Study on bio-interference of electronics

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Abstract. Electronics have come a long way since their beginning conception. Instead of simple switches, they have now evolved to help in every industry. Some of the most advanced electronics have come from medical applications, especially those that deal with reading electrical signals. These types have had a tremendous impact on the healthcare of the population and advanced our understanding of the inner workings of the human body. Though these have had great successes, there is a very prominent issue that arises, bio-interference. This is when any type of biology has interference with the electrical signals trying to be read. EEGs are one of the most prominent electronic signaling detection, and great efforts have been made to minimize bio-interference, such as advances in signal processing, improved materials, multi-modal approaches, miniaturization, and real-time artifact detection. We aim to expound on these and offer a future of where these can lead.

1. Introduction
Bio-interference is one of the biggest problems facing the accuracy of EEGs today. To understand this issue, one must first understand the EEG.

The electroencephalogram, otherwise known as the EEG, was created in 1929 by Hans Berger. This technology continued to be expounded on for many years and has grown to be very instrumental in medical and clinical applications [1]. These are currently on a range of products such as neurofeedback therapy. EEGs are typically lower than 100 Hz [1]. These impulses are measured through the electrodes that the EEG utilizes and this is completely non-invasive and due to the skull bone material; the acquirement of an accurate reading is challenged more than other measurements [1].

EEGs record bio-signals by converting the bio-potentials into electrical signals. The most common material for the electrodes is Silver Chloride [1]. Since the Silver is soluble, equilibrium is reached quicker and is great for skin contact electrodes [1, 14]. However, not just the material of the electrode, but the skin itself should be properly regulated [1].

Though material plays a crucial role in bio-signaling and processing, so does the surrounding electrical noise. Noise can arise from many different areas. These can include the surrounding electrical wires, the type of insulation for those wires, and background noises in the environment. Technically, thermal, shot, flicker, and burst are all terms used to describe different noises that could interfere with the readings [1].

These materials and surrounding noise hindrances have been disrupting signaling for a significant amount of time. Research has been trying to fix these problems for the sense they were discovered and throughout the following sections we will discuss the current research being presented to combat electrical bio-interference. This paper aims to provide current research and possible suggestions on how to improve such facets to minimize bio-interference. This will help to progress the solutions forward so that the field of bio-signaling can progress further for clinical applications.

2. Signal Processing
Signal processing is one of, if not, the most important aspects of improving the current electrical technology in minimizing bio-interference during bio-signaling. This is because one can work to improve the collecting technology, however, if the software is not up to the task, then it becomes the limiting factor. By improving the signal process, the entire problem with bio-interference could be mitigated.

What is currently going on in the field of improving signal processing? The following has been written about the field and where it is going. These especially have been researched in conjunction with EEG signaling. They include Filtering Methods, independent component analysis, empirical mode decomposition, wavelet transform, and lastly hybrid methods.

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Filtering methods consist of a combination of different techniques that have been implemented in the past for unsatisfactory results, and new modern ones that have shown great promise [11]. The conventional methods include mathematical concepts and directly apply from those such as Laplace and Fourier theories. There have been improvements leading to smoothing filters and one titled “Kalman” filters which considers that filtering is a linear quadratic estimation and measures a series of observations over time and this has been shown to produce more accurate unknown variables to get the waveforms. Signal Processing like this would greatly help to aid in understanding the brain on the many different levels that thoughts/neural networks take place on. By separating the observations, it is easier to determine the patterns that one factor might give on the overall output that is being studied. This gives way to using more channels in the processing and recently, a non-integer order filter has been successfully applied to bio-interference and shows the greatest flexibility due to the “non-integer order base” [11] Increasing and using other mode and other bases while also having separated observations could really help to improve the possible other factors attributing to the results of an EEG.

Another is the independent component analysis, ICA. This processing is “based on the assumption of the linear combination of the independent sources of signals which are represented with a vector with a mixing matrix which its inverse matrix represents the source of the original signals”. This technique is also used in conjunction with other techniques such as the previously mentioned Kalman filters. There have been some modifications over the recent years in working with individuals who were unable to move, and this analysis was able to help deter the artifacts such as fewer voluntary movements which would typically interfere in bio-signaling processing. This shows promise to the EEG bio-hindrance community because it was able to show that the artifacts being produced by eye movements and blinks, even when no other motor function was happening, could be singled out and therefore, could be coded out of the software. The signal processing could notice it, and remove it, providing a better picture of just the information within the brain that is being read. Most algorithms will require a lot of training data; however, it can become taxing on the computers it is running on as well as not adequately quick. This was combined with an online format which also has been showing improved results [11].

The empirical mode decomposition has been used and this algorithm will acquire data, take out the intrinsic mode functions, and detect minimums and maximums, thus eliminating the low and narrow bands, however, this is on a single channel, rather than the multichannel independent component analysis. The empirical mode shows that by narrowing the field at which one is searching through, the outliers of that data can be seen and thrown out as not to interfere with the rest of the data. This method has been adjusted and one of the most advanced has seen the ability to “simultaneously [decompose] the multi-channel EEG signals into a group of multivariate IMFs (MIMFs)”. Combining these processes, it was able to extract information from multiple channels at once and was able to gain the location of a specific frequency as well as it was being used for human motion, but the research could still apply [11].

