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A survey on using swarm intelligence algorithms on the data collected from IoT- capturing EEG signals.

[1]Kavita Goura [2] Dr. Kiran Kumari Patil
(1 VTU Scholar ,Asst prof. CBIT) (2 VTU Research Guide)

Abstract: Few years ago it was a fantasy or a science fiction, to control the working of real world devices with thoughts. But now it has become a reality, thanks to Brain Computer Interface (BCI). BCI based on scalp electroencephalogram (EEG) signals is a non-invasive technique that is the major and economical mode of data acquisition from brain. Other forms of non-invasive brain data acquisition are Magneto encephalography (MEG), Functional magnetic resonance imaging (fMRI), Functional near-infrared spectroscopy (fNRIS). BCI can be applied to plethora of varied applications from both medical and non-medical fields. In medical field, it can be applied in prevention, detection and diagnosis, rehabilitation and restoration. In non medical field it can be applied in neuroergonomics, smart environment, gaming applications etc. BCI is a direct communication pathway between a human or animal brain and an external device. With BCI, a person with all kinds of disabilities but having a functioning brain can do anything to everything. As brain is the most complex organ of the human body, the data acquired from the brain will also exhibit complex features. To analyze these features we have to use efficient and competent algorithms. Algorithms working on the concept of collective intelligence are found to perform better in the anlaysis of EEG signals. There are numerous Swarm intelligence (SI) algorithms like Ant colony optimisation(ACO), Particle swarm optimisation(PSO), Bee colony optimization (BCO) that harness the collective intelligence. Here we endeavour to present the survey on the usage of swarm intelligence algorithms on the EEG data collected from the IoT device.

Keywords: Neuroergonomics, Electroencephalogram (EEG), Magneto encephalography (MEG), Functional magnetic resonance imaging (fMRI), Functional near-infrared spectroscopy (fNRIS), Ant colony optimization (ACO), Particle swarm optimization(PSO), Bee colony optimization (BCO), Swarm Intelligence (SI).

1. INTRODUCTION

Today, the real world is filled with innumerable IoTs which we can see all around us. With time, the increase in the number of IoT devices would be very high. IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and has the ability to transfer data over the network. Though individually IoT is a trending technology but along with it comes many challenges. The data collected from the various IoT devices are varied in nature depending upon the type of the device, the parameters or the features considered, noise in the environment while capturing the data , type of the signals considered like digital or analog etc. These things make the analysis of IoT data a complex task. The EEG data collected from the brain also exhibits these features. Researchers have found that to analyze complex data, algorithms working on the concept of collective intelligence perform better. This collective intelligence can be captured by harnessing the collective behavior exhibited by some of the natural systems like colony of ants, flock of birds, shoal of fish, swarm of bees etc. Intelligence can emerge from social interaction. Swarm intelligence is a relatively new subfield of artificial intelligence which studies the emergent collective

intelligence of groups of simple agents, to achieve a global goal. Popular swarm intelligence algorithms are Ant Colony Optimization(ACO), Particle Swarm Optimization(PSO), Bee Colony Optimization(BCO), Artificial Bee colony (ABC), Butterfly optimization algorithm (BOA) , Grey wolf optimization (GWO) etc.

With the advancements in technology, Internet of Things (IoT) aims to connect everything for information sharing and intelligent decision-making. Brain Computer Interface (BCI) is a IoT based mechanism to have communication between users and systems to give the commands to external devices without any muscular movement [1]. These systems can be used by persons suffering with neurological disorder as assisted living or by normal persons for their ease of work, luxury, in gaming etc. It is used to restore the motor functionality of the people disabled by neuromuscular disorders such as amyotrophic lateral sclerosis, cerebral palsy, stroke, or spinal cord injury. BCI is a direct communication pathway between a human or animal brain and an external device. With BCI, a differently abled person suffering with many disorders can do many things which otherwise are difficult to do for him. With BCI, no need to have the movement of muscle at all but things can be done just by thoughts.

