the minimum attention values
- Get the count where the values is greater than 90
- Involve in communication etc ..

Meditation agent

- Read Meditation values
- Calculate the average
- Calculate the maximum Meditation value
- Calculate the minimum Meditation values
- Get the count where the values is greater than 90
- Involve in communication etc...

Artifact Removal Agent

This agent will come in to action when unnecessary artifacts are detected. In the meditation solution we remove eye related artifacts.

Theta agent

- Read theta values
- Calculate the average
- Calculate the maximum theta value
- Calculate the minimum theta values
- Involve in communication etc. …

Low gamma agent

- Read low gamma values
- Calculate the average
- Calculate the maximum low gamma value
- Calculate the minimum low gamma values
- Involve in communication etc ..

Management Agent

The management agent will get involved with the coordination.

Decision Agent

Decision agent will involve with other agents and involve in negotiation in order to provide the output.

Following is an example, where the all the agents work together and provide the output. Agents receive values from the environment and using communication, coordination, negotiation etc... The final result is generated. It is the emergent feature.

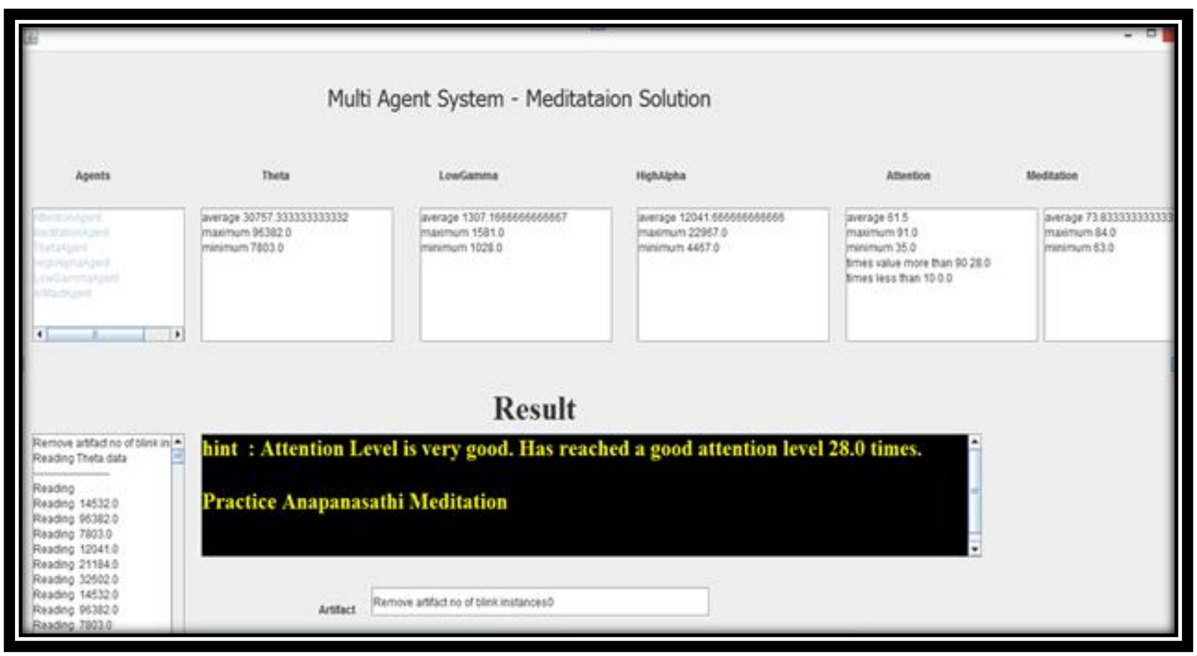


Figure 6.5: Multi Agent System – Meditation Solution

In the above example the Attention level is in the average status. All the necessary values are also displayed. “The Anapanasathi meditataion” style is recommended. Expert meditators were consulted to obtain such information to be used in the system by recommendation agent.

