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Improving EEG Electrode Sensitivity with Graphene Nano Powder and Neural Network for Schizophrenia Diagnosis

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Abstract: Hallucinations and delusions are symptoms of schizophrenia. Due to persistent auditory and visual hallucinations, a person with schizophrenia cannot process reality clearly. Abnormal brain activity results from delusion and hallucination. During the capture of EEG signals, aberrant behavior is detected. The EEG electrodes do not well detect the brain's current distribution. Schizophrenia causes the EEG signal to be warped and less sensitive, which results in incorrect interpretation of brain activity. In this paper, an EEG electrode constructed of graphene nanopowder is suggested that is sensitive to the brain's weak electrical activity. The cold spray approach created graphene EEG electrodes, improving the material bonding and chemical characteristics. By obtaining EEG readings from schizophrenic patients, the sensitivity of the graphene electrode was assessed. The EEG signal was collected from the subject when taking part in cognitive tests like question sessions and numerical problems. Several neural networks (NN) algorithms can be used to identify hallucination and delusion aspects in EEG recordings. Further details regarding the hallucination and delusion aspects in the EEG signal were provided by the NN, showing a Graphene electrode. As compared to other NN models, the comparative study of several NN models revealed that the BFGS quasi-Newtonian backpropagation algorithm accurately recognized hallucination and delusion features.

تحسين حساسية القطب الكهربائي باستخدام مسحوق الجرافين النانوي والشبكة العصبية لتشخيص انفصام الشخصية

الخلاصة

تعتبر الهلوسة والأوهام من أعراض انفصام الشخصية. بسبب الهلوسة السمعية والبصرية المستمرة، لا يستطيع الشخص المصاب بانفصام الشخصية من معالجة الامور الواقعية بوضوح. كناتج للوهم والهلوسة يُظهر الدماغ نشاطاً غير طبيعي. أثناء التقاط إشارات EEG، يتم الكشف عن سلوك شاذ. ان أقطاب مخطط كهربية الدماغ لا تكتشف توزيع تيار الدماغ بشكل جيد. يتسبب الفصام في تشوه إشارة EEG وجعلها أقل حساسية، مما يؤدي إلى تفسير غير صحيح لنشاط الدماغ. في هذا البحث، تم اقتراح إقطاب EEG كهربائية مبنية من مسحوق الجرافين النانوي وهو حساس للنشاط الكهربائي الضعيف للدماغ. خلقت طريقة الرش البارد أقطاب الجرافين EEG، مما أدى إلى تحسين ترابط المواد والخصائص الكيميائية. من خلال الحصول على قراءات EEG من مرضى انفصام الشخصية، تم تقييم حساسية قطب الجرافين. تم جمع إشارة EEG من الموضوع عند المشاركة في الاختبارات المعرفية مثل جلسات الأسئلة والمشكلات العددية. يمكن استخدام العديد من خوارزميات الشبكات العصبية (NN) لتحديد جوانب الهلوسة والوهم في تسجيلات EEG. تم توفير مزيد من التفاصيل المتعلقة بجوانب الهلوسة والوهم في إشارة EEG بواسطة NN، والتي تُظهر قطب الجرافين. بالمقارنة مع نماذج NN الأخرى، كشفت الدراسة المقارنة للعديد من نماذج NN أن خوارزمية BFGS شبه النيوتونية للتكاثر العكسي تعرفت بدقة على ميزات الهلوسة والوهم.

الكلمات الدالة: الجرافين، الرذاذ البارد، انفصام الشخصية، مخطط كهربية الدماغ، الشبكة العصبية.

