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CONTINUOUS MONITORING SYSTEM FOR ANALYSING VEGETATIVE STATE AND COMATOSE PATIENTS WITH THE HELP OF SOMATOSENSORY EVOKED POTENTIAL AND DEEP LEARNING

Engineering

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ABSTRACT

As of today's age, growing of technologies in every field has been creating an astonishing revolution. In the mead of medical also, technologies like robotics and AI has been creating a whole new transformation in the field of monitoring, surgeries or in an assistance. Likewise, Brain computer interface is also one of the fast growing technologies that has helped the researchers and medical practitioners to work with the electroencephalography (EEG) activity in the context of degree of consciousness of patients by means of Different types of EEG signal detecting tools. Various methods have been proposed so far for the prognosis of between a (VS /UWS) and MCS patients or a comatose patients and its level of recovery. Diagnosis for the possibility of recoveries has been mostly emphasized in the recent research work for the comatose, LIS or other vegetative state. So by implementing a continuous monitoring system for the unresponsive wakefulness syndrome(UWS) with the help of deep learning we can accelerate the pre diagnosis of the patients. In some of the cases, patients who are in Vegetative state sometimes may end up with comatose or LIS. To check continuously or monitoring the condition of the patient, we can set up a system which can track the continuous changes of the signal of the brain or the sudden recovery of the patient in aspect of continuous stimuli. So with the help of somatosensory evoked potential(SSEP) and deep learning we will set up a continuous monitoring system for the patient with the help of non-invasive(NIV) methodology.

KEYWORDS

Electroencephalography (EEG) – vegetative state /unresponsive wakefulness syndrome(VS/UWS) --Coma—LIS (locked in syndrome) – MLFFNN (Multilayer feedforward neural network) --Somatosensory evoked potential (SSEP)--NIV (non-invasive) – Artificial intelligence (AI) -- Grey matter—ANN (artificial neural network)

INTRODUCTION

EEG as a diagnostic tool that can be used as a prognostic value of its patterns when combined with the etiology often remarks as efficient and well acknowledged **[1].** This EEG Signals are assessed by BCI technology. BCI (Brain computer interface) is a fast growing emergent technology in which researchers aim to build a communication channel between the human and the computer **[2].** Brain computer interface can also be known as human computer interface where it depicts the relation between a human-computer relation. Now a day, with the rapid change of technologies and with the help artificial intelligence, people are speculating different sorts of technology whether it is related to commercial uses or any research oriented purposes. But most of the cases BCI technology are used for the research in medical field oriented scope. BCI mainly emphasize on the brain and nervous system and their interconnection to other function of the body. It mainly works with the signal in the form of electro genic i.e. electrical impulses. It can have its own limitation despite of having many advantages, like the low signal strength, data transfer or high error rate. Now a days BCI has become a important mode of communication between a human who hardly has any muscletory movement or can't communicate through normal mode of communication. In most general cases, this technology can be represented by its three types: -

I)invasive acquisition type BCI system: -where the electrode is directly implanted in to the brain by critical surgery. It is said be accurate as it is directly being in contact with the grey matter. But due to its intensive mode of implementation. So it is not so in practice as most of the patients or their guardians deny to give their consent due to the aftereffect of the invasive electrodes which sometimes live a scar or damage a neuron.

II) partial invasive acquisition type BCI system: - This type of method can be used where the electrode is inserted in the top of the skull but the strength of the signal is weaker than the invasive one. So it is not commonly used in practices.

III) Non-invasive acquisition type BCI system: - This are the safest and low cost effective system of all. This can be applied over the scalp they are not injected or implanted like others they are only placed on different position which gives produces signal and can be obtained by the associated application on any Pc or mobile.

EEG signals obtained from the BCI can be further classified into four different waves. Which are in the following: -

1) Delta wave: - This type of signal comes with the frequency range of (0.5-3.5) Hz. **[2]** this can be found in deep sleep or babies. But it can also be the signal found in comatose patients or the first stage of locked in syndrome.