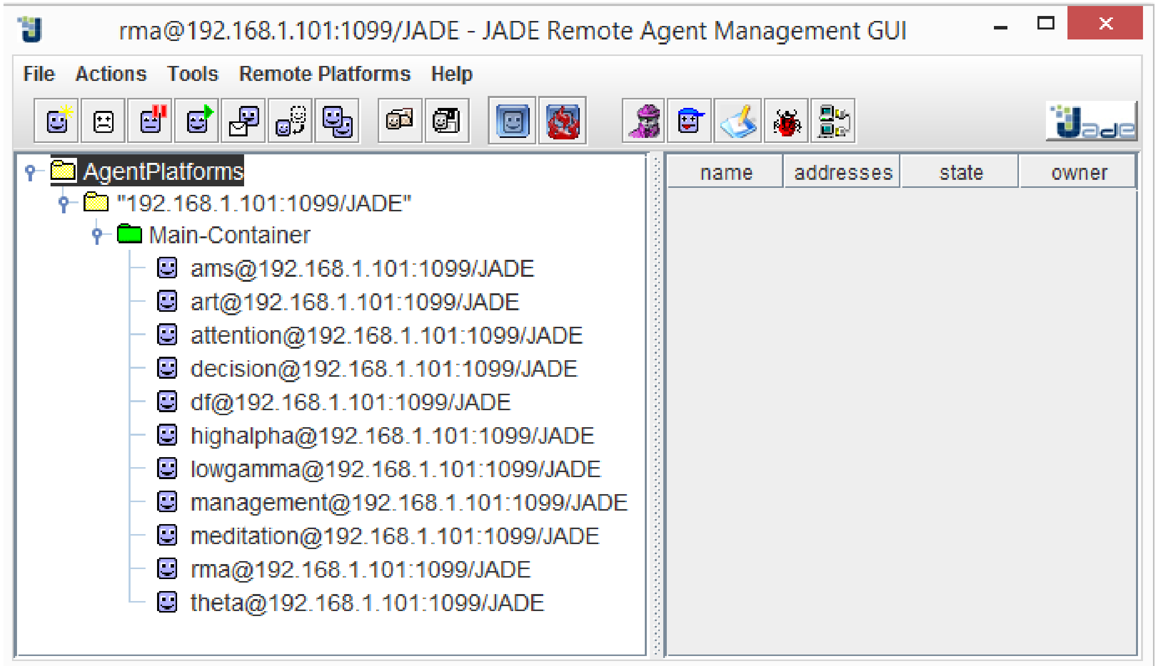


Figure 6.6: JADE Agent Management GUI

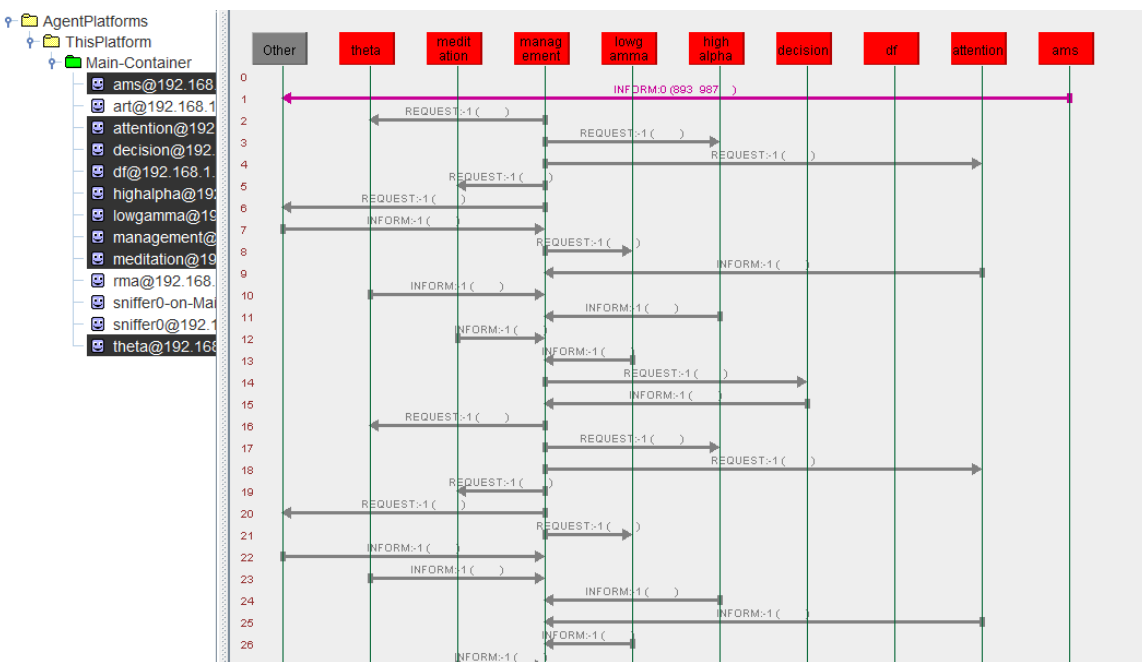


Figure 6.7: Agents in action

Agent communication is happening via ACL messages.

```
AID r = new AID("management@" + myAgent.getHap(), AID.ISGUID);
ACLMessage aclMessage = new ACLMessage(ACLMessage.INFORM);
aclMessage.addReceiver(r);
```

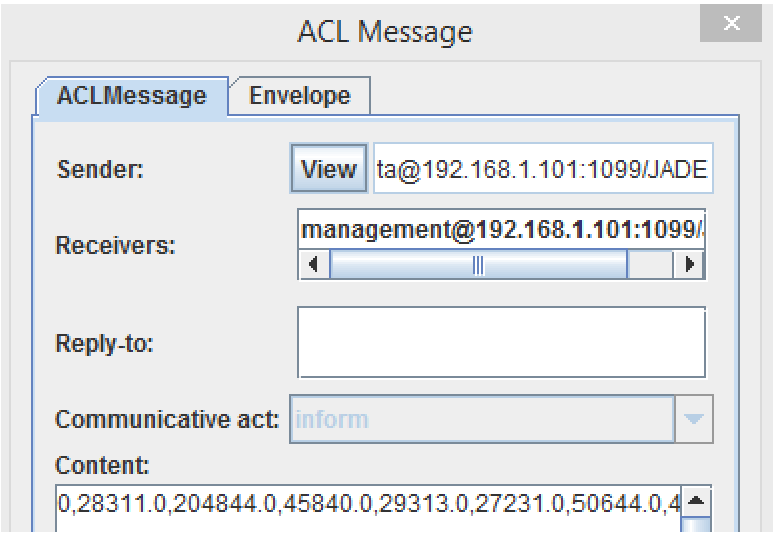


Figure 6.8: ACL Message

6.10 Summary

This chapter focused about the implementation details about the meditation solution. Mainly it discussed about the two main components such as EEG analysis with ANN and multi agent system. In this chapter we have discussed EEG data acquisition, FFT and artifact removal. The data is then used to train an Artificial Neural Network (ANN). A detailed explanation about the implementation of all the above mentioned components and the tools used for the implementation are presented in this chapter. Trained ANN was used to monitor the meditation progress. The EEG results are analyzed by the multi agent system to provide the recommended meditation technique.

Chapter 7

Evaluation

7.1 Introduction

This chapter mainly focusses on the experiments conducted to evaluate the meditation feedback solution. It presents the selection of participants, evaluation strategy, data collection, analysis, experiment output and conclusion.

7.2 Participants

This experiment used 25 meditators (age ranged between 20 and 65 years) for evaluation. The participants had an understanding about the meditation. The meditators were given instructions about the process to wear the Neurosky mind wave EEG capturing device.

7.3 Evaluation strategy

The experiment was done as two stages. First the meditation solution which is trained with expert meditators data (especially monks) was used to monitor the meditation session of novice. And the number of times which matched was counted. Next the meditators were asked to stay without meditating. The details are depicted below.

7.4 Data Collection

Following table measure the output of the ANN. Number of times the meditators have achieved the level.

	Meditation Session (No of time the " The Meditation session is good message received ")	Control session (No of time the " The Meditation session is good message received ")
Meditator 1	1	0
Meditator 2	4	0

Meditator 3	2	0
Meditator 4	3	1
Meditator 5	7	0
Meditator 6	7	1
Meditator 7	8	0
Meditator 7	10	0
Meditator 9	7	0
Meditator 10	8	0
Meditator 11	6	0
Meditator 12	1	3
Meditator 13	1	2
Meditator 14	1	4
Meditator 15	1	2
Meditator 16	0	0
Meditator 17	0	0
Meditator 18	0	1
Meditator 19	1	0
Meditator 20	1	0
Meditator 21	1	1
Meditator 22	5	0
Meditator 23	1	0
Meditator 24	1	2
Meditator 25	1	0

Table 7.1 Experiment results

After analyzing the above results, we can see that some meditators have managed to reach the expected level for some time. Generally in the control session which is the non-meditation session meditators have not achieved that level.

When we consider above details the accuracy is 72%.