1.INTRODUCTION

EEG electrodes are used to gain information about the neurological functioning of the brain. The electrodes consist of capacitive sensors, batteries, and integrated circuits to improve the acquired signal magnitude and eliminate noise in the EEG signal. The EEG electrodes are used to obtain a signal for different cases to analyze the spontaneous EEG response, brain stems potential analysis, and cognitive evaluation. The dry EEG electrodes require no more preparation time. The dry electrodes can be applied directly on the skin, which increases the SNR. The higher number of channels for dry electrodes, shielding, and pre-amplification overcomes the effect of signal degradation during the EEG signal acquisition. Nanosensors are nanoscale devices that assess the physical quantities of a substance and transform it as a signal to analyze its properties. Chemical and mechanical nanosensors are the main types of nanosensors. Chemical nanosensors work by observing the nanomaterials' electrical conductivity and noticing the shift in conductivity while being bound or adsorbed. One-dimensional nanomaterials with one dimension greater than 100nm, such as nanowires and nanotubes with electrically confined structures, are the best examples of chemical nanosensors. The mechanical nanosensors work by noticing the change in electrical conductivity of the nanomaterials while undergoing physical manipulation. The nanopowder provides enhanced sensitivity, which can be applied almost in all fields. Examples of its application are given below. Optical Nano-sensing: The optical nanosensors have nanomaterials with nontoxic receptors that measure optical changes within their environment. It is utilized in various biological applications monitoring ion concentration and tracking any unwanted and interfering species. Environment Monitoring: In real-time, the microorganisms and toxic chemical compounds in environmental samples can be observed and analyzed with nanosensors. Radiation Sensing: Electromagnetic and UV radiation at low levels can be measured using nanowires by evoking a change in the resistive state of the nanowires. Currently, nanosensors are combined with microelectromechanical systems and microfluidic devices to trace microorganisms in fluid samples and cholesterol levels in blood samples. Nanoparticle diameter size ranges between 1 and 100 nanometers. It is classified into natural, engineered, and incidental nanoparticles. Biotic and abiotic matters such as volcanic dust, minerals, clays, and metal oxide have natural nanoparticles. Engineered nanoparticles have specific shapes, sizes, and surface morphology contrived for specific usage. Incidental nanoparticles are byproducts from manufacturing and production facilities. In addition, Nanoparticles must be encapsulated with various molecular ligands for better usage. This paper discusses the ink development from graphene nanoparticles for inkjet printers, scalable printing process, and resource-efficient process chain to produce electrodes [1] for direct skin contact, which can be used to improve the electroencephalogram (EEG) accuracy.

2. LITERATURE REVIEW

Table 1 below shows the measures and benefits of fabrication methods reported in the literature survey.

Table 1 Measures and Benefits of the Fabrication Methods.

Reference	Sensor / Measure	Fabrication Method / Used EEG Features	Benefits / Findings
[2]	Augmented wire-embedded silicon-based dry-contact sensor (WSBDS)	Embedding metal stud and copper wires into the fingers of an acicular SBDS	Better performance in brain-computer-interface experiment
[3]	International 10-20 sensor placement system	The stimulus-based functional associations	Raga was pleasant and induced mood change after listening
[4]	14-channel EEG machine	Hjorth parameters (activity, mobility, and complexity	Improved the emotion recognition rate [5]
[6]	Wireless electroencephalography (EEG) sensor networks (WESNs)	Modular neuro-monitoring platform for high-density EEG recordings,	Power-efficient, in particular by avoiding data centralization
[7]	32-channel implantable recording device	Simultaneous near-infrared spectrometry (NIRS) and intracerebral EEG (icEEG)	Measured normalized root-mean square deviation was under 2%
[8]	Consumer grade EEG devices	Comparative analysis performs with power spectra of EEG signal.	Evaluated consumer level EEG electrode performance [9] with research grade devices
[10]	Conductive fabric electrode with the multifunction sensor	Measure humidity of multifunction sensor	Continuous measurement of sweat rate simultaneously with EEG signal recording
[11]	Multitude of mini-EEG devices	Greedy group-utility based channel selection strategy	WESNs insignificantly suffered from EEG miniaturization effects in the case of AAD [12]
[13]	Clustering variational mode decomposition (VMD)	Optimum allocation sampling into homogeneous EEG-clusters and decomposed into band-limited modes	Identification of focal EEG signals
[14]	Three-layer spherical head model with different and random-layer conductivities	Sensitivity and correlation analysis of EEG sensors	Observation of least influenced electrodes along the great longitudinal fissure
[15]	Wireless neuroheadsets	Empirical studies with an off-the-shelf Emotive EPOC Neuroheadset	Minimizing the energy usage in EEG sampling and maximizing the sum of all applications' fidelities
[16]	Wearable mechatronic rehabilitation devices	Changes in system dynamics caused by user actions	Improvement of adaptability [17] and robustness of wearable mechatronic rehabilitation devices [18]
[19]	Review of the latest graphene-based sensors for health monitoring.	Graphene-based sensors realize the real-time measurement of body temperature, heart rate, blood glucose, electrocardiogram signal, and electroencephalograph signal	Potential challenges were discussed and outlined

