Discrete Wavelet Transform and Empirical Mode Decomposition Algorithms for

Automatic Seizure Detection

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Abstract

This paper discusses two popular automatic seizure detection algorithms that have proven useful in recent years: the Discrete Wavelet Transform (DWT) algorithm, and the Empirical Mode Decomposition (EMD) algorithm. Despite both methods being relatively accurate, the DWT algorithm is advantageous over the EMD algorithm. The DWT method for automatic seizure detection uses dynamic settings that are adjustable on a per-case basis, making this method more accurate than the static EMD method; therefore, DWT more efficiently detects epileptic activity, increasing the time frame and effectiveness of precautionary action against seizures. This paper discusses each method individually and support the claim that DWT is the superior method. Before presenting the supporting arguments, the paper provides background information on epilepsy and the algorithms themselves, as well as a brief discussion of related technology. Following these sections, support will be provided for the main claim as well as a discussion of the social impacts of this claim.

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**Introduction**

Epilepsy is a neurological disorder that impacts the lives of over 50 million people worldwide. Neurologists have spent years developing various technologies and methods to detect epileptic activity and predict seizures in order to improve the lives of those who have epilepsy. A commonly used piece of technology in the neurology field is an electroencephalogram (EEG) machine, which is used to monitor and record electrical activity in the brain. EEGs are a crucial tool for detecting seizures, as they are marked by abnormal electrical activity in the brain; however, this machine alone cannot automatically detect epileptic activity. That depends on the algorithm used to analyze the recordings of the EEG. There are several algorithms for analyzing EEG data, but two popular ones are the Discrete Wavelet Transform (DWT) method and the Empirical Mode Decomposition (EMD) method. The DWT method for automatic seizure detection uses dynamic settings that can be adjusted on a per-case basis, making it more accurate when used with technologies to identify seizures than the EMD method; therefore, DWT more efficiently detects epileptic activity, increasing the time frame and effectiveness of precautionary action against seizures.

In order to discuss this claim, both the DWT and the EMD methods will be discussed in detail. Explanations of how they function independently, as well as how they differ from one another will be provided. After supplying this information, there will be an argument to support the claim that the DWT algorithm is more effective with regards to automatic seizure detection than EMD due to its unique configurable parameters. Finally, an ethical analysis will be provided, as well as a conclusion summarizing the claims made and their implications. Before continuing to the explanations and supporting arguments, context will be provided to ensure a stronger understanding of the impacts of epilepsy.

**Background**

By using small electrodes attached to a patient’s scalp, an EEG machine is able to monitor the electrical activity in the brain and output this data in the form of a set of wavy lines on a chart. After the data is visualized on the chart, a doctor can make observations based on it; however, this reactive approach does little for the issue of proactive seizure detection. Out of the several automatic seizure detection algorithms, two of the most discussed in the neurology community are Discrete Wavelet Transform and Empirical Mode Decomposition. Both of these methods serve the same purpose of detecting epileptic activity but achieve this in different ways. One of the defining factors of DWT is its settings that can be adjusted to better fit a specific EEG signal, allowing it to be more efficient in analyzing the data (Chen, Wan, Xiang, et al., 2017, para. 1). These settings set DWT apart from EMD, which follows a static process of analyzing the data, calculating the energy of functions based on the EEG data, and then determining whether a particular energy pattern alludes to a seizure (Orosco, Laciar, Correa, et al., 2009, para. 1). Despite these both being well known and effective methods of seizure detection, the improved efficiency in DWT can make a significant difference to those with epilepsy.

In her TEDx talk regarding AI smartwatches and seizure detection, Professor Rosalind Picard states that Sudden Unexpected Death in Epilepsy (SUDEP) is the second highest cause of years of potential life lost across all neurological disorders (Picard, 2018). Despite it not being commonly known, SUDEP shows the severity of epilepsy and the impact that seizures can have on the lives of patients and their families. Outside of medication, one of the most effective ways of preventing SUDEP is to have someone with you at the time of a seizure to help you or get help from a professional; thus, having algorithms that can efficiently and accurately predict seizures can potentially save the lives of millions of people.