Series 1 - Meditation Session (No of time the “SUCCESSFULL: MEDITATION PROGRESS IS GOOD message received “)

Series 2 - Control session (No of time the “UNSUCCESSFUL: MEDITATION PROGRESS IS NOT GOOD message received “)

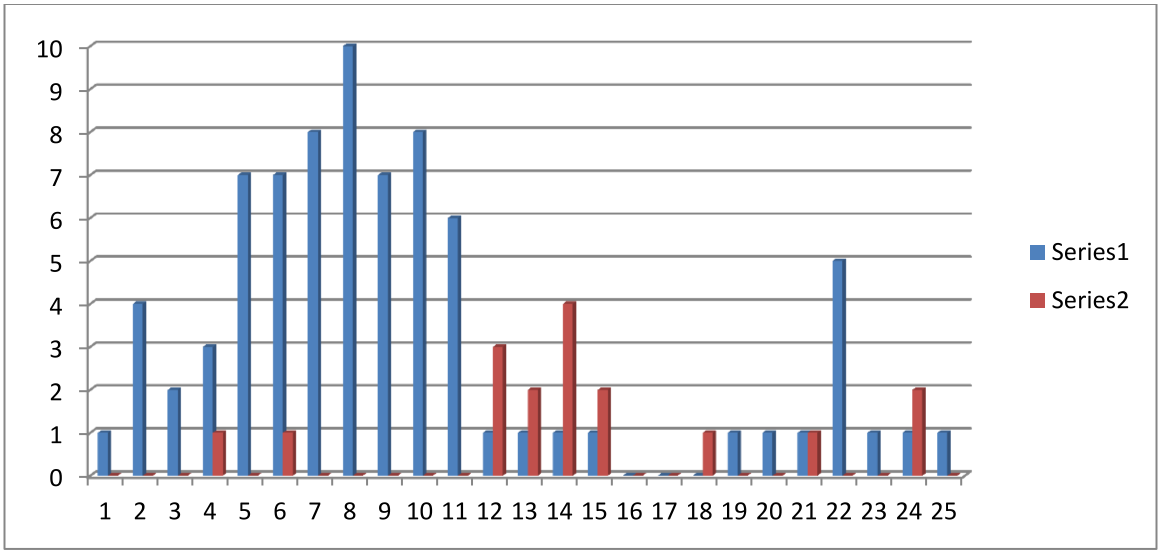


Figure 7.1: Analyzing meditation vs control results

Next stage the average attention values were compared. The two situations are as follows.

- Mediation session
- Control session

Participants were instructed to sit in the same posture for both the meditation and control task recordings

	Average Attention Value (Meditation Session)	Average Attention Value (Control Session)
Meditator 1	52	10
Meditator 2	66	25
Meditator 3	80	35
Meditator 4	70	44
Meditator 5	44	66
Meditator 6	77	46
Meditator 7	90	47
Meditator 7	66	70
Meditator 9	77	44
Meditator 10	66	20

Meditator 11	55	70
Meditator 12	77	44
Meditator 13	37	66
Meditator 14	55	66
Meditator 15	47	30
Meditator 16	66	25
Meditator 17	74	55
Meditator 18	56	76
Meditator 19	71	55
Meditator 20	47	40
Meditator 21	25	17
Meditator 22	48	16
Meditator 23	19	44
Meditator 24	47	30
Meditator 25	66	37

Table 7.2 Experiment results

After analyzing the results, it is clear that the meditation session has the ability to provide more attention. The accuracy rate is 72%

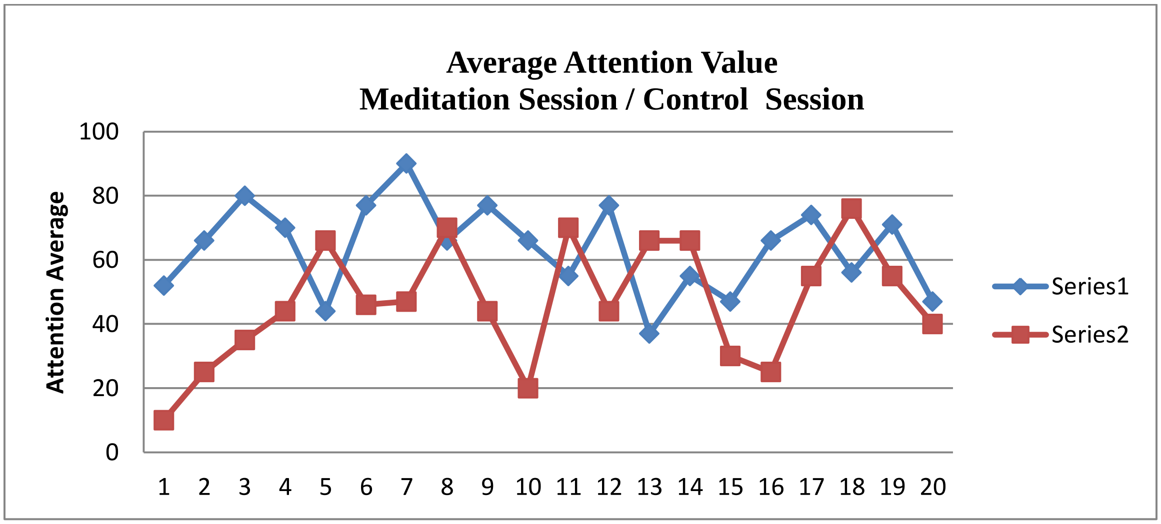


Figure 7.2: Analyzing meditation vs control results

Series 1 - Average Attention Value (Meditation Session)

Series 2 - Average Attention Value (Control Session)

In the next experiment, we selected people who learn meditation for more than five years and recorded the highest attention value. Only 5 meditators were selected. Those meditators have practiced “Samatha meditation” style.

	Highest attention value – Samatha Meditataion Session	Highest attention value – Control Session
Meditator 1	71	55
Meditator 2	88	40
Meditator 3	45	17
Meditator 4	78	16
Meditator 5	19	44
Meditator 6	47	30
Meditator 7	66	37