2) Theta wave: - This type of signal ranges from (3.5-7.5) Hz. This is linked with the inefficient and daydreaming situation of the brain. It can distinguish between the stage of wakefulness or sleep. In high range it can be said to be abnormal for the human beings.

3) Alpha Wave: - This type of wave can be in the range of (7.5-12) Hz which was first discovered by Hans Berger **[3].** This signal often cited in high amplitude in dominant side and is found or generated when one is relaxing or closing the eye.

4) Beta wave: - This type often ranges in the (12-30) Hz.it is seen in both the sides with equal distribution but it is produced at the time of concentrating or suppressing a movement. It can be divided in beta1 and beta2.

5) Gamma Wave: -This type of signal can be in the range of 31 Hz and up. It depicts the consciousness.

This signals are later analysed and are fed to an ANN to distinguish between the signals and predicts the scale of recovery. This can be found in the raw data from the samples i.e. from the respective volunteers which may be a patient or a normal person. But each signals are different from one another and can be obtained from different electrode positions. Comatose patient or those which stays in vegetative stays for longer they can depict or produce delta waves at first stage of recovery of consciousness in respect to stimuli. But normally in locked in syndrome either delta or theta wave can be visible. In earlier days, medical practitioner or doctors used CRS-R (coma recovery scale- revised) to check the degree of consciousness. It was a long process to prevent the time consuming BCI came into picture and with the help ANN. It gets more efficient and less time consuming of the diagnosis process. It can depict the level of recovery from the vegetative state and distinguish between the patients in case of faster recovery between the UWS and MCS (minimally conscious state). Whereas in this paper we will be trying to build a system which can monitor even the slightest signal produced by the VS patient who is in that state for a longer time in any interval of time with the help of SSEP and ANN.

Multilayer feedforward Neural network and its learning algorithm

Deep learning is the new method of training multiple neural network **[4].** Earlier we use to check manual or in person to every patient who is in vegetative state at least once in a week. With the help of CRS-R or Glasgow coma scale. In case of CRS-R, the scale at which it is measured ranges up to 10 by the help of event related evoked potential. But with the growing age of technology, BCI and EEG signal has become so profound that it can be helpful in the hassle free monitoring of the patient in (VS/UWS).

Feedforward neural network was the first neural network which was introduced in the artificial neural network, at first it was considered as a single layer perceptron model where it consisted of an input layer, one output layer and one associated layer that is a hidden layer. When proceed in the hidden layer input always gets multiplied by a weight which help to quantified the data and for the outcome one bias were also added to the input. For every input the weight changes according to the desired outcome. So for more complex problem and for easement of the problem statement, the multilayer feedforward neural network was introduced. As this neural network is unidirectional for that we will not be using the backpropagation method, rather we will be using RBM (Restricted Boltzmann's machine) and radial basis function (RBF).

So according to the respective input and desired output, the required design of neural network we have selected is having 6 input (no. of electrodes) and desired output is one so according to the formula, we have taken hidden layer as 2, and the no of nodes as per (D. Statakhis., 2008) **[5]** the no nodes or units present in the formula given below: -

Formula 1: To find the no. of hidden layer, we used., N=input layer, m=output layer and H=hidden layer

H=(N+m)/3

Formula 2: To find the no. of nodes or input in the hidden layer so for First layer we used the formula, x=no. of nodes

x=sqrt [(m+2) N] + 2*sqrt[N/(m+2)]

similarly, for **second layer,**

x=m*sqrt[N/(m+2)]

According to the above formulas, the desired two layer feedforward neural network is designed, which is shown below in the form of block diagram,

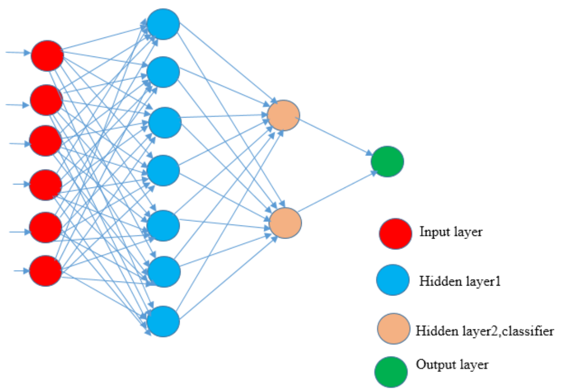

Fig 1: - The design of the two-layer feedforward neural network

From the above design, we implemented input layer=6. Hidden layer 1=7, hidden layer which is mainly classifier=2 and output =1