3. METHODOLOGY

3.1. Frontal Lobe

The human brain is broadly classified into four lobes, as shown in Fig. 1, among which the Frontal Lobe is the largest. It is responsible for voluntary actions, expression through language, executive functions like cognitive skills, planning, organizing, initiating, monitoring, goal setting, behavioral and emotional balance, multi-tasking, and personality. Hence, this brain region was chosen to study neurological activity. This part of the brain is more prone to traumatic brain injury. Any abnormality in this region may result in significant complications such as Paralysis, speech abnormalities, reduced coordination, irresistible impulses, and difficulty planning, affecting lifestyle and social behavior. The brain produces electrical conductivity through electrodes placed at different points, as shown in Fig. 2.

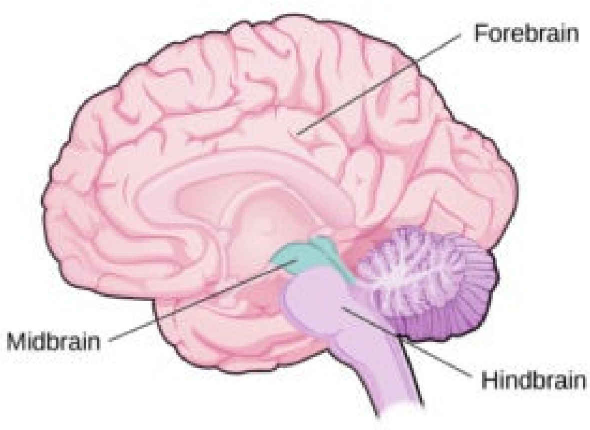

Fig. 1 The Categories of the Brain.

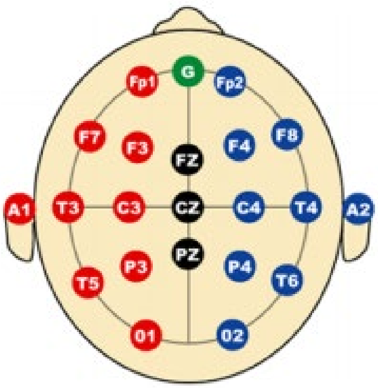

Fig. 2 Fp1 and Fp2 Position of Frontal Lobe.

Fig. 3 shows the proposed Nano edge system of producing efficient EEG with improved direct skin contact electrodes that use graphene nanoparticle inkjet printing. The graphene-nanoparticle ink [20] was developed using the following process. Firstly, modified commercial graphene ink was used to create graphene-based ink. Secondly, ethanol was included to prevent bubbles and lower the ink's surface tension. Thirdly, carbon nanoparticles were added to improve the printed structures' resistance to wear. Lastly, a surfactant was applied to improve the printability, conductivity, and surface smoothness of printed structures.

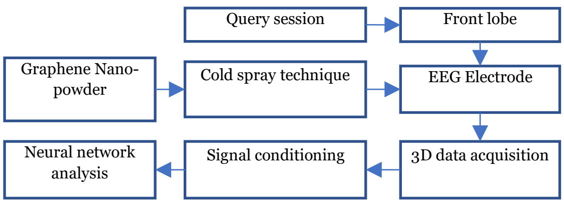

Fig. 3 Overview of EEG electrode fabrication for hallucination and delusion identification in EEG signal.

3.2. Skin Electrode Fabrication

The ink printing on soft material, blade cutting, and a passive adhesive layer lamination was used to create the skin-electrode for EEG's production. The thickness of each element and layer affects how well the electrode couples to the skin. To enhance the optimization of these layers for EEG applications, the thickness and stiffness were reduced [21]. This new generation of wearable sensors combines ultra-thin electrodes with low-cost skin electronics. These sensors measured the biological signals that serve as indications of mental state. These signals provided a more thorough depiction of mental processes and improved mental disorders and functional restoration analysis.

3.3. Scalable Printing Process

The steps listed below were used to complete the resource-efficient printing procedure. The tracks and contact pads were initially printed in silver ink. Next, customized graphene ink was used to create electrodes. For high-quality printing, an inkjet printer with a 16-nozzle print head was employed. The development of desirable pre- and post-processes was the next step. Eventually, an inkjet system was used to transfer the printing process for mass production.