2.BCI applications:

Various clinical and biological applications of BCI are: 1)Artificial Sensory channel 2)Artificial Hearing: allow a mute person to have their thoughts displayed and spoken by a computer.3)Artificial Vision : Transmit visual images to the mind of a blind person , allowing them to see 4)Artificial Motor Channel: By thoughts the person can give commands to external devices without any muscular movement. 5) BCI can be used to cure Neural disorders like Parkinsons disease , Alzheimer's, Schizophrenia, autism spectrum disorder , depression, anxiety etc. 6) Seizure prediction and control 8) Allow paralyzed people to control prosthetic limbs with their mind . Techniques like EEG, MEG and neurochips have come into discussions since the BCI application have started developing.

BCI Limitations:

Some of the Disadvantages with BCI are:1) very costly to setup BCI environment.2) Ethical implications of BCI will arise in future. 3) With invasive BCI , formation of scar issue 4) There is a need of extensive training before user can use techniques like EEG 5) Research is still in beginning stages 6) Electrodes outside of the skull can detect very few signals from the brain

Working of BCI:

How the brain turns thoughts into action: The brain is full of neurons which are connected to each other by axons and dendrites. Neurons are at work whenever one thinks or does something. Neurons connect with each other to form a pathway for nerve impulses to travel from neuron to neuron to produce thought , hearing , speech or movement .All the neurons are electrically excitable and communicate with each other via electrical events called 'action potentials'. When a person thinks and does different tasks, neurons of various areas of the brain fire and results in some electrical activity. The electrical signals generated by thought and action travel at a rate of about 250 feet per second or faster. Whenever large groups of these neurons are firing up in a synchronized pattern, the generated electricity radiates to the scalp surface which can be captured by noninvasive BCI.

Human brain actually has 5 brain waves. The brain signals can be transferred from the time domain into frequency domain, with discrete Fourier transform (DFT). Brain signals can be divided into different frequency bands, delta waves (0.5-3Hz), theta waves (4-7Hz), alpha /mu waves (8-13Hz), beta waves (14-30Hz) and gamma waves (>30Hz). Each one has a distinct electrical pattern which operates when a person moves, thinks , behaves and processes.

Brain activity is collected using EEG headset (signal acquisition phase) and then use conversion algorithms and convert the analog signals to digital signals. These digital signal are then passed through preprocessing steps, as the raw signals will be noisy and complex to process. After pre-processing the signals, features will be extracted and used to train a classifier. The system will have

interface and API for associating the trained mental commands to IoT device inputs.

There are various EEG headsets for measuring brain activity that measures alpha, beta, gamma, delta and theta waves. Some are used in hospitals for diagnosing neurological disorders. There are systems that use these EEG headsets and implement BCI but they lack a easy training interface and are hard to integrate with other devices.

3. Usual Experimental setup for EEG signal acquisition:

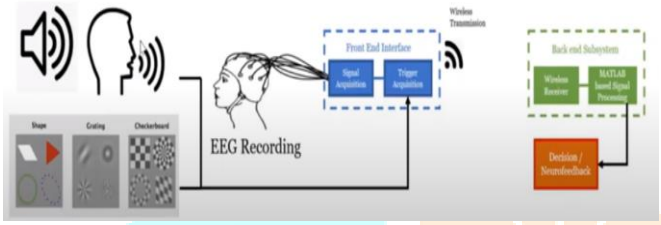
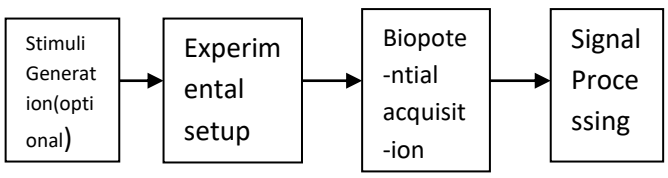


Fig 1.1 Basic experimental setup for EEG signal acquisition

The basic experimental setup for capturing EEG signals is shown in figure 1.1.The electrical activity will happen on giving stimulus to brain. Stimuli can be visual or auditory. In fig 1.1, the stimuli generation unit at the left is shown with two types of auditory stimuli. One is the sound produced by machine and other is the human speech. In figure the visual stimulus is shown .Stimuli is specifically designed beat audio or video , in order to get required response. In the left part of the figure , two types of auditory stimuli are shown. One is just sound produced by some machine and the other one is human speech. In the figure is also shown the visual stimulus. Based on the presented stimuli , brain responds and some form of potentials gets elicited, which is then captured by IoT device-EEG headset.