Restricted Boltzmann Machine (RBM) Algorithm

For the first hidden layer we have introduced RBM algorithm popularly known as restricted Boltzmann machine, it is designed to work on the raw data which will create two groups of unit or data sets," visible group of data", and "hidden group of data". Visible group of data will be the data where it supposed to work on it as the prefiltered group of data. Where as in case of the hidden data, this group of data will remain as unused as it is one which is not filtered properly and consists of noises.so the filtered data is then fed to the hidden layer two.so according to the the ano function , the desired algorithm of the RBM is as follows : -

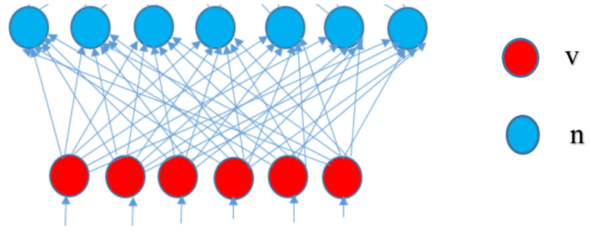

Fig 2: Input layer and Hidden layer

According to above diagram, the energy equation for the RBM is defined as: -

$$E(v,n) = -b'v - c'h - h'wv \qquad \text{[since, w=weight]} \quad (1)$$

For free energy,

$$F(v) = -b'v - \sum_{I} \log \sum_{hi} e^{hi(ci+wiv)} \quad (2)$$

Because of the specific structure of RBM, visible and hidden units are conditionally independent from one another.

$$P(h|v) = \pi_{i}\, p(hi|v)$$
$$P(v|h) = \pi_{J}\, p(vj|h)$$

By using binary units,

$$P(hi=1/v) = sigm(ci+wiv)$$
$$P(vj=1/h) = sigm(bj+wj'h)$$

Further simplifying,

$$F(v) = -b'v - -\sum \log(1+e^{ci+wiv}) \quad (3)$$

so for negative samples,

$p_{train}(x)$

proxies to likelihood: -

$$PL(x) = \pi_{I}\, p(xi|\,xi-1) \quad (4)$$

since,

xi-1= the setoff all bits of n excepts bit I

so the final output which will further fed into the hidden layer or the classifier will be given as:-

$$\log pL(x) = N.\log[(e^{-FE(x)})/(e^{-FE(x)} + e^{-FE(xi')})] \quad (5)$$

similarly, **N.log[sigm(FE(xi)-FE(x)]**

Sigmoid function and the Radial Basis Function (RBF) Algorithm

then after receiving the signal from the output of the first hidden layer it will be then fed to the second hidden layer where the two classifiers will be set one is for positive and other is for negative. In the second hidden layer we will use the RBF (radial basis function) algorithm to sort the output data into two classifiers. Before that we also apply one function name sigmoid to the first hidden layer in case of activation function. For more smoothing of the output curve and to make it a continuous cure we use the sigmoid function.

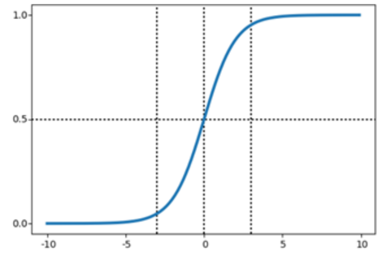

Fig:-3 Sigmoid function graph(Courtsey:Internet sources)

Where the function is given by:

Since, the activation function is given by: $z=\sum_{i=1}^{m} wixi+bias$

$$\sigma(z)=1/(1+e^{-z}) \quad (1)$$

From the above fuction we interpreted the data into the sigmoid functio after that the didden unit data and visible data into the two classifier in the hidden layer 2. So the associated algorithm that is given below :-