3.4. Nano edge Implementation

The Nano edge used Senso Medical Laboratories BIOPOT. The BIOPOT is a tool for nanotechnology product development that combines wireless bio-impedance and bio-potential amplification with data transmission and collecting. For data transfer, it uses Bluetooth low-energy 5.0 technology. In order to acquire data, it has an onboard data buffer. It can be set up using EEG, EMG, or other bio-potential readings and has eight or 19 channels.

3.5. Graphene EEG sensor

Graphene is a single-layer carbon atom, and the carbon atoms are available in a 2D honeycomb lattice. The graphene is sensitive to bioelectrical signals. The active cells in the human brain constantly produce electrical activity. The cells and tissue have a transmembrane flow of ions in action potential and resting potential. Electrodes are frequently used to collect clinical bioelectric signals, which can then be processed into an Electrocardiogram (ECG), Electroencephalogram (EEG), Electromyography (EMG), Electroretinogram (EOG), and Electroretinogram (EOG) by amplification, filtering, and post-processing. It has been used in various domains, including mobile health care, cognitive psychology, and human-machine interactions, as a critical electrical signal indicating the state of the human body. Nevertheless, reliable signal acquisition becomes necessary for signal analysis due to their high contact impedance, common mode noise, and weak value. As a result, the electrodes' quality significantly impacts how the bioelectrical signal is measured. It is herein suggested that the Graphene Nano powder-based sensors [22] can be used for the most remarkable accuracy since the bioelectrical electrode sensors should have an extended dynamic range, accuracy, high SNR, low impedance, robustness, durability, and remarkable repeatability among deformation ranges. The Graphene Nano powder-based sensors keep less touch with the skin while achieving consistent and accurate impulses even during a person's kinetic motion. These sensors are increasingly used in wearable biometric sensor creation to acquire bioelectrical signals in real-time, high fidelity, low impedance, and high SNR.

3.6. Cold Spray Technique

It is a coating deposition method where fine Solid powder sizes range from 1 to 50 μm diameters. The particles are accelerated up to 1200 m/sec in a supersonic gas jet beyond its critical velocity. During the impact of a spherical particle with the substrate, per the principle of adiabatic shear instability, the kinetic energy deforms the plastic. The deformed plastic adheres to the surface. The particles spray through a nozzle for a uniform surface. The graphene nanocrystalline powder was used for cold spraying [23]. Unlike thermal spraying techniques, the powders do not melt during cold spraying; hence, the basic physical and chemical properties are restored. Furthermore, the major advantages include high density, conductivity, homogeneity, productivity, power feed, deposition rate, efficiency, reusability, operational safety, low energy consumption, surface preparation, and shrinking and stand-off distance. This method is free from toxic wastes and combustion. Spraying micro or nanosized particles, amorphous materials, metals, crystals, and alloys is possible.

3.7. 3D Data Acquisition

3D Laser Scanning, also known as Light Detection and Ranging (LiDAR); Photogrammetry; Videogrammetry; RGB-D Camera; Stereo Camera; and 3D Scanner have commonly used data acquisition tools in EEG. The 3D Scanner [24] is preferred due to its affordability and fast electrode digitizer with better positional accuracy than template ones. The source models of EEG improve with 3D electrode positions. 3D data acquisition can be classified into two types, i.e., the Non-Contact Method and the Tactile Contact Method. Magnetic, Acoustic, and Imaging are under the Non-Contact Method. The CMMs and Robotic arms are under the Tactile contact method.

3.8. Signal Conditioning

The acquired analog signals should be processed before digitization. The Signal conditioning converts the signal from Analog to Digital with an anti-aliasing filter. In the present work, bioelectric signals were the input impulses. Signal conditioning involves several techniques, including filtering, amplifying, attenuating, excitation, linearizing, electrically isolating, and surge-protecting.

4. RESULTS AND DISCUSSION

The psychological process of a person was analyzed with EEG signals. The EEG is a cost-effective method that provides information about the brain-behavior with respect to time. The person's EEG behavior changed with respect to cognitive function. For example, a study validated the relationship between cognitive function and interictal EEG discharge [25]. A person with frequency IEDs had a low IQ compared to a normal EEG, and the latency of a person was inversely proportional to IQ.