**Precedents and Related Technology**

 Automatic seizure detection is a powerful tool that can save lives every day, especially when paired with modern technology. Large corporations such as IBM have invested time and resources into developing portable automatic seizure detection devices to provide 24/7 awareness for people with epilepsy and their families. IBM is developing a wearable chip, similar to the one shown in the figure below, meant to be worn by people whose medication may not be improving their symptoms, as a warning system to alert the patient and nearby by people to get help (Draper, 2019, para. 1). According to an article on *IEEE Spectrum*, this device is still in the proof-of-concept stage because they “need to reduce the false positive rate before this system can be used as a real device on patients,” (Waltz, 2017, para. 5-6). If this technology were to use a more reputable algorithm such as EMD, this could increase the accuracy and effectiveness of a similar.

Figure 1. First FDA approved portable seizure monitor by Empatica.

A study documented on *IEEE Xplore* described how EMD “first computes the Intrinsic Mode Functions (IMFs) of EEG records, then calculates the energy of each IMF and performs the detection based on an energy threshold,” (Orosco, Laciar & Correa, et al., 2009, para. 1). IMF’s are functions that the algorithm generates based on the EEG data, that are used to determine whether or not epileptic activity is present. This process allows EMD to have a high accuracy rate; thus, using this algorithm on the wearable chip could yield better results than IBM’s algorithm, making the chip a product that is viable for human use. With that being said, the DWT algorithm would be a more effective option, as its dynamic settings make it more efficient and accurate than EMD.

**Support**

**Technical Details**

A screenshot of a cell phone

Description automatically generatedThe Discrete Wavelet Transform (DWT) algorithm has proven extremely effective in recent years as a way to analyze EEG data. As described in an *IEEE Xplore* article, the process of DWT, similar to the EMD algorithm, follows three main stages. The algorithm begins by splitting the EEG signal into several sub-bands, as shown in Figure 2 (Hamad, Houssein & Hassenein, et al., 2017). The algorithm then extracts the necessary information from the sub-bands and determines whether or not the data is indicative of epileptic activity (Deshmukh, Ingle & Kehri, et al., 2017, para. 1). As stated in a journal article by Laxman Tawade and Hemant Warpe (2011), the majority of the information used when identifying seizures is found in the delta band. Once the delta band has been isolated from the rest of the data, DWT, along with the use of a neural network classifier, is able to compare normal and epileptic data waves to determine whether or not a seizure is taking place (Tawade & Warpe, 2011, para. 3). This process alone yields high results; however, DWT is unique in that it offers a variety of configurable settings in order to achieve even better results. As stated in an article titled *A high-performance seizure detection algorithm based on Discrete Wavelet Transform (DWT) and* EEG, a wavelet is “a quickly vanishing oscillating function localized both in frequency and time domains,” (Chen, Wan, Xiang, et al., 2017, para. 15). During the process of splitting the EEG data into two sub-bands, the algorithm uses the data to form a function called the mother wavelet. This mother wavelet is used as the basis to identify seizure activity in the EEG data (Chen, Wan & Xiang, 2017, para. 16). Given that this mother wavelet is such a crucial factor in the algorithm’s success, it is paramount that an appropriate mother wavelet is selected. This process of choosing the mother wavelet is where the DWT’s settings are immensely valuable.

Figure 2. Sub-bands of EEG data set after being separated by DWT.

One major parameter of the DWT algorithm is the decomposition level. There are various decomposition levels that can be applied to the EEG data; however, if used carelessly, they can lead to errors in the detection process. According to the aforementioned article, as more decomposition levels are applied to the data, they provide a clearer depiction of the EEG signal. If too many levels are applied, though, the process of analyzing the data can be prolonged and lead to inaccuracies in seizure detection (Chen, Wan & Xiang, 2017, para. 19). When applied properly, the decomposition level is a critical parameter that improves the efficiency of the algorithm. The decomposition levels go hand in hand with an aspect of the EEG data itself, the frequency band.