As radial basis function also act as a activation function but we used to classify the data into more precise manner so that it can accurately processed abd be fed into final output.

$$\Phi(x)=\sum_{i=1}^{N} wp(\|x-ci\|) \quad (2)$$

Where, N=no. of neurons (nodes) in hidden layer
Ci=the center vector for neuron i
W=the weight of neurons 'i'

$$P(\|x-ci\|)=\exp[-\beta\|x-ci\|^2] \quad (3)$$

Then according to gaussian basis function,

$$\lim_{x\to\infty} p\|x-ci\| \quad (4)$$

so in case of changing of one neuron has only a effect for the input which is far away from the center of that neuron. So thus we will get a separate graphs representing the two classifier data. The merged graph will eventually be get separated from one another and will form two normalized graphs and the data will also form of two groups of different classification with other data who posses the same classification.

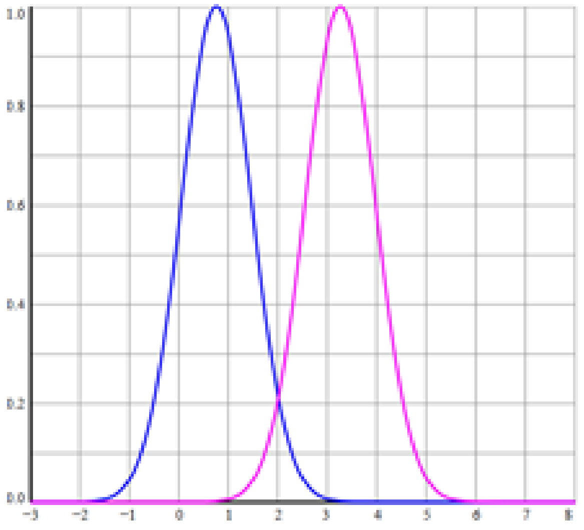

Fig:- 4 The RBF graph showing two different sign wave of same amplitude(courtesy: Internet sources)

Finally, the output will be chosen according to the simple logic i.e. who has more positive value which will totally depends on the bias and the weight associated with the input data.

Experimental Methods and its classification

BCI Headset-Emotiv Epoc Plus

This device has been medically and practically proven by (Ekanayake, H., (2010)) **[6].** Emotive epoc normally comes with 14 channels or 24 channels and in higher range 64 or 128 channels. So emotive is non-radioactive and is very easy to use. For research purpose it is very handful and can be easily portable as it comes with by default application for both pc and smartphones. It is non-invasive which makes it more reliable without affecting the patient or harming them as it can be seen while doing experiment by means of invasive instrument.it is like a cap and can be fitted to any size of head. It has electrodes attaches which have high quality of sensor can capture signals. For testing and research, it is the best the device so far, but for later uses we can use conventional electrodes which comes single without the headset and according to that we can set up a system with the help of computer and take readings for conventional and regular uses.

Electrode position for the experiment

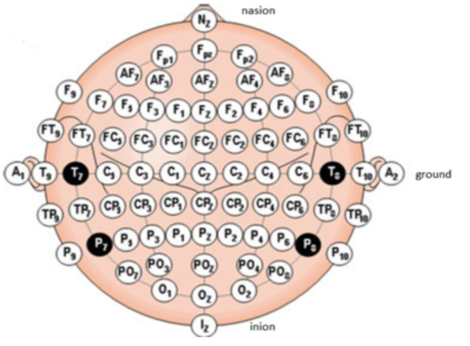

Fig 5:- The basic 64-electrode position of the head(courtesy:Rabie A. Ramadan et al., 2016)