4.1. EEG variation during cognitive questioning

During the Cognitive tasks, analytical questions were posted to assess critical thinking and problem-solving. While the tasks were executed, significant changes were noticed among various individuals. EEG predicts the brain's health, sharpness, distinguishing complex behavior, and sensory-motor nerve coordination. For patients who have Paralysis, Epilepsy, Schizophrenia, bipolar disorders, and other systemic mental disorders, the EEG patterns showed abnormal behavior. The analytical task was performed as a response to the stimulus, an outstanding feature of the human brain, which varies for different people. The responses or reactions depended closely on the characteristics, such as an individual's mental condition, the cognitive task's load and complexity, and an individual's skill and aptitude. Besides these, cognitive resources to fulfill the task and working memory also play a major role. In the present work, three cognitive tasks were proposed to study neurological activity through variations in an EEG signal. The tasks were numerical Reverse Counting from 100 to 1, rotating the eyes, and answering the questions. A comparative Study for Secondary Assessment in Answering the Question of Cognitive Task is represented. Here, the wavelet transform (WT) was used as a tool for signal conditioning. The WT broke down a signal into a series of fundamental functions made up of contractions, expansions, and translations of the wavelet, which is a fundamental function. However, the wavelet transform was applied to achieve time domain variations, not in connection with the impulse shape. In continuous wavelet transform, the multiresolution was analyzed by contractions and dilation of a wavelet function. For accurate analysis, A Discrete Wavelet Transform, the basic level one where the filter banks were used for multiresolution time-frequency entities, was employed. Special wavelet filters were used for signal analysis and reconstruction. A spectrum was divided into multiple frequency domains by filters cascaded in filter banks. An input signal passed through a Low pass filter, followed by a high pass filter, and the amount of data available was doubled in quantity yet at the same frequency range, as shown in Fig. 4. A downsampling by a value of 2 was applied to existing output signals for analysis through filter banks. Signal reconstruction was done by Synthesis Filter Bank. The frequencies were added by upsampling the signal by a value of 2 and passing them through the filter; hence reconstruction took place. The filter bank technique was also called as Sub-band coding technique as the analysis filter bank split the frequency domain into different sub-bands. Here, to overcome the cons of DWT, the EEG data were analyzed on MATLAB by replacing with the other algorithms, such as Levenberg-Marquardt backpropagation, Bayesian Regulation backpropagation, BFGS quasi-

Newton backpropagation, and Conjugate gradient backpropagation with Powell-Beale restarts.

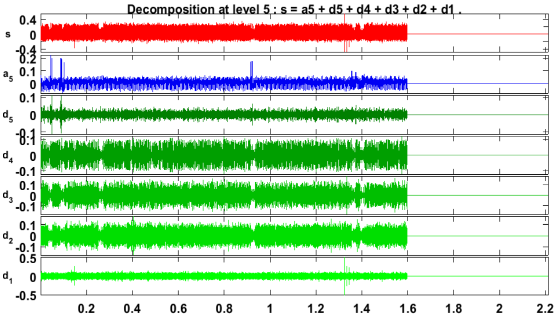

Fig. 4 Decomposition of EEG Signals Acquired During Query Session.

Computationally serious neural organization models were additionally evolved and named "Profound Learning" models. Some profound learning models are Convolutional Neural Networks, Deep Neural Networks, and Contractive Auto-Encoders. Recently, neural organization models have been generally embraced in different trains, such as energy frameworks, medical care, mechanical technology, horticulture, climate demonstrating, and geospatial picture investigation. The effect of neural organizations in the clinical field is relatively high. The heterogeneous information from various sources can be examined with a neural organization due to its nonlinearity. Innovation advancement assumed an essential job in the improvement of medical services offices. It has a wide range of applications in diagnosing and assessing mental disorders, such as epilepsy, schizophrenia, bipolar disorders, and neurological disorders.

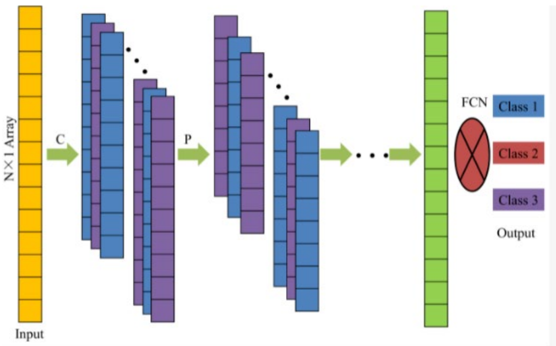

Fig. 5 Construction of Convolution Neural Network Layers.