The wavelet transform is also another approach to help lower the bio-interference levels for the output. There are various types of wavelet transforms and these wavelet transforms are promising due to their ability to process those high frequencies while separating the low frequencies. There are quite a few types of wavelet transforms which will not be mentioned here, however, what is important to note is that each has been designed for a specific reason. Understanding those reasons are important. Since there are many types of wavelet transforms, one must determine which would be best for a specific circumstance. For example, Mexican Hat and Daubechies are great when processing signals from individuals with no cognitive impairments, and the orthogonal Meyer wavelets were most useful when in use for individuals with epilepsy.

Hybrid Methods have also shown a significant increase in signal processing. This process occurs when two or more of the previously mentioned methods, or the several that weren’t, are combined. Since there are quite a few types, the specific application must be considered before implementing it into a system [11]. The use of these hybrid methods are the way to go when acquiring the best overall data. That is if it can be processed on a correct time and budget for the individuals and researchers needs.

All of these processing techniques have their independent strengths. The important thing is to determine the exact information that is being hindered by the bio-hindrance and pick the process that would be best from there. Some are more computationally challenging, costlier, and longer time processing. Narrowing down the specific parameters would help one choose which would suit their needs the best.

3. Improved Materials

In the realm of biomimetic materials for EEG applications, current research investigates materials designed to decrease electrical interference. Conductive polymers, such as polypyrrole and poly(3,4-ethylenedioxythiophene) (PEDOT), when combined with flexible substrates, emulate the mechanical properties of brain tissues while concurrently reducing electrical noise. These polymers provide a conformal and adaptable interface, minimizing motion artifacts and enhancing the stability of EEG recordings [10]. Additionally, hydrogels incorporating conductive nanomaterials, such as graphene, not only offer a supportive matrix for electrodes but also reduce impedance mismatch, thereby mitigating electrical noise and ensuring more accurate signal detection [4].
In the nanotechnology domain, nanostructured materials are tailored to decrease electrical interference in EEG electrodes. Silicon nanowires and nanotubes, with their high surface-to-volume ratio, offer improved signal-to-noise ratios by enhancing the sensitivity of electrodes [16]. Furthermore, controlled deposition of metal nanoparticles on electrode surfaces at the nanoscale can optimize electrical conductivity, reducing impedance and minimizing artifacts caused by electrical interference. These nanostructured modifications contribute to a cleaner signal, allowing for more precise neural signal extraction while mitigating the impact of external electrical noise [15]. The integration of advanced sensors and adaptive electronics into EEG electrodes represents another strategy to decrease electrical interference. For example, the incorporation of microsensors that monitor and adapt to changes in the local neural environment enables dynamic impedance adjustments. This adaptability ensures optimal electrode performance by actively compensating for variations in impedance caused by factors such as tissue movement or changes in the conductivity of the surrounding medium, ultimately contributing to a more robust and interference-resistant EEG signal [9]. By employing these specific materials and techniques, researchers aim to not only improve the mechanical compatibility of EEG electrodes but also enhance their electrical performance, leading to more reliable and accurate neuroscientific and clinical applications by minimizing the impact of electrical interference.

4. Multi-Modal Approaches

Current research on multi-modal approaches in the context of EEG electronics aims to minimize bio-interference through a synergistic integration of various techniques. One avenue of exploration involves combining advanced signal processing algorithms with improved electrode materials. For instance, researchers are developing novel signal processing methods that can intelligently filter out non-neural artifacts, such as muscle activity or eye movements, from EEG signals. Simultaneously, the utilization of advanced electrode materials, such as dry electrodes or those incorporating nanomaterials like carbon nanotubes, helps reduce contact impedance and enhance signal quality. This combination ensures a cleaner and more accurate representation of neural activity, diminishing the impact of electrical interference on EEG recordings. Convolutional neural networks (CNNs) and recurrent neural networks (RNNs) autonomously identify and filter out unwanted interference, such as muscle artifacts or eye blinks, in real-time EEG data. These networks are trained on extensive datasets, incorporating diverse scenarios and types of artifacts, to develop a robust understanding of patterns associated with both neural and non-neural activities. The application of deep learning in this context enables adaptive signal processing, allowing the system to continuously learn and improve its ability to distinguish between relevant neural signals and unwanted interference, thus enhancing the overall accuracy of EEG recordings [7]. Moreover, in the realm of concurrent physiological measurements, ongoing research involves the integration of photoplethysmography (PPG) sensors with EEG electrodes. PPG sensors measure blood volume changes, providing information about heart rate and vascular activity. By synchronizing PPG data with EEG recordings, researchers can identify and filter out artifacts related to cardiac-induced electrical interference [3]. This multi-modal approach helps disentangle the intertwined physiological signals, enabling more accurate interpretation of neural activity and minimizing the impact of interference originating from the cardiovascular system. In addition, advancements in neuroimaging technologies, like functional magnetic resonance imaging (fMRI) or near-infrared spectroscopy (NIRS), are being incorporated in multi-modal setups with EEG. These imaging modalities provide spatial information about brain activity, aiding in the localization of neural sources and enabling the identification and elimination of interference originating from nonbrain sources. The integration of fMRI, for instance, assists in distinguishing true neural signals from artifacts, resulting in more accurate and interference-resistant EEG data [2]. Together, these multimodal approaches not only enhance the precision of EEG recordings but also contribute significantly to minimizing electrical interference, ultimately advancing the capabilities of EEG technologies in both research and clinical applications.