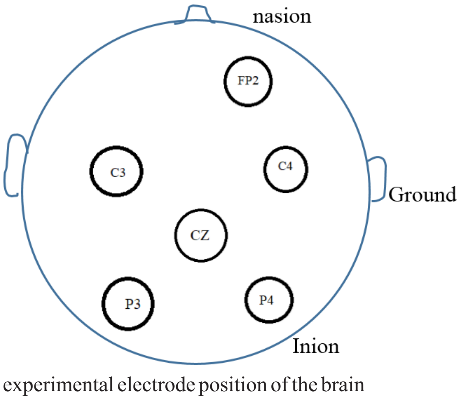

Fig 6:- experimental electrode position of the brain

In the above fig 6, we have chosen only 6 electrodes out of 64 channels, as we know its optimality increases if we put all 65 electrodes but our main motive to I to gets signals from limited brain position so that the patient can experience less discomfort. Another reason is that from minimum no. of electrode if we can the efficient result and best outcomes then using a bulk amount of electrode will be reduced and and we can get data in the form of signal with just few electrodes. So for that, it is been already described as the best position as per the stimulation by (hussam abu.,2016)[7]. Where as the impletation in the electrode position that he has chosen is 5 nodes where as I am implementing with 6 nodes i.e. p3 is the extra electrode position for better sensory feedback. For (VS/UWS) patients this electrode position can be effective to check the level of feedback responses against the applied stimuli. So if the patient somehow recovers from the vegetative state but were unable to move or make any muscletory movement, this will help them to communicate through EEG signals.

Somatosensory Evoked Potential(SSEP)

SSEP is used mainly in neuromonitoring to check the function of a patient's spinal cord during surgery, but it can also be used in monitoring the patients specially for those who are in comatose or in UWS condition. The EEG signals can be recorded by stimulating peripheral nerves likes tibial nerve, median nerve, and ulnar nerve. But in this paper the main focus will be on median nerve which is safer then stimulating in ulnar nerve and faster than tibial nerve. The stimulation mainly consists of the electrical signal. As we know, there are many stimulations possible for evoked potential like visual, auditory or event related evoked potential. In visual evoked potential a supervisor is always needed to provide a constant stimulus, which is not possible for a human being to constantly stay with the patient to give stimuli to him/her, so it is only limited to measure the recovery level not for the continuous monitoring. Where as in case of auditory evoked potential(AEP) one need a constant supply of clicking sound for continuous monitoring which is impossible to do so. First it will need a good quality of audio device with a good quality of battery back-up and then sometime continuous sound may harm the patients hearing organs. Same problem may arise with the event related evoked potential, one person has to stay constantly for providing different types of event stimulus like moving the hand or saying the patients name and etc.

So as a result for continuous stimulus the sensory evoked potential is the best solution of all the evoked potentials. In this experiment the patient will be given stimuli in the form of electrical shock with minimum voltage ranging 10 mv/5 minute as normal human being can take up to 5 mA current in their body i.e 10 mv as depicted by ohms' law in the median nerve of the patient. It will be continuous as it time locked event. After every interval it will continuously give this amount of shock to the patient and also it is not necessary for a person to stay with the patient for the whole time of monitoring that's why it is advantageous to use in commercial purpose also.

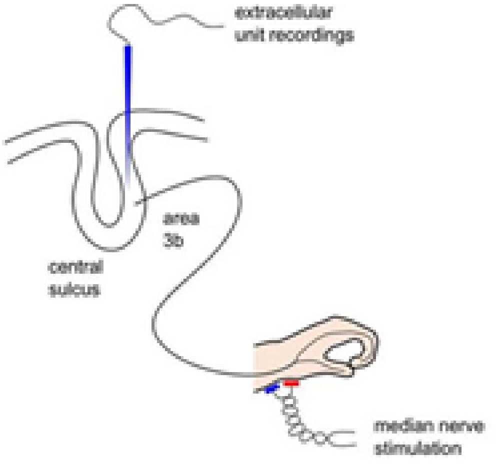

Fig 7: -SSEP applied to median nerve (courtesy: Internet sources)

Implementation of the outcome into the continuous monitoring system

As we have already led the vision of the continuous monitoring system in the above article, now how the process is going to take place will be given in a complete block diagram given below: -