Table 7.3 Experiment results

Series 1 - Highest attention value – Samatha Meditataion Session

Series 2 - Highest attention value – Control Session

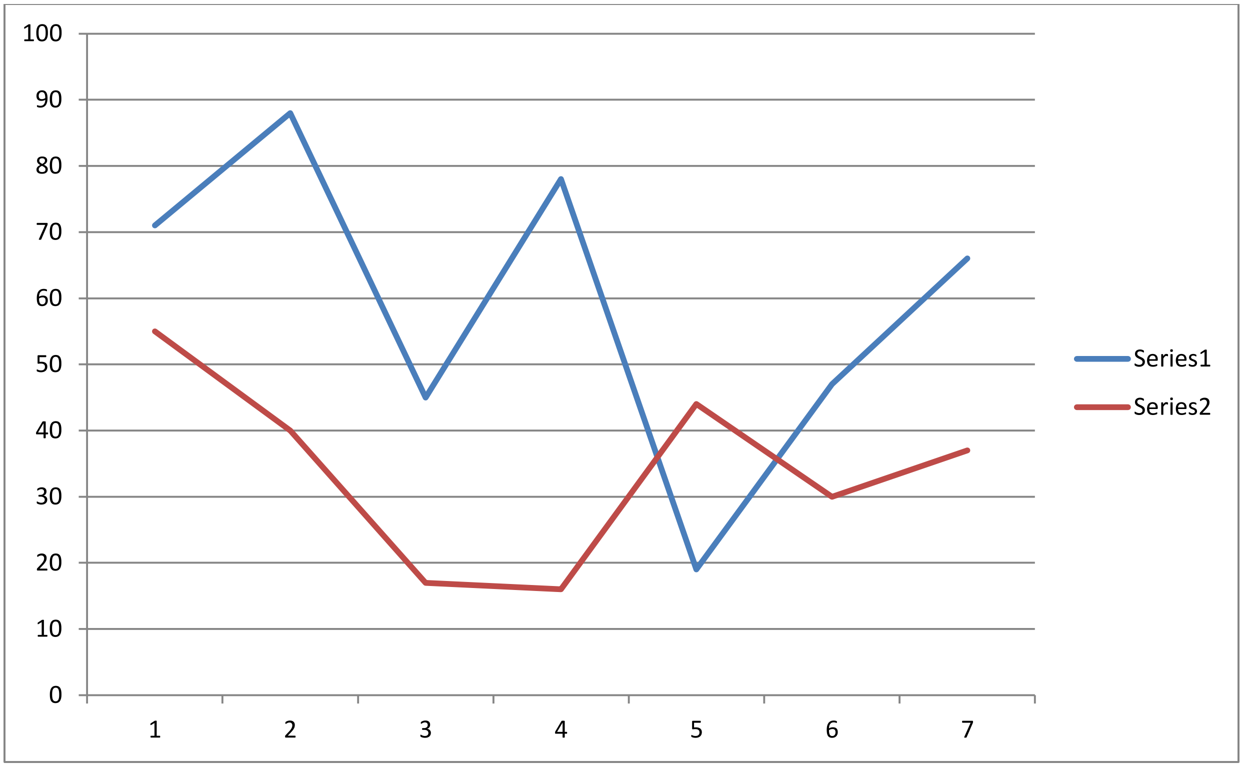


Figure 7.3: Experiment results

7.5 Experiment output and conclusion

When we take an account of all the results we can see that the meditation solution application has produced satisfactory results and provided a way to monitor meditation sessions. It has been proved that meditation session has the ability to provide more attention and the meditation sessions can be monitored successfully. The accuracy rate is 72%. The multi agent system has provided more value to the meditation solution by recommending the meditation technique. Multi-agent system mimics the way how several experts get together and investigate the meditation results. Eye related artefacts are also handled by the multi agent system. When that effect is there artefact removal agent will come in to action and remove the unnecessary artifacts.

7.6 Summary

The meditation solution is evaluated using proper experiment mechanism. We have designed and conducted experiment to measure the success of the meditation solution application and presented the results. The solution has been tested using twenty five meditators (age ranged between 20 and 65 years). The experiment results show that meditation session has the ability to improve attention and the meditation sessions can be monitored successfully. The accuracy rate is 72%. The multi agent system mimicked the way how several experts get together and investigate the meditation results and successfully provided the meditation feedback by recommending the meditation technique.

Chapter 8

Conclusion & Further work

8.1 Introduction

This thesis shows evidence that it is possible to solve the problem of monitoring meditation sessions and providing feedback. The neuro sky head set which is a brain computing interface has been used as the main equipment for the data acquisition. Expert meditation data was acquired and the ANN was trained with them. Next it has been tested with the novice meditators. The multi agent system analyses the EEG data and provides necessary feedback to the meditator by recommending the meditation technique.

8.2 Conclusions

This thesis shows evidence that it is possible to monitor meditation sessions and provide feedback. This solution collects the EEG data from expert meditators which has been used to train the artificial neural network. Next the EEG signals of the novice meditator has been given as the input to the trained ANN for classification which outputs whether it is successful or unsuccessful.

It was noticed that non-invasive nature of the EEG electrodes, cannot be considered as completely error free. However, placing electrodes inside the brain (invasive approach) is not a safe way which can be used for all meditators. Therefore, the neurosky EEG device has been used with non-invasive approach for the research and it has managed to do the data acquisition successfully. The multi agent approach is highly appropriate to solve this type of a complex problem. The important features of MAS such as agent communication, coordination and negotiation played a major role in order to recommend the meditation technique.

The aim of this project is to design, develop and evaluate a system to monitor the meditation session and provide feedback. However, after analyzing the results of the experiment, it was evident that it is possible to monitor meditation session and provide the recommended meditation style.

Following objectives mentioned early in the thesis are met successfully during the execution of the research.

8.2.1 Objectives

- A sound study of the problem domain to identify the existing approaches and their advantages and weaknesses.
- A study of the technologies such as EEG analysis, Multi agent systems , artificial neural network (ANN) and artefact removal to find the best way to solve the problem
- Design and develop a system for solving the problem
- Evaluation of the proposed solution
- Preparation of final documentation

All the above mentioned objectives are met during the execution of the project.

8.3 Limitations and Further Work

This application has the ability to monitor meditation sessions and provide valuable feedback. To receive data, a non-invasive approach is used. If invasive approach is used with more electrodes, it would generate more data. The electrode should be properly placed in order to receive data. If the user try to move or change the position the signal will be lost. Poor signal situation is handled by the application.

8.4 Summary

This chapter was dedicated to the conclusion of the research. The full life cycle of the project was addressed. Problem encountered, limitations of the solution, and further work also discussed in this chapter. The experiment results supported the hypothesis. Future work on related areas was identified and document.

References

[1] Y.-Y. Tang, B. K. Hölzel, and M. I. Posner, "The neuroscience of mindfulness meditation," *Nat. Rev. Neurosci.*, vol. 16, no. 4, pp. 213–225, Mar. 2015.

[2] B. K. Hölzel *et al.*, "Mindfulness practice leads to increases in regional brain gray matter density," *Psychiatry Res. Neuroimaging*, vol. 191, no. 1, pp. 36–43, Jan. 2011.

[3] H. A. Slagter, R. J. Davidson, and A. Lutz, "Mental Training as a Tool in the Neuroscientific Study of Brain and Cognitive Plasticity," *Front. Hum. Neurosci.*, vol. 5, 2011.

[4] "Meditation and the Brain," *MIT Technology Review*.

[5] R. J. Davidson and A. Lutz, "Buddha's brain: Neuroplasticity and meditation," *IEEE Signal Process. Mag.*, vol. 25, no. 1, p. 176, 2008.

