Assessment of Epileptic Seizures and Non-Epileptic Seizures via Wearable Sensors and Priori Detection of Epileptic Seizures

Ömer Faruk Ertuğrul, Yasin Sönmez, Necmettin Sezgin and Eşref Akil

Abstract— **Epilepsy is one the most prevalent neurological disorders whose causes are not exactly known. Diagnosis and treatment of epilepsy are closely related to the patient's story, and the most important indicator is the frequency and severity of seizures. Since the disease does not only affect the patients but also the lives of their environment seriously, it is very important to make the diagnosis and treatment correctly. However, sometimes misrecognition from patients and their relatives, unnecessary epilepsy treatment to the patient in non-epileptic seizures mixed with epileptic seizures, or increasing the dose of the drugs used for the patient are the situations frequently encountered.**

The so-called video-EEG method is used in the detection and segregation of epileptic / non-epileptic seizures. In this method, the patient is kept in an environment where video recording is continuously taken until the seizure occurs, and EEG, EMG, and ECG records of the patient are taken. When the patient has a seizure, the seizure type is separated by examining these records. In this project, seizure detection and seizure type (epileptic / non-epileptic) detection is aimed to be done by using wearable sensors increasingly applied in the field of health. The achievable benefits from the project and data set will provide a different perspective on the epilepsy illness, as well as reduce the number of epilepsy patients who are not in fact epilepsy patients needing treatment, and keep epileptic seizure recordings constantly in the electronic environment so that the treatment processes are monitored more closely.

Index Terms— **Epilepsy; Epileptic Seizures; Non-Epileptic Seizures; Priori Detection of Epileptic Seizures**

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Manuscript received January 17, 2022; accepted March 5, 2022.

DOI: 10.17694/bajece.1054818

I. Introduction

EPILEPSY is one of the most common neurological diseases in society and is generally analyzed using EEG signals (Sezgin et al., 2013; Kaya et al., 2012; Proix et al., 2021). According to WHO, the prevalence of epilepsy disease is in the range of 0.4-1% (Çakıl et al., 2013, Kanas et al., 2015). Epilepsy can be divided into two sub-groups and the reason behind the more common subgroup, which is the idiopathic epilepsy subgroup, is unknown. The other subgroup is based on some physiological or hereditary reasons. Since epilepsy is a disease that requires long-term treatment, its diagnosis has great importance and the most important symptom for diagnosis is seizures. However, in addition to epileptic seizures, which is associated with simultaneous neuronal activity, non-epileptic seizures (pseudo-epileptic, psychogenic, or physiological seizures), which are not associated with dysfunction of the central nervous system, may present symptoms similar to epileptic seizures and make it difficult to diagnose (Arıkanoğlu, 2011; Kanas et al., 2015; Lai et al., 2022). An epileptic and non-epileptic EEG signals, which were recorded from epileptic and non-epileptic patients in Dicle University, Faculty of Medicine, Department of Neurology, were given in Figure 1(a), and 1(b), respectively.

As seen in Figure 1(a) and 1(b), the EEG signal, which can be taken during a seizure is enough to classify it as an epileptic or non-epileptic seizure, and the main difference between epileptic and non-epileptic seizures is that epileptic seizures are accompanied by neuronal discharges, on the other hand, no special changes are observed in EEG in non-epileptic seizures (Arıkanoğlu, 2011; Tatlı, 2004; Cobb and Beebe, 2022).

However, the most important problems in differentiating epileptic and non-epileptic seizures are that the patient comes to the medical doctor after having a seizure and sometimes non-epileptic seizures occur in patients who have had epileptic seizures (Kotsopoulos et al., 2003; D'Alessio et al., 2006). For this reason, the first diagnosis is mostly made according to the patient and his environment (medical history) and the age of the patient (Çakıl et al., 2013; Arıkanoğlu, 2011; Tatlı, 2004), since the EEG recordings of the patient cannot be obtained at the time of the seizure.