The different decomposition levels that DWT has at its disposal all correspond to a specific frequency band. A frequency band data responsible for generating the EEG segments that the DWT algorithm analyzes. The proper decomposition levels in tandem with the right frequency band can yield extremely high results, as shown in the study discussed in this article in which they had upwards of a 92% accuracy rate on the two EEG data sets that they used the DWT algorithm on (Chen, Wan & Xiang, 2017, para. 7). These results prove that DWT is more consistent and accurate than the EMD method.

A close up of a logo

Description automatically generated The Empirical Mode Decomposition (EMD) algorithm is another method for detecting epileptic activity in EEG signals that has been studied in recent years. As described in an article titled “An Epileptic Seizures Detection Algorithm Based on The Empirical Mode Decomposition of EEG”, the process of shares some similarities to that of DWT, but ultimately differs in one major area. Unlike DWT, EMD does not have any parameters that can be adjusted based on the patient or the data that is provided. Due to the absence of those extra variables, EMD follows a simpler, fixed process for detecting seizures among EEG signals. Firstly, the algorithm analyzes the Intrinsic Mode Function (IMF) algorithms of the EEG data. Figure 3 shows an example of the raw EEG data the EMD derives the IMFs from (QEEG, n.d., para. 6). These functions used during the EMD process in order to classify the brain activity depicted by the EEG waves. After identifying the IMFs, the algorithm proceeds to calculate the energy values of each function and use this information to determine whether or not a seizure is occurring (Orosco, Laciar & Correa, et al., 2009, para. 1). This process, while simple, does yield relatively high results as, according to the previously mentioned article, after analyzing 90 segments of EEG data the algorithm yielded roughly a 75% success rate (Orosco, Laciar & Correa, et al., 2009, para. 1).

Figure 3. Raw EEG data used by EMD to produce Intrinsic Mode Functions.

One argument against the viability of DWT is that the algorithm is inconsistent as it relies heavily on its parameters to perform optimally; however, with the correct settings, the DWT method is more efficient in breaking down the data and it is also almost 20% more accurate. This difference in accuracy is not only significant on paper but can make a considerable difference in the lives of those with epilepsy.

**Social Impact**

A picture containing monitor

Description automatically generatedDespite not being among the most well-known neurological diseases, Epilepsy is an extremely dangerous condition; therefore, it is important to take into account the impact that an effective automatic seizure detection algorithm can have. If someone who suffers from epilepsy were to have a grand mal seizure, a severe seizure that effects the entire body, with no warning and nobody around to assist them, it could lead to serious injuries or even death. As shown in the figure above, SUDEP is the cause of the second highest amount of potential years lost due to a neurological disease with about 100,000 years of potential life lost (Picard, 2018). In her previously mentioned TEDx talk on seizure detection, Picard states that SUDEP does not occur during the seizure itself, but directly after it. After a severe seizure, there is a chance for the person to enter a state of distress in which they are unable to breathe unless stimulated by an outside source (Picard, 2018). Situations like these highlight the importance of accurate and efficient seizure detection algorithms. Apart from taking medication to lower the effects of epilepsy symptoms, the most effective way to reduce the risk of injuries or deaths caused by seizures is to have someone there in the event of a seizure so that they can get the necessary help or assist themselves (Picard, 2018). In the current era of technology, it is possible to have seizure monitoring available to epilepsy patients at all times, but it must be effective in order for it to serve its purpose.

Figure 4. Graph comparing years of potential life lost due to SUDEP to other neurological disorder.