[6] R. J. Davidson and B. S. McEwen, "Social influences on neuroplasticity: stress and interventions to promote well-being," *Nat. Neurosci.*, vol. 15, no. 5, pp. 689–695, Apr. 2012.

[7] K. A. Norman, S. M. Polyn, G. J. Detre, and J. V. Haxby, "Beyond mind-reading: multi-voxel pattern analysis of fMRI data," *Trends Cogn. Sci.*, vol. 10, no. 9, pp. 424–430, Sep. 2006.

[8] Y. Kamitani and F. Tong, "Decoding the visual and subjective contents of the human brain," *Nat. Neurosci.*, vol. 8, no. 5, pp. 679–685, 2005.

[9] K. A. Garrison *et al.*, "Real-time fMRI links subjective experience with brain activity during focused attention," *NeuroImage*, vol. 81, pp. 110–118, Nov. 2013.

[10] A. Lutz, H. A. Slagter, N. B. Rawlings, A. D. Francis, L. L. Greischar, and R. J. Davidson, "Mental Training Enhances Attentional Stability: Neural and Behavioral Evidence," *J. Neurosci.*, vol. 29, no. 42, pp. 13418–13427, Oct. 2009.

[11] A. Lutz, L. L. Greischar, N. B. Rawlings, M. Ricard, and R. J. Davidson, "Long-term meditators self-induce high-amplitude gamma synchrony during mental practice," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 101, no. 46, pp. 16369–16373, 2004.

[12] J. A. Brefczynski-Lewis, A. Lutz, H. S. Schaefer, D. B. Levinson, and R. J. Davidson, "Neural correlates of attentional expertise in long-term meditation practitioners," *Proc. Natl. Acad. Sci.*, vol. 104, no. 27, pp. 11483–11488, 2007.

[13] E. Baron Short *et al.*, "Regional Brain Activation during Meditation Shows Time and Practice Effects: An Exploratory FMRI Study," *Evid. Based Complement. Alternat. Med.*, vol. 7, no. 1, pp. 121–127, 2010.

[14] D. G. MacCoon *et al.*, "The validation of an active control intervention for Mindfulness Based Stress Reduction (MBSR)," *Behav. Res. Ther.*, vol. 50, no. 1, pp. 3–12, Jan. 2012.

[15] P. Malinowski, "Neural mechanisms of attentional control in mindfulness meditation," *Front. Neurosci.*, vol. 7, 2013.

[16] B. R. Cahn, A. Delorme, and J. Polich, "Event-related delta, theta, alpha and gamma correlates to auditory oddball processing during Vipassana meditation," *Soc. Cogn. Affect. Neurosci.*, vol. 8, no. 1, pp. 100–111, Jan. 2013.

[17] B. R. Cahn, A. Delorme, and J. Polich, "Occipital gamma activation during Vipassana meditation," *Cogn. Process.*, vol. 11, no. 1, pp. 39–56, Feb. 2010.

[18] V. Pizzella *et al.*, "Brain Activity of Buddhist Monks During Focused Attention Meditation: A MEG Study," *NeuroImage*, vol. 47, p. S156, Jul. 2009.
[19] S. W. Lazar, G. Bush, R. L. Gollub, G. L. Fricchione, G. Khalsa, and H. Benson, "Functional brain mapping of the relaxation response and meditation," *NeuroReport*, vol. 11, no. 7, pp. 1581–1585, May 2000.
[20] UNIVERSITY of WISCONSIN–MADISON, "The Dalai Lama and scientists unite to study meditation."
[21] B. K. Holzel *et al.*, "Investigation of mindfulness meditation practitioners with voxel-based morphometry," *Soc. Cogn. Affect. Neurosci.*, vol. 3, no. 1, pp. 55–61, Jun. 2007.
[22] F. Ferrarelli *et al.*, "Experienced Mindfulness Meditators Exhibit Higher Parietal-Occipital EEG Gamma Activity during NREM Sleep," *PLoS ONE*, vol. 8, no. 8, p. e73417, Aug. 2013.
[23] A. Ahani, H. Wahbeh, H. Nezamfar, M. Miller, D. Erdogmus, and B. Oken, "Quantitative change of EEG and respiration signals during mindfulness meditation," *J Neuroeng Rehabil*, vol. 11, no. 87, pp. 10–1186, 2014.
[24] R. Singla and N. Sharma, "Function Classification of EEG Signals Based on ANN," *Int. J. Soft Comput. Eng.*, vol. 2, pp. 158–163, 2014.
[25] J. V. Haxby, "Multivariate pattern analysis of fMRI: The early beginnings," *NeuroImage*, vol. 62, no. 2, pp. 852–855, Aug. 2012.
[26] Russell, Stuart J., Peter Norvig, and John Canny., *"Artificial Intelligence: A Modern Approach". 2003.* .
[27] G. Rzevski, V. Soloviev, P. Skobelev, and O. Lakhin, "Complex adaptive logistics for the international space station," *Int. J. Des. Nat. Ecodynamics*, vol. 11, no. 3, pp. 459–472, Jul. 2016.
[28] B. Hettige, A. S. Karunananda, and G. Rzevski, "A multi-agent solution for managing complexity in english to sinhala machine translation," *Int. J. Des. Nat. Ecodynamics*, vol. 11, no. 2, pp. 88–96, Apr. 2016.
[29] J. Lagopoulos *et al.*, "Increased theta and alpha EEG activity during nondirective meditation," *J. Altern. Complement. Med.*, vol. 15, no. 11, pp. 1187–1192, 2009.
[30] Courtney Humphries, "Brain Mapping : MIT Technology Review."
[31] Nature, "Brain Mapping."
[32] F. Pereira, T. Mitchell, and M. Botvinick, "Machine learning classifiers and fMRI: a tutorial overview," *Neuroimage*, vol. 45, no. 1, pp. S199–S209, 2009.