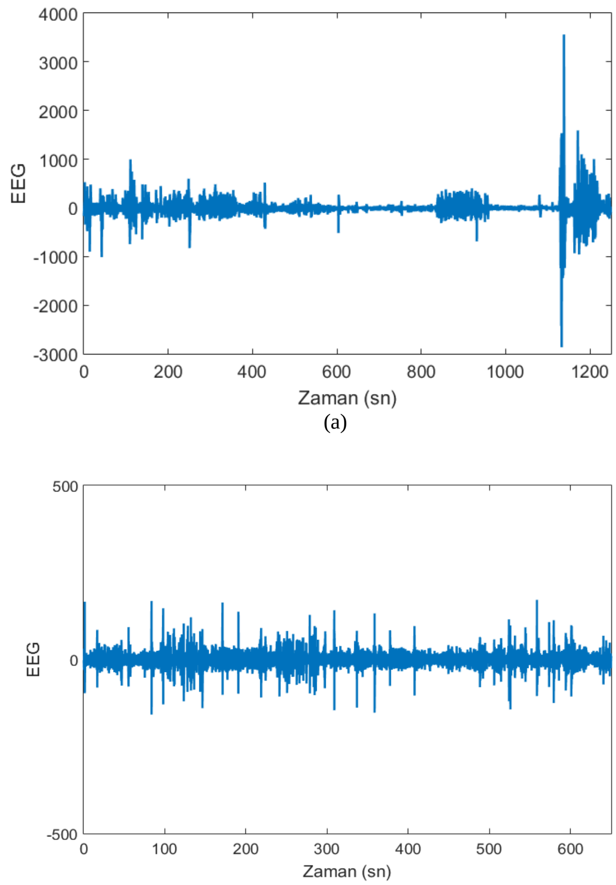

Figure 1.(a) EEG signal change during epileptic seizure process, (b) EEG signal change during non-epileptic seizure process

Bodde et al. (2009) stated in their review study that it is not easy to distinguish between epileptic and non-epileptic seizures, and the cost per patient of misdiagnosis is around $231,432. It has been stated that the estimated annual loss from misdiagnosis of epilepsy in the UK alone is around £185 million (Kanas et al., 2015). It has been reported that 10-20% of patients who applied to a physician with the suspicion of having epileptic seizures were not epileptic (Cuthill and Espie, 2005). It was stated that in case of misdiagnosis (diagnosis of epilepsy in a patient with non-epileptic seizures), the treatment was stopped based on the patient's response to epileptic drugs, and this process has established an average of 7.2 years after the patient started the treatment (Çakıl et al., 2013; Reuber and Elger, 2003).

Considering that many unnecessary antiepileptic drugs are given to the patient during this wrong treatment process, many side effects occur in patients due to these drugs, it causes significant labor, time, and cost, and the patient's quality of life decreases, it is seen how important it is to differentiate non-epileptic seizures from epileptic seizures in the early period. (Çakıl et al., 2013; Arıkanoğlu, 2011; Kanas et al., 2015).

For these reasons, it is vital to detect epileptic and non-epileptic seizures with a good differential method (Çakıl et al., 2013; Arıkanoğlu, 2011; Araz et al., 2009; Buchanna et al., 2022). Many EEG-based differential tests have been recommended for differential diagnosis due to their low cost, and success rates of 60-90% have been reported with these tests (Çakıl et al., 2013). On the other hand, no adequate method has been proposed to differentiate epileptic and non-epileptic seizures except video-EEG (Kotsopoulos et al., 2003; Bodde et al., 2009; Cuthill and Espie, 2005; Reuber, 2008; Çakıl et al., 2013). Video-EEG, on the other hand, is an expensive and long-term test routine that bothers the patient. In order to obtain distinctive results in video-EEG, the patient must have had a seizure during the recording process. In addition to video-EEG, age-related autonomic nervous system tests, serum prolactin levels, neurocardiogenic and psychological tests are also used for this purpose (Çakıl et al., 2013; Arıkanoğlu, 2011; Tatlı, 2004; Araz et al., 2009; Bodde et al., 2009; Cuthill and Espie, 2005; Cragar et al., 2002; Reuber and Elger, 2003; Reuber, 2008). These suggested tests are based on the statistical analysis of the physiological characteristics of the patients or the test results obtained (Kotsopoulos et al., 2003; D'Alessio et al., 2006; Turner et al., 2011). For example, patients' response to epileptic drugs, seizure frequency, genetic epileptic history, seizure characteristics, physiological and neurophysiological tests, and similar parameters were used for this purpose (Cragar et al., 2002; Reuber and Elger, 2003; Reuber, 2008).

With the decrease in size and cost of wearable sensors, they have started to be used in many areas, including health applications (Akbulut and Akan, 2015; Worrell et al., 2021). It has been reported that successful results were obtained by using signals from wearable sensors (especially accelerometers) during the seizure process as a differential diagnosis (Gubbi et al., 2015; Kusmakar et al., 2015-a, 2015-b). The methods recommended in the literature and the success rates obtained for the differentiation of epileptic and non-epileptic seizures are summarized in Table 1.