Flow of non-invasive BCI experimentation for clinical interpretation will go through the following phases.



Stimuli Generation : The Auditory stimulus can be characterized by Event , frequency, rate, timber (it is different in different instruments for the same code , like guitar and keyboard), customized. The visual stimulus can also be characterized by event, image, rate, intensity. One more type of potential is somatosensory potential where auditory and visual both potentials are localized at ear and eyes, somatosensory is global, related to sensations.

Experimental setup: All these potentials can be acquired by using electrodes which are of different kinds like dry electrode, wet electrode or flat shaped electrode, comb shaped electrode etc. If we directly read the values from the electrode, it is like monopolar value but if we refer value to some other electrode, it is called as reference montage (is a way to acquire different potential based on electrode). Referencing will help in eliminating the common noise. If any electrode is not connected properly to scalp, the reading may be incorrect. When performing any experimentation on the subject involving human, proper consent form should be taken from the subject/parents/guardian. Wet electrodes come with gel, dry electrodes are of two types ,flat and comb type.

Biopotential acquisition: Biopotentials are electrical signals (voltages) that are generated by physiological processes occurring within the body. It can be done using patch electrodes, wet electrodes and dry electrodes.

Signal processing: Preprocessing algorithms are available to remove the artifacts. Artifacts are of two types, one is generated by the subject itself like blinking of an eye etc. Other one is generated by the environment like electromagnetic interference. Basic range for EEG processing is 0.5 Hz to 30 Hz. In software also use of notch filter is done to filter out the signals which are not required. Option of notch button will also be there in the hardware. Due to the variabilities of EEG potentials , a particular stimulus or set of stimulus is given multiple times to record the event and then averaged . The number of times this is repeated, say 100 times, to get 100 different time intervals from the obtained run of EEG is the epoch generation .

3.1 Potential Users of EEG headsets: Initially it was used in the fields of psychology, medicine, neuroscience to help people in overcoming neurological disorders and assisted living to enhance the lifestyle of the people having disorders. Now-a-days it is also used by people in gaming, human-computer-interaction, neuromarketing, simulations and many other areas.

Various EEG hardware products available in the market are Neuroelectrics Enobio8, Neuroelectrics 20, Neuroelectrics32, Neuroelectrics 8 with headband, ABM B-Alert X10EEG, ABM B-Alert X24EEG, Emotiv epoch +EEG, Brain Products actiChamp.

3.2 Limitations of EEG: EEG varies in terms of various manufacturers, its technical set-up, number of channels, cost, type of stimuli (visual, auditory, haptic). It has Low spatial resolution on the scalp. EEG poorly measures neural activity that occurs below the upper layers of the brain (the cortex). Since measurements are taken at the scalp, the received signal is, essentially, the sum of the electric field (in the direction perpendicular to the scalp) that is produced by a large population of neurons. One of the big disadvantages of EEG is that it's hard to figure out where in the brain the electrical activity is coming from. It takes longer time to do the experimental setup with the subject as it requires the placement of number of electrodes on the scalp precisely. It requires use of various gels, saline solutions or paste to maintain good conductivity. Signal to noise ratio of EEG signals are poor and therefore sophisticated methods are to be used for data analysis.