Appendix A

Multi-Agent System

A.1 Introduction

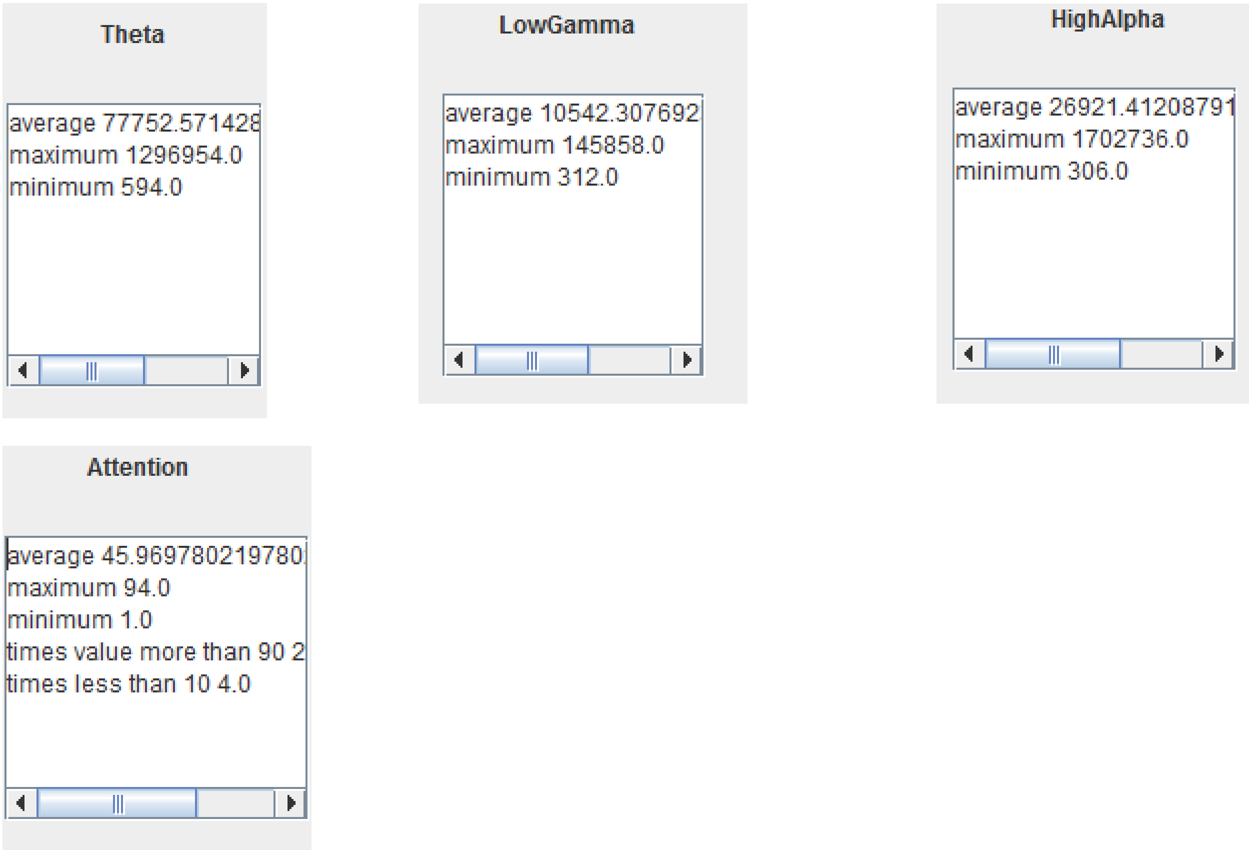
This section provides screenshots of the multi agent system of the meditation solution and the jade configuration.

A.2 Multi agent system – Meditation solution

Figure 10.1: Multi agent system results

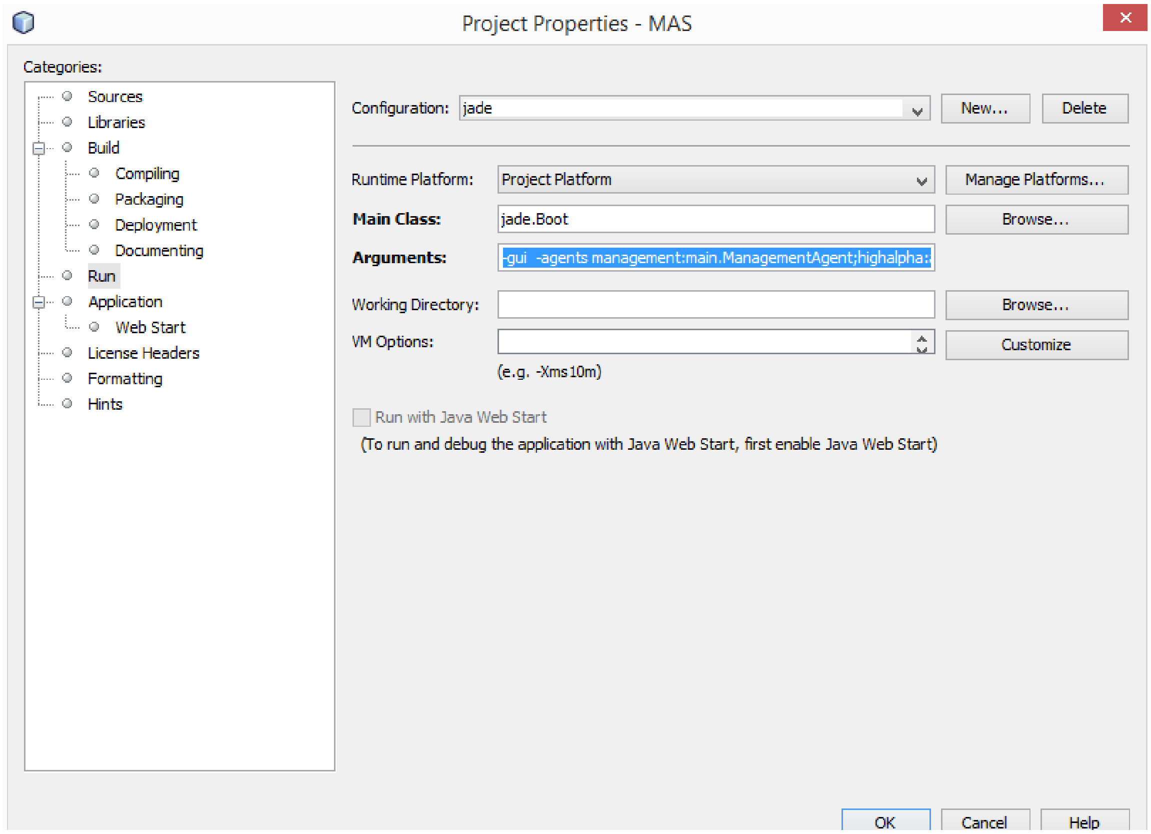
The activated agents are listed

Various agents have data which they get from the environment. (From sensors)



Setting up JADE

JADE (Java Agent Development Framework) is a software Framework fully implemented in the Java language. It simplifies the implementation of multi-agent systems through a middle-ware that complies with the FIPA specifications. JADE is free software and is distributed by Telecom Italia, the copyright holder, in open source under the terms and conditions of the LGPL (Lesser General Public License Version 2) license.



-gui -agents management:main.ManagementAgent;highalpha:agents.HighAlphaAgent;theta:agents.ThetaAgent;decision:main.DecisionAgent;attention:agents.Attentionagent;meditation:agents.Meditationagent;art:agents.ArtifactAgent;lowgamma:agents.LowGammaAgent

Appendix B

Source code of the system

B.1 Introduction

This section will include source code which was used to develop the proposed system.