5. Miniaturization

Current research in the miniaturization of EEG electronics plays a pivotal role in minimizing biointerference, offering advancements in both wearability and signal quality. Miniaturization involves the development of compact, lightweight EEG devices with reduced electrode size and inter-electrode distances. The decreased electrode size reduces contact impedance and enhances the spatial resolution of EEG recordings, contributing to a more accurate representation of neural activity and mitigating the impact of electrical interference. Researchers are exploring the use of microfabrication techniques to create ultra-small electrodes with dimensions on the order of micrometers. These microelectrodes, often made from materials like platinum or iridium, exhibit reduced contact impedance due to their smaller surface area in contact with the skin. The decreased impedance enhances signal quality by minimizing the resistance to electrical current flow between the electrode and the skin [13].
In addition to electrode miniaturization, research is focused on the integration of advanced amplification and signal processing circuitry directly into the EEG electrodes. This approach, known as on-chip amplification, reduces the length of the signal paths and minimizes the susceptibility to interference. For example, researchers are developing ultra-low-power amplifiers that can be integrated into compact EEG electrodes, amplifying neural signals close to the source [8]. This not only decreases the vulnerability of the signals to external noise but also allows for a reduction in the number of external components, contributing to a more streamlined and interference-resistant EEG system. These examples illustrate how the miniaturization of EEG electronics, encompassing electrode size reduction and on-chip integration, contributes significantly to minimizing electrical interference. The advancements in materials and circuit design not only enhance the portability and comfort of EEG devices but also improve the accuracy and reliability of neural signal recordings in various environments.

6. Artifact Detection

Current research in EEG technology is actively addressing the challenges posed by biointerference through advanced artifact detection methods. One notable approach involves the utilization of sophisticated signal processing algorithms to automatically identify and mitigate artifacts in EEG recordings. For instance, researchers are employing independent component analysis (ICA), as previously mentioned, to decompose EEG signals into independent components, allowing for the isolation and removal of artificial sources such as eye blinks or muscle activity. This technique enhances the accuracy of neural signal extraction by effectively separating genuine brain activity from unwanted interference, thereby reducing the impact of electrical artifacts [5].

Another area of research focuses on machine learning-based artifact detection systems. These systems are trained on diverse datasets containing various artifact types, enabling them to learn patterns associated with different sources of interference. For instance, convolutional neural networks (CNNs) have been employed to recognize and filter out specific artifacts, such as movement-related or environmental noise, from EEG signals. By leveraging machine learning algorithms, these systems adapt to different contexts, continuously improving their ability to discriminate between genuine neural signals and unwanted interference [12]. This approach significantly enhances the robustness of EEG recordings by effectively decreasing the influence of electrical artifacts.

Moreover, researchers are exploring the integration of real-time monitoring systems that combine physiological measurements with EEG data to aid in artifact detection. For example, concurrent monitoring of electrooculogram (EOG) signals alongside EEG recordings allows for the identification and removal of artifacts induced by eye movements. The real-time integration of such auxiliary data helps in distinguishing between genuine neural signals and artifacts, contributing to more accurate and interference-resistant EEG measurements (Jia). These multifaceted approaches to artifact detection underscore the importance of advanced signal processing techniques and machine learning algorithms in minimizing the impact of electrical interference in EEG recordings, enhancing the reliability and interpretability of neurophysiological data.

7. Improved Future Applications

These applications have all been used and utilized in the electronic research community to build on the past to mitigate bio-interference for bio-signaling. The future is looking bright when it comes to all of these improvements. With all these working together, the problem of bio-interference could be on its way to being negligible for calculations. The field continues to expand and the realm that has been mainly discussed is that of EEGs. Within this realm, many clinical applications could improve due to these efforts moving forward. If these were all combined, the electrical readings for the brain could be fully processed, and no longer is the limiting factor of the technology, but rather, our knowledge of what those signals are doing. This is a great problem to be headed towards as it allows for the advancement of knowledge, especially that centered around the brain and EEGs, to enhance the quality of life of humans, the expansion of deep learning processes, and many future clinical applications that medical researchers might not even know they need yet.

By mitigating bio-interference, bio-signaling is processed and read on a maximized level, leaving the world better than before, thus being the aim of whole person-oriented science.

References