3.3. Advantages of EEG: Hardware costs are lower than other techniques available to measure brain activity like event related optical signal (EROS), positron emission tomography (PET), nuclear magnetic resonance spectroscopy (NIRS), Magneto encephalography (MEG), functional magnetic resonance imaging (fMRI). People can avoid going to the busy hospital. EEG sensors are mobile and can be used in number of places compared to other techniques which are immobile. EEG's are far less bulkier than other techniques of brain activity acquisition. People don't have any inhibitions in using EEG as it is a noninvasive technique, and with no side effects. It has high temporal resolution in the order of milliseconds. It is usually recorded at the sampling rates of 250Hz to 2000Hz which can also be increased to above 20,000 Hz if needed. It is tolerant to subject movement and can remove the artifacts caused by movements. EEG doesnot cause any claustrophobia as it can be used anywhere. EEG doesnot expose subject to high intensity magnetic fields which may trigger nausea , dizziness , metallic taste in mouth , though it is temporary. It can be used with the persons who are immobile or with the persons who cannot make motor response. EEG acts as a powerful tool to record the changes in the brain during different phases of life. Compared to other techniques, in EEG there is the better understanding of the signals measured. With EEG one can diagnose or treat brain tumor, brain damage from head injury, brain dysfunction due to various causes, inflammation of the brain called as encephalitis, stroke, sleep disorders, epilepsy, brain death. EEG can diagnose the two most common types of dementia that is AD (Alzheimer's dementia) and VaD (vascular dementia) because both of these types are cortical and also reflect hidden brain abnormalities.

4. Swarm Intelligence algorithms

The synonym for swarm is army, bevy, blowout, concourse, crowd, flock, herd, horde, jam, mass, mob, pack, push, school, shoal, throng, troop. The behavior of a single ant, bee, termite and wasp often is too simple, but their collective and social behavior is of paramount significance. The collective and social behavior of living creatures motivated researchers to undertake the study of swarm intelligence. Historically, the phrase Swarm Intelligence (SI) was coined by Beny and Wang. SI systems are typically made up of a population of simple agents (an entity capable of performing/executing certain operations) interacting locally with one another and with their environment. Although there is normally no centralized control structure dictating how individual agents should behave, local interactions between such agents often lead to the emergence of global behavior. Many biological creatures such as fish schools, bird flocks, honeybees, ants, clearly display structural order, with the behavior

of the organisms so integrated that even though they may change shape and direction, they appear to move as a single coherent entity.

The main properties of collective behavior are illustrated below:

- Homogeneity: Every bird in flock has the same behavioral model. The flock moves without a leader, even though temporary leaders seem to appear.
- Locality: Its nearest flock-mates only influence the motion of each bird.
- Vision: Vision is considered to be the most important senses for flock organization.
- Collision avoidance: Avoid colliding with nearby flock mates.
- Velocity matching: Attempt to match velocity with nearby flock mates.
- Flock centering: Attempt to stay close to nearby flock mates.

Datamining with swarm intelligence is a powerful new technology, which aims at the extraction of hidden predictive information from large databases. They help in predicting new future trends and behaviors, allowing businesses to make proactive, knowledge driven decisions. The process of knowledge discovery from databases necessitates fast and automatic clustering of very large datasets with several attributes of different types. This challenge can be overcome by using hybridization techniques for clustering.

Benefits of Swarm Systems

- **Adaptable** - It is possible to build a clockwork system that can adjust to predetermined stimuli. But constructing a system that can adjust to new stimuli, or to change beyond a narrow range, requires a swarm - a hive mind. Only a whole containing many parts can allow a whole to persist while the parts die off or change to fit the new stimuli.
- **Evolvable** - Systems that can shift the locus of adaptation over time from one part of the system to another (from the body to the genes or from one individual to a population) must be swarm based. Noncollective systems cannot evolve (in the biological sense).
- **Resilient** -Because collective systems are built upon multitudes in parallel, there is redundancy. Individuals don't count. Small failures are lost in the hubbub. Big failures are held in check by becoming merely small failures at the next highest level on a hierarchy.
- **Boundless** - Plain old linear systems can sport positive feedback loops -- the screeching disordered noise of PA microphone, for example. But in swarm systems, positive feedback can lead to increasing order. By incrementally extending new structure beyond the bounds of its initial state, a swarm can build its own scaffolding to build further structure. Spontaneous order helps create more order. Life begets more life, wealth creates more wealth, information breeds more information, all bursting the original cradle. And with no bounds in sight.
- **Novelty** - Swarm systems generate novelty for three reasons: (1) they are "sensitive to initial conditions" - scientific shorthand for saying that the size of the effect is not proportional to the size of the cause - so they can make a surprising mountain out of a molehill. (2) They hide countless novel possibilities in the exponential combinations of many interlinked individuals. (3) They don't reckon individuals, so therefore individual variation and imperfection can be allowed. In swarm systems with heritability, individual variation and imperfection will lead to perpetual novelty, or what we call evolution.