B.2 Source code of the proposed system

Code snippet from AttentionBehavior

```
private void Report() {
        AID r = new AID("management@" + myAgent.getHap(), AID.ISGUID);

        ACLMessage aclMessage = new ACLMessage(ACLMessage.INFORM);
        aclMessage.addReceiver(r);
        try {
            List<String> esense = TextFileReader.readData("attention");
            String eeg = TextFileReader.readAverage(esense);
            aclMessage.setContent("aaaaa" + eeg + "-" + TextFileReader.readMax(esense) +
"-"+TextFileReader.readMin(esense)+"-" + TextFileReader.getValueList(esense)+
                "-"+                                    TextFileReader.moreThan90(esense)+"-"+
TextFileReader.lessThan10(esense));

        } catch (Exception e) {
            e.printStackTrace();
        }

        myAgent.send(aclMessage);
    }
```

Code snippet calculating average

```
public static HashMap<String, Integer> EegPowerAverage(List<JSONObject> obj)
throws JSONException {
```

```
        int deltasum = 0, thetaSum = 0, lowAlphaSum = 0, highAlphaSum = 0, lowBetaSum
= 0;
        int highGammaSum = 0, highBetaSum = 0, lowGammaSum = 0;
        int attentionSum = 0, meditationSum = 0;

        for (JSONObject obj1 : obj) {
            deltasum += (int) obj1.get("delta");
            thetaSum += (int) obj1.get("theta");
            lowAlphaSum += (int) obj1.get("lowAlpha");
            highAlphaSum += (int) obj1.get("highAlpha");
            lowBetaSum += (int) obj1.get("lowBeta");
            highGammaSum += (int) obj1.get("highGamma");
            highBetaSum += (int) obj1.get("highBeta");
            lowGammaSum += (int) obj1.get("lowGamma");
        }

        HashMap<String, Integer> hmap = new HashMap<>();
        hmap.put("deltaAvg", (deltasum / obj.size()));
        hmap.put("thetaAvg", (thetaSum / obj.size()));
        hmap.put("lowAlphaAvg", (lowAlphaSum / obj.size()));
        hmap.put("highAlphaAvg", (highAlphaSum / obj.size()));
        hmap.put("lowBetaAvg", (lowBetaSum / obj.size()));
        hmap.put("highGammaAvg", (highGammaSum / obj.size()));
        hmap.put("HighBetaAvg", (highBetaSum / obj.size()));
        hmap.put("LowGammaAvg", (lowGammaSum / obj.size()));

        return hmap;
    }
```

Retrieving minimum, maximum and average

```
public static String readAverage(List<String> obj) {


    int size = obj.size();

    double count = 0;

    for (int i = 0; i < size; i++) {

        count = count + Double.parseDouble(obj.get(i));

    }


    String avg = Double.toString(count / size);

    return avg;


}


public static String readMax(List<String> obj) {


    double max = 0;


    for (String obj1 : obj) {

        double val = Double.parseDouble(obj1);

        if (val > max) {

            max = val;

        }

    }
```

```
    return Double.toString(max);
}

public static String readMin(List<String> obj) {

    double min = Double.parseDouble(obj.get(0));
    for (String i : obj) {
        double temp = Double.parseDouble(i);
        min = min < temp ? min : temp;
    }

    return Double.toString(min);
}
```

Code from ANN Approach

loadTrianedANN

```
public void loadTrianedANN()
  {
     setTrainedNetwork(new BasicNetwork());
     eegDataTxtArea.append("Loading ANN\n");
     try
     {
        FileInputStream fin = new FileInputStream("meditationsol.dat");

        ObjectInputStream ois = new ObjectInputStream(fin);
        setTrainedNetwork((BasicNetwork) ois.readObject());
        ois.close();

        eegDataTxtArea.append("Loading ANN Completed\n");
     } catch (IOException | ClassNotFoundException e)
     {
        JOptionPane.showMessageDialog(null, e.getMessage());
     }
  }
```

startEEGMonitoring

```
            if (currentEEGReading.contains("eSense"))
            {
eegDataTxtArea.append(currentEEGReading.substring(currentEEGReading.indexOf("ee
gPower")) + "\n");
                eegDataTxtArea.setCaretPosition(eegDataTxtArea.getText().length());
            }
            else
            {
                eegDataTxtArea.append(currentEEGReading + "\n");
                eegDataTxtArea.setCaretPosition(eegDataTxtArea.getText().length());
            }



            double attention = 0;
            double meditation = 0;
            if (currentEEGReading.contains("eSense"))
            {
                double delta = 0, theta = 0, lowAlpha = 0, highAlpha = 0, lowBeta = 0,
highBeta = 0, lowGamma = 0, highGamma = 0, poorSignalLevel = 0;
                currentEEGReading = currentEEGReading.replace("\"", "");
                currentEEGReading = currentEEGReading.replace("{", "");
                currentEEGReading = currentEEGReading.replace("}", "");
                currentEEGReading = currentEEGReading.replace("eSense:", "");
                currentEEGReading = currentEEGReading.replace("eegPower:", "");
```

```
String[] eegValues = currentEEGReading.split(",");
for (String eegVal : eegValues)
{
    String[] eegReadings = eegVal.split(":");
    double tempReading = Double.parseDouble(eegReadings[1]);
    switch (eegReadings[0])
    {
        case "attention":
            attention = tempReading;
            break;
        case "meditation":
            meditation = tempReading;
            break;
        case "delta":
            delta = tempReading;
            break;
        case "theta":
            theta = tempReading;
            break;
        case "lowAlpha":
            lowAlpha = tempReading;
            break;
        case "highAlpha":
            highAlpha = tempReading;
```

```
            break;
        case "lowBeta":
            lowBeta = tempReading;
            break;
        case "highBeta":
            highBeta = tempReading;
            break;
        case "lowGamma":
            lowGamma = tempReading;
            break;
        case "highGamma":
            highGamma = tempReading;
            break;
        case "poorSignalLevel":
            poorSignalLevel = tempReading;
            break;
        default:
            break;
    }
}

if (poorSignalLevel < ACCEPTED_SIGNAL_LEVEL)
{
    INPUT[0] = delta;
    INPUT[1] = theta;
```

```
        INPUT[2] = lowAlpha;
        INPUT[3] = highAlpha;
        INPUT[4] = lowBeta;
        INPUT[5] = highBeta;
        INPUT[6] = lowGamma;
        INPUT[7] = highGamma;

        fullGamma += highGamma;
        iterations = iterations + 1;
    }

}
```