Table 1. Success rates in differentiating epileptic and non-epileptic seizures

Reference	Seizures	Data Type	Method	Accuracy
Kanas et al. (2015)	126	EEG	Support Vector Machines	%96
Xu et al. (2014)	25	EEG	Support Vector Machines	%92
Pippa et al. (2014)	205	EEG	Bayes	%86
Gubbi et al. (2015)	27	Accelerometer	k Means and Support Vector Machines	%93.3
Kusmakar et al. (2015-a)	34	Accelerometer	Support Vector Machines	% 89
Kusmakar et al. (2015-b)	34	Accelerometer	Support Vector Machines	%80

When Table 1 is examined, it is observed that differential diagnosis is achieved with high success when EEG signals are used. However, it is not easy to obtain a differential diagnosis with this method, since it is difficult to predict the moment of seizure and the EEG signals received for differential diagnosis must be at the time of seizure. On the other hand, wearable sensors are used for many different purposes in integration with many systems such as smartwatches or mobile phones without reducing the comfort of life.

The main reason that motivates us for this study is to provide a test routine for the differential diagnosis of epilepsy that will cause less discomfort to the patient and their relatives and can be applied at a low cost. The development of such a test method will not only differentiate between epileptic and non-epileptic seizures but will also enable the digital recording of seizures and seizure characteristics, opening the door to many possibilities that could improve the quality of life of epileptic patients.

In addition, seizure detection (Gonzalez-Velldn et al., 2003; Yadav et al., 2009; Hussain et al., 2021) is an important process for the detection and treatment of the disease, as well as an important output to improve the quality of life of the patient and their relatives. Because the relatives of the patients put limits on the patient's and their own economic and social lives due to the patient's desire to be taken into consideration, as the patient has the possibility of having a seizure, and naturally their quality of life decreases. Detecting the moment of epilepsy of the patient will open the way of informing/warning the relatives of the patient with simple software, and the number and characteristics of seizures also contain important information in terms of the course of the disease.

II. MATERIAL AND METHODS

A. Dataset

Patients who routinely apply to the Dicle University Hospital, Department of Neurology for diagnosis and treatment and whose seizures cannot be differentiated as epileptic or non-epileptic seizures are subjected to video-EEG testing. In this test, both EEG, ECG, and EMG recordings of a total of 88 patients are taken and they are recorded with the video. In this process, after the patient has a seizure, the images of this seizure process and the recorded EEG, ECG, and EMG signals are examined, and a diagnosis is made about whether the patient has epilepsy or not.

In addition to this routine test, additional information from the patient was recorded with a sensor node to be attached to each leg and arm of the patient, as seen in Figure 2. Obtained sensor records were recorded on the computer. In addition, each record was recorded by associating the diagnosis of the expert neurologist with the record in question, and the data set used in the study was formed.

Figure 2. Obtained sensor records were recorded on the computer.

In summary, while creating the data set, 18-channel EEG, ECG, and EMG signals received during the routine video-EEG tests taken from the subjects during epileptic and non-epileptic seizures, signals received from wearable sensors attached to the arms and legs, and the diagnosis of the specialist neurologist (epileptic or non-epileptic seizure) information. has been recorded in accordance with the permission of the regional ethical committee (Per. no.: 2016/352, Provider: Dicle University Ethical Committee).

B. Method

Wearable sensors have started to be used in many areas with the decrease in the size, cost, and energy needs of the sensors and the developments in communication and processor technologies. In the literature review, it was seen that wearable sensors were used successfully in detecting seizures and seizure types (Nei, 2009; Zijlmans et al., 2002; Behbahani et al., 2012). The connection of the sensors is shown in Figure 3.

Figure 3. The connection of the sensors.

In addition, the data from the sensor nodes were transferred to the portable computer with an Arduino Due and RF transceiver. The energy needs of the sensor nodes are met by a rechargeable lipo battery. In Figure 4, there is a sample epileptic seizure and EEG signal of non-epileptic seizure process taken from patients treated in Dicle University, Faculty of Medicine, Department of Neurology.