In Fig. 5, C denotes the convolution layer, P denotes the pooling layer, and FC denotes the fully connected layer. Each Confusion kernel component multiplied the Confusion layer input data by the subsection item and summarized the products to get an item on the feature map. Each time, subsection 1 moved down, and the process was repeated until all input data components were included; eventually, the compression function created a new matrix (i.e., feature map). The clustering function was a paradigm that significantly improved the computational speed of CNN and effectively prevented overcorrection. Usually, there are two different grouping modes, i.e., the maximum grouping and the average grouping. The maximum group used in the present study was better than the average group. The implementation layers, Softmax and fully integrated, were similar to the CNN 2-D standard. In this study, through EEG, the analysis was performed in 4 stages: Training, Testing, Validation, and finding the Best or optimum performance. Initially, certain threshold values were fixed as a Training set, and the results were used compare with the values extracted from the patient through EEG. These values were validated and correlated to understand the deviation amount. The values were differentiated for all three analytical tasks, and the results were evaluated through Best Validation Curve, Error Histogram, and Confusion Matrix.

4.2. EEG signal analysis with Levenberg-Marquardt Backpropagation (LMB)

The Mean Magnitude of the Squares of Error (MSE) is the distance between the model's estimate of the calculated and actual test values. As the values were squared, fiddling and overshooting can be avoided by attaining the absolute value. The physical interpretation was correlated with the hyperplane drawn by the network, which predicted the values almost close to the exact ones. The MSE of 10-25 expressed the accuracy of reaching the closer targets. Figs. (6, 7) show the variations in the neural activity while performing the numerical activity in reverse order, from 100 to 1.

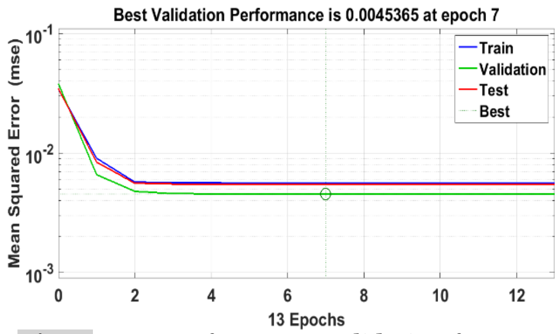

Fig. 6 LMB Performance Validation for EEG Signal Acquired During a Query Session.

The LMB reached the best validation at epoch 7. The difference between variable output and known target output represented the error caused in the neural network model. The error was caused due to biases and weight adjustments in the neural network model. The training process in the neural network aimed to optimize the model's weight distribution and reduce squared errors.

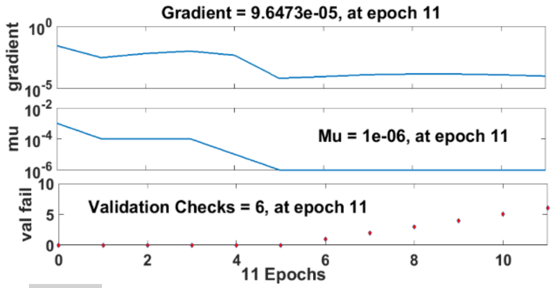

Fig. 7 LMB - Gradient with Steep Descent with Momentum During a Query Session.

The Error histogram shows the errors between predicted and actual values. The performance of the network model was evaluated after each training session of the model. Since the difference was shown between the predicted and target values, the outcome was also negative. Fig. 8 shows the error range of the LMB model. The maximum errors occurred at 0.003688, and the training dataset bin was near 250. At 0.003688, the validation and test dataset lay in the range of 180 to 250, which showed that samples from datasets had an error in that particular range.

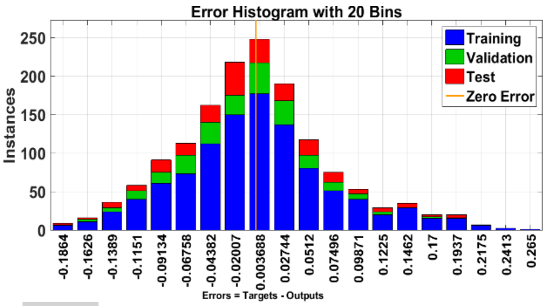

Fig. 8 LMB Error Histogram of EEG Signal During a Query Session.

4.3. *EEG signal analysis with Bayesian regularization backpropagation (BRB)*

The EEG signal was processed with the BRB neural network model to predict the hallucination and delusion features in the EEG signal. The model reached the validation for schizophrenia features at 4 epochs, as shown in Fig. 9. The gradient of the BRB was low compared to the LMB model, as shown in Fig. 10. The model's error histogram was maximum at 300, which was low compared to LMB. The maximum error occurred at 0.00129, and the lowest occurred at -0.1319, as shown in Fig. 11.