In an article published in *IEEE Spectrum*, author Emily Waltz discusses a project being worked on by researchers at IBM. They are developing “a wearable warning system that detects pre-seizure brain activity and alerts people of the onset,” (Waltz, 2017, para. 1). This warning system could help alleviate the high amounts of stress for both the patient and their families that come along with the spontaneity of epilepsy. While it may not prevent the seizures themselves from occurring, it would remove the element of surprise and allow them to prepare for the situation that may occur which, as Picard stated previously, is one of the most effective ways to reduce the risk of seizure-induced injuries. As stated in Waltz’s article, however, IBM researchers have said that this product is still in its early stages due to its sensitive algorithm which caused the device to enter its warning mode too frequently and gave a high number of false positives (Waltz, 2017, para. 6). This situation is where more effective, well-tested algorithms could play a critical role. Using DWT in a wearable warning device for constant seizure monitoring could have a significant impact on the amount of years lost due to SUDEP. While DWT’s advantage over EMD is its settings, this does not invalidate it as an option for a portable device. If a device such as this wearable chip were to incorporate the DWT algorithm for increased accuracy, it could be programed individually with the settings that would best suit the patient based on previously gathered EEG data. This device would be a substantial tool, allowing for patients and their families to have access to a portable warning system with over a 92% accuracy rate at all times.

**Ethical Analysis**

As with any major development in technology, it is important to discuss the ethics surrounding the topic. There are several ethicists’ perspectives which can be used to analyze the concept of a constant seizure warning device, two of whom are John Stuart Mill and Thomas Hobbes. Going off of Mill’s mindset of utilitarianism, one must consider the utility of this warning device for all parties involved. The primary parties effected by this device include the companies whose resources are being put towards developing and manufacturing this technology, and the patients and families who would use this device. The direct impact of this situation on the company would be use of resources. In order to develop a technology like this that is actually effective and reliable, the company must sacrifice time, money, and people. At first glance, this use of resources appears to be a negative impact; however, while the product it will have a positive impact on the company once it is available to the public. Once the device is ready for use by patients, hospitals will purchase the device for their patients and recommend it to others, giving them money to make up for the resources spent, as well as a boost in reputability. These benefits to the company come in addition to the patients and their families feeling safer in their day to day live because of this product. Due to all major parties seeing a positive impact, this product would yield a high net utility; thus, Mill would see the development and use of this device as ethical.

Another ethicist whose ideas are important to consider in this situation is Thomas Hobbes. According to Hobbes’ idea of social contracts, it is the responsibility of tech companies to provide products that are useful and reliable to the public. Given the tens of millions of people effected by epilepsy, this warning device would be extremely impactful. Not only would it have a practical use in these people’s daily lives, but it also provides them with the security and ease-of-mind that they otherwise would not have. For these reasons, both Mill and Hobbes view the use of DWT for portable automatic seizure detection as an ethical practice.

**Conclusion**

Epilepsy is a serious neurological condition that effects over 50 million people around the world; thus, the data surrounding both the DWT and EMD algorithms is important to analyze. Both algorithms are extremely effective and have proven to be useful in detecting seizures before they occur. EMD makes use of the IMF functions gathered from the EEG signal in order to categorize the data into either normal or epileptic depending on the energy levels of the functions when compared to an energy threshold. DWT, on the other hand, has a more complex process of decomposing the EEG data into multiple sub-bands from which it can extract various pieces of information and ultimately determine whether or not the brain activity is indicative of an incoming seizure. Despite the EMD algorithm being popular in recent years and proving useful with a 75% accuracy rate, DWT has a clear edge with an accuracy rate of over 92%, determined from testing on various EEG data sets. This advantage is attributed to the DWT algorithm’s settings that can be adjusted on a per case basis in order to perform most efficiently and yield the highest results, increasing its value over EMD, not only from a statistical standpoint, but from a practical one as well. The higher accuracy rate allows the patient and the family to be more aware epileptic events that would otherwise occur without warning, which is extremely dangerous for the patient as there is a chance that they suffer from SUDEP if nobody is there to assist them. DWT can also serve as a much larger tool should it be implemented with something such as IBM’s wearable chip product, giving the patient a highly accurate warning system for a highly spontaneous condition. This algorithm, if used to its full potential, could provide a much greater sense of security and safety for those who suffer with epilepsy and their families who go through each day with the constant fear that a seizure could occur at any moment, and they were not prepared for it.

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