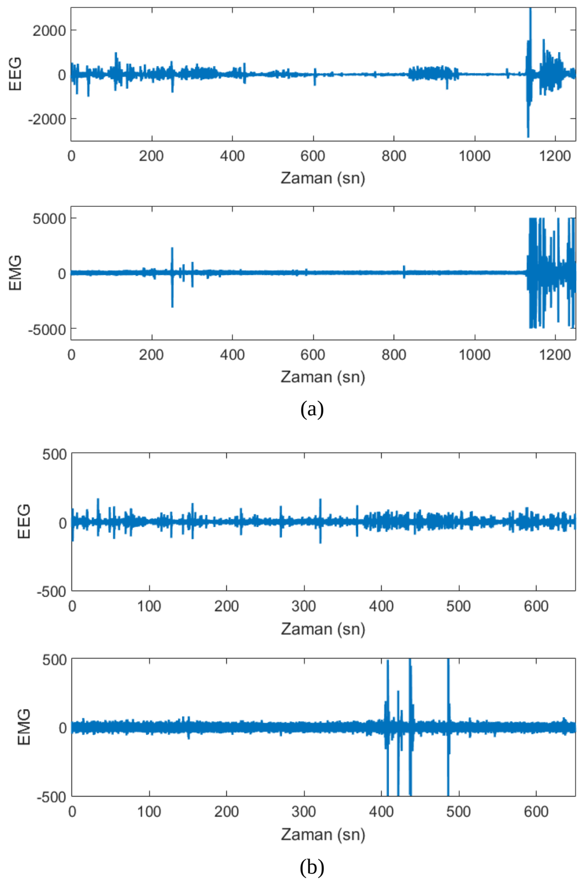

Figure 4. Example for Seizure Segregation (a) Epileptic Seizure, (b) Non-Epileptic Seizure

For the purpose of seizure detection, a priori seizures detection, and seizures type detection:

1. Extracting features from the signal,
2. Determining the features that are active for each target of the extracted features,
3. Classification with artificial intelligence,

stages were carried out.

III. Results and Discussion

Statistical features extracted from the processed signals are classified by artificial intelligence. All classification results were obtained and reported by 5-part cross-validation. First of all, the artificial intelligence method used in all experiments was optimized and the obtained accuracy results were shared. The following classification processes were performed in the simulations

- Seizures Detection: It is the determination of whether the patient has seizures (epileptic or non-epileptic).
- Seizures Type Detection: Separation of epileptic / non-epileptic seizures,
- Classification of all data: Normal/Epileptic/Non-Epileptic signals,

As an example of optimization, the results obtained in the process of seizures detection of EEG, ECG + EMG signals, and wearable sensors in detecting seizure types, and separation of all data are summarized in Table 2.

Table 3. Accuracies (%) in the detection of a seizure before it occurs

Dataset	Detection of Seizures	Detection of Seizure Type	Classification of Signal
EEG	**100**	**100**	**100**
ECG + EMG	100	98,2	**95,4**
Wearable S.	100	100	**100**

As can be seen from the literature, it is possible to achieve higher success with fewer features. This is because higher achievements can be achieved by not using complex, noisy or irrelevant features. In addition, using fewer features reduces the operational load and memory requirement, which allows more successful and real-time usable hardware to be developed with fewer data and processor capacity.

In addition, seizures were detected a priori using wearable sensors. The signal was processed with the method used previously and the obtained features were classified and the accuracy rates obtained with the wearable sensor attached to the upper arm are summarized in Table 3.

Table 3. Accuracies (%) in the detection of a seizure before it occurs.

Task	Accuracy (%)
Detection of an epileptic seizure 0-10 seconds before it occurs	100
Detection of an epileptic seizure 10-20 seconds before it occurs	100
Detection of an epileptic seizure 20-30 seconds before it occurs	100
Detection of an epileptic seizure 60-70 seconds before it occurs	98,5
Detection of an epileptic seizure 90-100 seconds before it occurs	97,6
Detection of an epileptic seizure 120-130 seconds before it occurs	95,6
Detection of an epileptic seizure 150-160 seconds before it occurs	94,9
Detection of an epileptic seizure 180-190 seconds before it occurs	92,2

As it can be seen from Table 3, the proposed approach can be successfully employed in the detection of a seizure before it occurs. It was seen from the results that although the human does not know that a seizure will have occurred, his body knows and tries to protect itself. Furthermore, a device was designed and its details can be found in www.insense.com.tr.

The designed device was employed in order to send the sensor data to a mobile phone that was paired. In mobile phone, the received signals were processed and relevant features were extracted. The extracted features were classified by a machine learning method. Each of the trained three learning methods have been employed to generate a decision about epileptic status, type of the seizure and the pre-epileptic status. Generated alarms were also saved to a database and may be shared with medical doctors according to the permission of the user.

IV. CONCLUSION

This paper reports the results of detecting, classifying, and pre-detecting an epileptic seizure. The obtained results showed that the employed methodology is good enough to be successfully detecting, classify, and pre-detecting an epileptic seizure. Furthermore, the proposed method was employed in a real-time device

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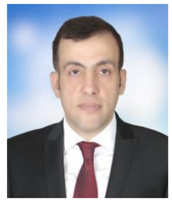
BIOGRAPHIES



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