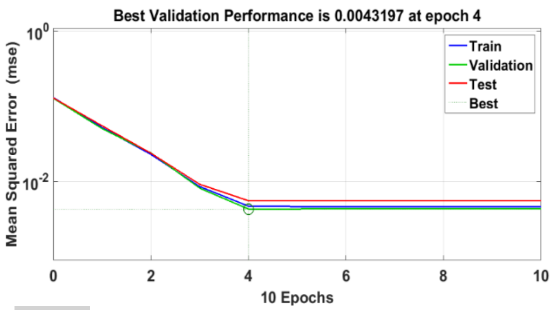

Fig. 9 BRB Performance Validation for EEG Signal Acquired During a Query Session.

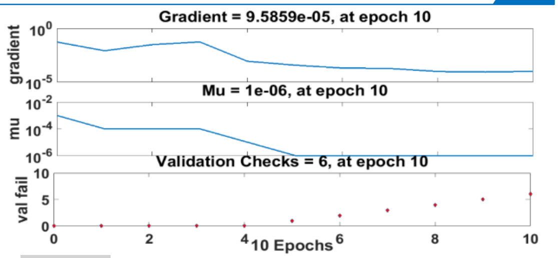

Fig. 10 BRB - Gradient with Steep Descent with Momentum During a Query Session.

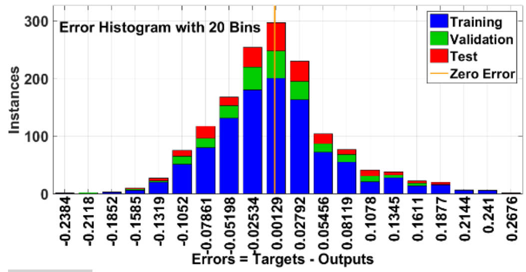

Fig. 11 BRB Error Histogram of EEG Signal During a Query Session.

4.4. *EEG signal analysis with BFGS quasi-Newton backpropagation*

Figs. (11- 16) show the comparative study report of the gradient variation curve, error histogram, and the confusion matrix of the EEG signal acquired during the query session. The comparison was between various wavelet transforms and neural network-based algorithms, which was effectively proved. The BFGS predicted that the variations in the EEG signal were caused due to hallucination and delusion. The model achieved the validation at 50, as shown in Fig. 12, which was high compared to LMB and BRB. The gradient a mu of the model is shown in Fig 13. The error histogram caused in the model reached its peak, i.e., 220 instances, at 0.009266. The error during the test phase was higher than in other models, as shown in Fig 14. The number of instances was low compared to LMB and BRB models.

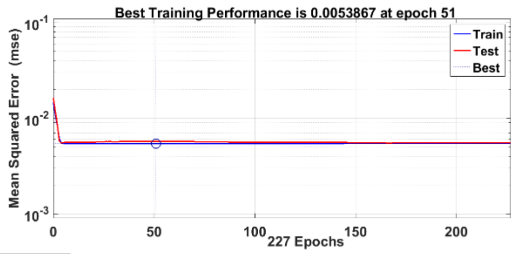

Fig. 12 BFGS Performance Validation for EEG Signal Acquired During a Query Session.

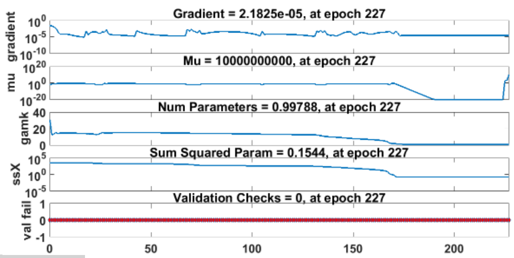

Fig. 13 BFGS - Gradient with Steep Descent with Momentum During a Query Session.

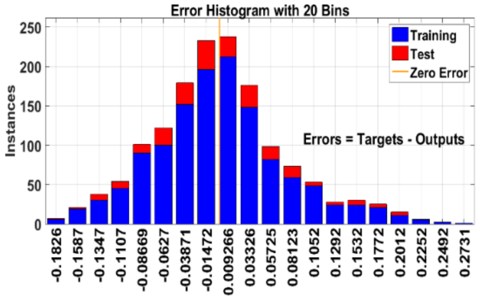

Fig. 14 BFGS Error Histogram of EEG Signal During a Query Session.