A swarm can be viewed as a group of agents cooperating to achieve some purposeful behavior and achieve some goal. This collective intelligence seems to emerge from what are often called large groups. According to Milonas, five basic principles define SI paradigm. First is the **proximity principle:** the swarm should be able to carry out simple space and time computations. Second is the **quality principle:** the swarm should be able to respond to quality factors in the environment. Third is the principle **diverse response:** the swarm should not commit its activities along excessively narrow channels. Fourth is the **principle of stability:** the swarm should not change its mode of behavior every time the environment changes. Fifth is the principle of **adaptability:** The swarm must be able to change behavior mode when it is worth the computational price.

Three widely used and popular SI algorithms are ant colony optimization and Particle Swarm Optimization, Bee Colony optimization. There are many other swarm intelligence algorithms inspired by insects and animals. Some of them are fish algorithm, monkey search, firefly algorithm, bat algorithm, Krill herd algorithm. Based on the requirement any of swarm intelligence algorithm or the hybridized SI algorithms can be used. The advantages and disadvantages of these algorithms are as discussed below.

Advantages of ACO

1) Inherent parallelism
2) Positive feedback accounts for rapid discovery of good solutions
3) Efficient for traveling salesman problems and similar problems

Disadvantages of ACO

1) Theoretical analysis is difficult.
2) Sequences of random decisions (not independent).
3) Probability distribution changes by iteration.
4) Research is experimental rather than theoretical.
5) Time convergence is uncertain but guaranteed.

Advantages of PSO:

1) PSO is based on Intelligence. It can be applied to both scientific research and engineering use.
2) Only the most optimist particle can transmit information onto the other particles and speed of researching is very fast.
3) Calculation in PSO is simple compared with other calculations and can be completed easily.

Disadvantages of PSO:

1) PSO is a clustering algorithm for dynamic optimization and constraint handling. PSO is mostly used to solve unconstrained single objective optimization.
2) Convergence is fast because of which PSO may not always be good in finding optimal solution or best solution and also in real world there may be multiple best solutions.

Advantages of BCO

1) Division of labour is there.
2) It avoids locally optimal solutions, it searches for the best solution based on the solutions obtained by entire bee colony.
3) It is adaptive to changes in the environment.

Disadvantages of BCO:

1) One of the youngest of the swarm intelligent algorithms.
2) Not been widely used in solving real world problems.
3) At present only few theoretical results support BCO concepts.

5. Role of Swarm intelligence algorithms with EEG signals:

Swarm intelligence algorithms are robust, scalable, adaptable, and are used to get optimized solutions. They are competent enough to give solutions for complex problems. EEG signals are complex in nature with lot of features. Here SI algorithms can be used to achieve good performance with various problem areas identified with EEG signals.

[13] Even though EEG is designed to capture cerebral signals, it also records signals that are not of cerebral origin and generally called artefacts. The existence of artefacts makes interpretation of EEG signals difficult by doctors and causes critical errors and inaccuracies. Hence elimination of artefacts from contaminated EEG signals is essential for better diagnosis. In this work, author has applied Improved Artificial Immune System (IAIS), Artificial Immune System (AIS) and Particle Swarm Optimization (PSO) to remove ECG artefacts from the EEG signals individually and shown the comparison of performances with each other. It was observed that EEG signal is contaminated by ECG artefacts predominantly in short-necked persons, and causes difficulty in the diagnosis of EEG especially for persons with epilepsy. In this work the performances of various swarm intelligence incorporated adaptive neuro-fuzzy inference system (ANFIS)-based techniques are compared in eliminating ECG artefacts from corrupted EEG signal.

One other major problem with EEG signals are the parameter selection. As we know, if the numbers

of parameters are reduced without losing on the relevant information, then one can achieve optimization with classification. [14] The author proposed SVM self-training classification algorithm based on parameter optimization that introduces PSO algorithm to select the optimal parameter pair (C,g) for SVM classifier. This effectively solves the problem that small training samples cannot reasonably determine parameter through cross-validation.