MeditationNEuroskySocketClient

```
/**
 *
 * @author Achala
 */
public class MeditationNEuroskySocketClient {

    /**
     * Logger for this class
     */
    private static final Logger logger =
Logger.getLogger(MeditationNEuroskySocketClient.class);
    public static final String DEFAULT_HOST = "127.0.0.1";
    public static final int DEFAULT_PORT = 13854;

    private static MeditationNEuroskySocketClient INSTANCE = null;
    private String host;
    private int port;
    private boolean connected;
    SocketChannel channel;
    Scanner in;

    private MeditationNEuroskySocketClient() {

        this.host = DEFAULT_HOST;
```

```java
    this.port = DEFAULT_PORT;
    this.connected = false;

}

public MeditationNEuroskySocketClient(String host, int port) {

    this.host = host;
    this.port = port;
    this.connected = false;

}

public static MeditationNEuroskySocketClient getInstance() {
    if (INSTANCE == null) {
        INSTANCE = new MeditationNEuroskySocketClient();
    }

    return INSTANCE;
}

public String getHost() {
    return host;
}
```

```
    public void setHost(String host) {
        this.host = host;
    }

    public int getPort() {
        return port;
    }

    public void setPort(int port) {
        this.port = port;
    }

    public boolean isConnected() {
        return this.connected;
    }

    public void connect(boolean enableRawData) throws IOException {

        if (!this.connected) {

            this.channel = SocketChannel.open(new InetSocketAddress(this.host, this.port));

            CharsetEncoder enc = Charset.forName("US-ASCII").newEncoder();

            String jsonCommand = "{\"timestamp\":true,\"enableRawOutput\": false,
\"format\": \"Json\"}\n";
```

```
            this.channel.write(enc.encode(CharBuffer.wrap(jsonCommand)));

            this.in = new Scanner(channel);
            this.connected = true;

           System.out.println("Meditation solution is ocnnected with the device");
        } else {

            System.out.println("Already connected");
        }

    }

    public void startRecording() throws IOException {
        if (this.connected) {
            CharsetEncoder enc = Charset.forName("US-ASCII").newEncoder();

            String jsonCommand =
"{\"startRecording\":{\"rawEeg\":true,\"poorSignalLevel\":true,\"eSense\":true,\"eegPow
er\":true,\"blinkStrength\":true},\"applicationName\":\"ExampleApp\"}\n";
            this.channel.write(enc.encode(CharBuffer.wrap(jsonCommand)));

            JOptionPane.showMessageDialog(null, "Start Recording");

        } else {
            logger.debug("startRecording meditation session () - Not connected...");
```

```
    }

}

public void stopRecording() throws IOException {
    if (this.connected) {
        CharsetEncoder enc = Charset.forName("US-ASCII").newEncoder();

        String jsonCommand = "{\"stopRecording\":\"ExampleApp\"}\n";
        this.channel.write(enc.encode(CharBuffer.wrap(jsonCommand)));

        JOptionPane.showMessageDialog(null, "Stop Recording");

    } else {
        logger.debug("stopRecording meditation session() - Not connected...");
    }
}



public boolean isDataAvailable() {
    if (this.connected) {
        return this.in.hasNextLine();
    } else {
        return false;
```

```
        }
    }

    public String getData() {
        return this.in.nextLine();
    }

    public void close() throws IOException {

        if (this.connected) {

            this.in.close();
            this.channel.close();
            this.connected = false;
        }
    }

}
```

```
    /**
     * Logger for this class
     */
    private static final Logger logger =
Logger.getLogger(MeditationNEuroskySocketClient.class);
    public static final String DEFAULT_HOST = "127.0.0.1";
    public static final int DEFAULT_PORT = 13854;

    private static MeditationNEuroskySocketClient INSTANCE = null;
    private String host;
    private int port;
    private boolean connected;
    SocketChannel channel;
    Scanner in;

    private MeditationNEuroskySocketClient() {

        this.host = DEFAULT_HOST;
        this.port = DEFAULT_PORT;
        this.connected = false;

    }

    public MeditationNEuroskySocketClient(String host, int port) {

        this.host = host;
```

```
    this.port = port;
    this.connected = false;

}

public static MeditationNEuroskySocketClient getInstance() {
    if (INSTANCE == null) {
        INSTANCE = new MeditationNEuroskySocketClient();
    }

    return INSTANCE;
}

public String getHost() {
    return host;
}

public void setHost(String host) {
    this.host = host;
}

public int getPort() {
    return port;
}
```

```
    public void setPort(int port) {
        this.port = port;
    }

    public boolean isConnected() {
        return this.connected;
    }

    public void connect(boolean enableRawData) throws IOException {

        if (!this.connected) {

            this.channel = SocketChannel.open(new InetSocketAddress(this.host, this.port));

            CharsetEncoder enc = Charset.forName("US-ASCII").newEncoder();

            String jsonCommand = "{\"timestamp\":true,\"enableRawOutput\": false,
\"format\": \"Json\"}\n";
            this.channel.write(enc.encode(CharBuffer.wrap(jsonCommand)));

            this.in = new Scanner(channel);
            this.connected = true;

           System.out.println("Meditation solution is ocnnected with the device");
        } else {
```

```
            System.out.println("Already connected");
        }

    }

    public void startRecording() throws IOException {
        if (this.connected) {
            CharsetEncoder enc = Charset.forName("US-ASCII").newEncoder();

            String jsonCommand =
"{\"startRecording\":{\"rawEeg\":true,\"poorSignalLevel\":true,\"eSense\":true,\"eegPow
er\":true,\"blinkStrength\":true},\"applicationName\":\"ExampleApp\"}\n";
            this.channel.write(enc.encode(CharBuffer.wrap(jsonCommand)));

            JOptionPane.showMessageDialog(null, "Start Recording");

        } else {
            logger.debug("startRecording meditation session () - Not connected...");
        }

    }

    public void stopRecording() throws IOException {
        if (this.connected) {
            CharsetEncoder enc = Charset.forName("US-ASCII").newEncoder();
```

```
        String jsonCommand = "{\"stopRecording\":\"ExampleApp\"}\n";
        this.channel.write(enc.encode(CharBuffer.wrap(jsonCommand)));

        JOptionPane.showMessageDialog(null, "Stop Recording");

    } else {
        logger.debug("stopRecording meditation session() - Not connected...");
    }
}



public boolean isDataAvailable() {
    if (this.connected) {
        return this.in.hasNextLine();
    } else {
        return false;
    }
}

public String getData() {
    return this.in.nextLine();
}

public void close() throws IOException {
```

```
        if (this.connected) {

            this.in.close();
            this.channel.close();
            this.connected = false;
        }
    }

}
```