4.5. EEG signal analysis with Conjugate Gradient Backpropagation (CGB)

The CGB model analysis of the EEG signal is shown in Figs. (15- 17). The model reached the validation at 1 epoch, which was drastically low compared to other NN models, as shown in Fig. 14. The gradient and mu are shown in Fig. 15. The gradient was 6.6209× e-06 which was low compared to other models that show the CGB had more errors. The error histogram is shown in Fig. 16. The maximum error occurred between -0.03203 and 0.04507 in the 240 to 290 instances range.

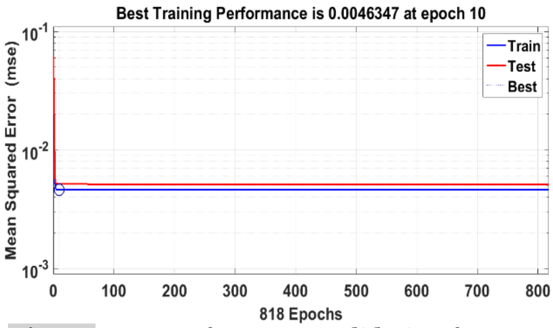

Fig. 15 CGB Performance Validation for EEG Signal Acquired During a Query Session.

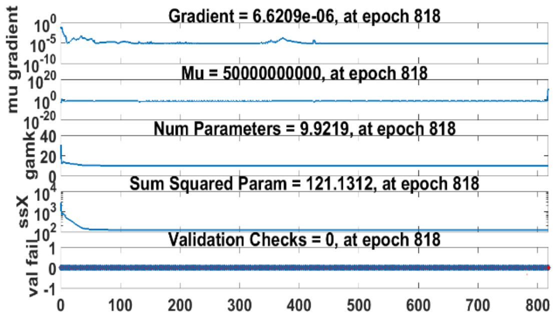

Fig. 16 CGB Gradient with Steep Descent with Momentum During a Query Session.

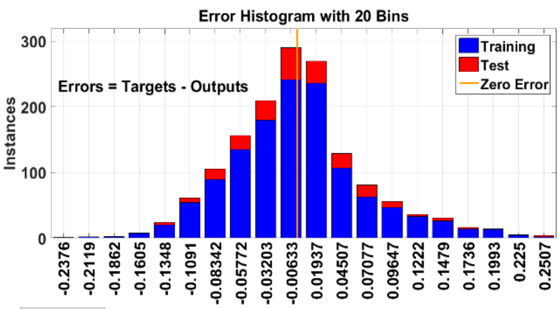

Fig. 17 CGB Error Histogram of EEG Signal During a Query Session.

The confusion matrix showed the variations with respect to predicted and actual values. The true and false values that caused the classification problem are defined by the confusion matrix. The confusion matrix showed the correct and error predictions with count values for each class. Confusion matrix shows how the classification model was confused when it made predictions. Confusion matrix is a method of measuring performance to assess how well the classification algorithms function. True Positive (TP), True Negative (TN), False Positive (FP), and False Negative (FN) were four crucial values in a confusion matrix (FN). TP depicted the anticipated outcome as favorable and as expected. According to TN, both the actual and anticipated results were unfavorable. FP, also known as Type—I error, occurred when a positive result was anticipated; however, a negative outcome was expected. Similarly, FN stands for Type—II mistake, where a positive outcome was anticipated; however, the result was predicted to be negative. The confusion matrix provided information about the types of errors caused by the classifier. The BFGS model had fewer errors concerning the actual outcome, as shown in Fig. 18, since it produced fewer errors in the histogram plot, as shown in Fig. 13.

Fig. 18 Confusion Matrix of BFGS NN Model.

5. CONCLUSION

This work proposed an EEG electrode made of graphene nanopowder to detect schizophrenia features in an EEG signal. The features detected with a neural network algorithm for the early diagnosis and assessment of mental health through EEG with the help of cognitive tasks were an effective method. While handling the cognitive tasks, a patient was set on an experimental study with an EEG. The comparative analysis of NN methods showed that the BFGS NN model identified the EEG signal variations more accurately than other models. This NN performance model was evaluated using a gradient, Mu, error histogram, true positive, false positive, true negative, and false negative. The NN model would assist medical practitioners in automated diagnostic procedures for schizophrenia and is cost-effective.

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