It is observed that SI algorithms give robust solutions to the complex problems, though at times, it may take more time. [15]SI algorithms were used in dimensionality reduction, in classification and clustering, in automated machine learning. SI methods have proved their potential in many of the real world applications like social community network analysis , scheduling and routing problems of real world, bioinformatics, resource allocation. SI were also used in data related applications like windfarm decision systems, autonomous distributed denial of service (DDoS) attack detection system , anomaly intrusion detection, image analysis, facial recognition, Medical Image Segmentation , natural language processing etc. Recently SI is being used with IoT as well due to SI's population based feature to make the system flexible and scalable. Due to the presence of IoT devices everywhere all around the world, it is estimated that by the end of 2020 almost 25 billion internet of things would be connected to internet which may produce the data in zettabytes. Therefore distributed and decentralized control, self organization and optimization is highly desirable which are the features of Swarm Intelligence algorithms.

[16] This work presents the use of swarm intelligence algorithms as a reliable method for the optimization of electroencephalogram signals for the improvement of the performance of the brain interfaces based on stable states visual events. The preprocessing of brain signals for the extraction of characteristics and the detection of events is of paramount importance for the improvement of brain interfaces. Author has proposed ant colony optimization algorithm for improvement in obtaining the key features of the signals and the detection of events based on visual stimuli. Author has used Independent Component Analysis method for the removal of nonrelevant and detection of relevant data from the brain's electrical signals. This lead to collection of information in response to a stimulus and separated the signals that were generated independently in certain zones of the brain.

One of the major challenges faced by BCI systems is obtaining the reliable classification accuracy of motor imagery (MI) mental tasks. [17] proposes a novel common spatial pattern \Attractor metagene-Bat optimization algorithm-support vector machine CSP\AM-BA-SVM for multi-class MI-BCI system based on hybrid bio-inspired algorithms for feature selection and classifier optimization. It attempts to simultaneously and systematically adapt the many parameters involved. As the emission time is not same for all subjects, it is beneficial to allow optimum time interval. CSP features are computed for each of the nine frequency bands that are extracted from the examined EEG interval (segment). Subsequently, the CSP of the nine bands are concatenated to form a set of 72 features. The hybrid AM (Attractor metagene) algorithm is applied to the CSP feature set where it provides a ranked list of features according to their significance. The author talks about the disadvantage of more time taken by BA (Bat optimization) algorithm.

Due to the many advantages of BCI based on EEG it is being used in many applications . [18] addresses the challenges faced by these systems in movement prediction intention, computational complexity and the problem of over fitting. Authors have proposed Particle Swarm Optimization (PSO)-based neural network (NN) to overcome the above discussed issues.

Usage of SI algorithms with EEG is new and recent approach. As the EEG data is complex , SI algorithms may prove their potential with EEG data like other domains . SI algorithms are good at achieving optimization, robustness, scalability, adaptability and thus increase in the performance measure. We propose that many of the problems and the tasks associated with EEG signals can be explored and solved in an efficient manner with various swarm intelligence algorithms.

6. Conclusion:

The review presents the overview of EEG, various hardware devices available in the market to capture EEG signals, basic experimental setup for EEG signal acquisition and the various phases in the EEG signal processing. The advantages of EEG signals compared to other brain signal acquisition systems were discussed. The kind of diseases that can be detected and predicted by EEG was highlighted. The major drawbacks with EEG signals were given. The fundamentals of swarm intelligence algorithms, various types of SI algorithms, and their application in varied domains were discussed. In sights were drawn on the role of SI algorithms with EEG signals which is a relatively recent trend. This area gives researchers lot of scope to address the unexplored problem areas and find the solutions. We can conclude that, the EEG acquisition devices are comparatively low cost, and very useful. This device allows for overall reduced system cost, mobility, subject preparation time and, allows for the subject to be prepared by a non-expert supervisor.
As a future work, we plan to implement the optimization in the classification of EEG signals by using various swarm intelligence algorithms and show the performance comparisons.

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