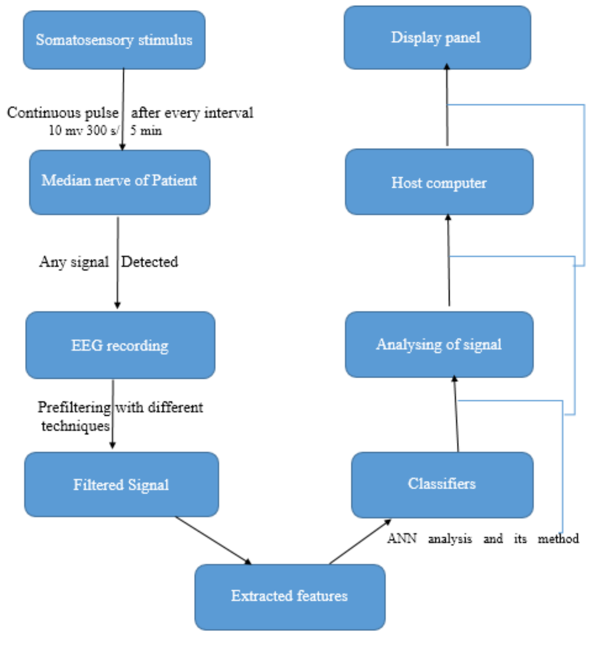

Fig 8: - Block diagram

So from the above diagram we understood about the process of the continuous monitoring. In most of the cases or research is done on the degree of recovery of the vegetative state to minimally conscious or comatose to locked in syndrome. But it is also necessary before analysing the mental strength stability and its chances to get better, one should take care of the continuous monitoring of the person who is in (VS/UWS) state or comatose state. Both the stages have a chance to sudden recovery. As it is very difficult for a medical assistance or for doctor to continuously check-up the patient who is in that state for a very long time, to minimise the effort and maximising the efficiency of the continuous monitoring we should attach the respective device to a system which can display the patients awakening state by giving automatic and continuous stimulus. This eliminates many pre diagnose failure between different state of consciousness of VS/UWS patient or those who is in a coma. So for example as a token of case study, we have presented some picture of a scenario presenting or depicting same monitoring system. Only the difference is that the case study is related to ECG (Echo cardiology) where the pulse rate monitoring stem is connected to the host computer and that is connected to the display panel. So that it makes easier for the both doctors and the medical assistance to continuously check-up the patient and the the display panel will track all the rooms, if any signal is received it will immediately show the room no. from which room it is coming and if it is establishing in a one single room with lots of bed, then the bed no. will be shown in case of the room no. so the images depicting the similar scenario-

Fig 9: - image showing the connection between the patient and the monitoring system

Fig 10: - pulse rate monitoring system

Fig 11: - Display Panel

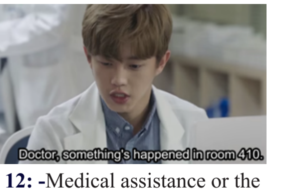

Fig 12: -Medical assistance or the receptionist

(Courtesy: The pictures are taken from 'Miscellaneous Sources').

Limitations and measures taken while doing the experiment

There should be proper amount of current shock to be given to the patient so that it should not harm the patient. Proper guidelines should be given to the practitioner so that when implementing the cathode and anode to the skin surface of the patient it should not be touched with other nerves except the median nerve. Patient consent or their members consent for practicing the experiment. Most effective nerve of all the nerves is the ulnar nerve, which is in spinal cord. As it is directly connected to brain but due to sensitivity of the inter related nerve in the spinal cord it cannot be done without the consent of the respective personnel.

Future scope

Continuous monitoring system can be done without the external source like stimulus but with the method of invasive implanting of electrodes in the brain with the help of emotion recognition system of the brain for the vegetative state patient in the hypothalamus of the brain where emotion signal of a person is produced or is responsible for the emotions a normal human have.

CONCLUSION

At last, we can conclude that this monitoring system can be helpful for the patients who often are mistaken between the coma and LIS, as both of them represents the same type of symptoms as both of them does not have any muscletory movements even the winking of an eye or twitching of a muscle. But the major difference is that LIS patient remains fully conscious despite of having unresponsive of the muscle and the comatose patients remain in vegetative state without any consciousness. And due to lack of continuous monitoring, due to long time often they are misdiagnosed for that. This way this monitoring system can be helpful for the rare cases of the patient who often left misdiagnosed.

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