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ANALYSIS OF WEARABLE SENSOR SYSTEM RELIABILITY IN THE MONITORING OF EPILEPTIC SEIZURES

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Abstract

The objectives of this paper are to review the existing wearable sensor systems used in seizure monitoring and determine the system reliability, while also suggesting a standardized reliability evaluation model for the systems. Research is purely a literature review and is focused on evaluating the seizure monitoring system based on the rate of false alarms.
Keywords:- *Wearable sensors, Epilepsy, Accelerometry, EEG and ECG based seizure detection methods, electrodermal systems, Generalized Tonic-Clonic Seizures*

Introduction

Wearable sensors refer to any 'wearables' that may be strapped onto the body or are weaved in with clothing. Evidence of wearable sensors use in healthcare monitoring dates back to the 1980s. Epileptic seizure management aided solely by medication is still a struggle, and it is believed that wearable sensors based monitoring could improve the providence of healthcare in this case. While the idea of wearable sensors in healthcare usually just brings to mind the Fitbit and other devices like the apple watch, several more specialized methods exist for seizure, especially epileptic seizure, monitoring. The paper will first analyse the functioning of the systems in place and then evaluate reliability in the results section by taking into account FPRs (false positive rates) and other measurements of each system's reliability. Discussion is necessary since some of the difficulties in managing treatment-refractory epilepsy can be ameliorated by the ability to detect clinical seizures [5].

The fact that diagnoses and treatment are to be reliant on data collected through these wearable sensors the data they yield must be accurate, valid and relevant.

Theory

Over the past few decades, several different wearable sensor systems have been put into practice in the monitoring of epileptic seizures in a hospital environment. The following section will discuss and describe at length each of the 3 most popular systems. The content will be limited to the functioning of each of the systems.

I. Accelerometry

This is a widely used monitoring system. It involves the use of a wrist-band accelerometer device which works by detecting vibrations to measure the proper acceleration of a body. Three-dimensional accelerometric devices are the preferred ones, of which the Empatica Embrace wristbands are the first commercially available multimodal wristbands that were designed to notice physiological markers of ongoing Generalized Tonic-Clonic Seizures [5]. The devices work by identifying accelerometric and electroencephalographic signatures of a grand mal seizure caused among epileptic patients. The data is then transferred to a mobile phone via

Bluetooth where the data can be accessed by caregivers and medical professionals. Identification of GTCS risk is especially important as it is one of the leading causes of SUDEP and helps to draw out individual care plans to prevent a fatal episode to the best of the healthcare provider's abilities.

II. ECG and EEG based seizure detection systems

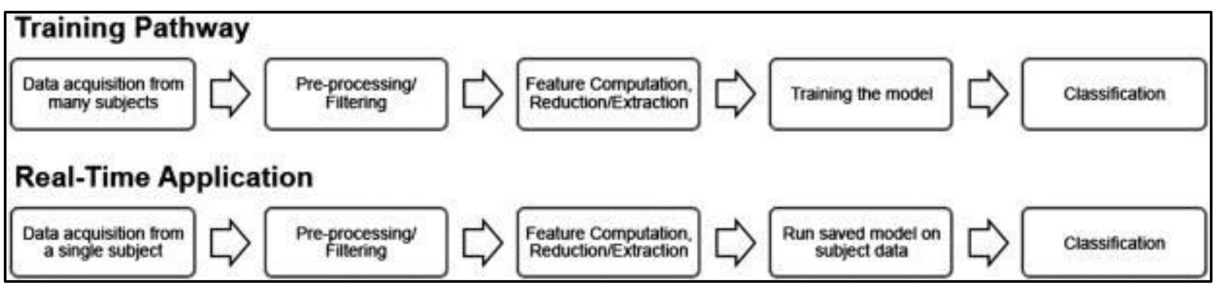
Epileptic seizures occur as a result of abnormal brain activity, so it is only rational to include Electrocardiogram and Electroencephalogram based sensors as part of their detection and analysis. The combination of EEG and ECG works by using physiological changes that happen before or during a seizure or an epileptiform discharge to activate an electromagnet worn as a wearable sensor by the patient. In this case, this is done through heart rate monitoring and brain activity tracking also using wearable wireless biosensors.

III. Electrodermal systems

EDA or electrodermal activity is another factor that is monitored among epileptic patients. The wearable sensors developed for this, work by tracking the modulation in skin conductance to account for the exclusively sympathetic activity in the body [9]. The theory behind the devices monitoring EDA is that the skin conductance is disturbed by seizures, especially GTCS ones. This works because during a seizure the skin conductance drops and there is a notable increase in EDA. The wearable sensors are placed in the form of electrodes in a band that is to be worn on the forearm. The battery packs are changed every 24 hours, and EEG and ECG monitoring systems are also in place to provide the seizure locator and semiological data.

All the wearable sensor systems shared the data collection pathways highlighted in the picture below, which has been taken from a study.

Fig. 1 [5]



Result

I. Accelerometry

In the case of the Empatica Embrace the sensitivity is 94.5 % while the false alarm rate is 0.2 per patient per day [3]. While the rates are quite promising we cannot completely trust the data. The wearable sensors are adept at identifying shaking that may result from a seizure, but it does not take into account the other indicators or even seizures of different kinds that are not generalized. As described in a paper 'accelerometers are subject to occasional technical and user-induced failures, and do not currently detect seizures lacking rhythmical shaking' [6]. Furthermore, another study quoted that during 36 hours 897 seizures occurred, of which 48% were accurately detected by accelerometric wearables, and that the detection was higher than what would have been otherwise reported by medical practitioners.

II. ECG and EEG based seizure detection systems

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The results of such seizure detection systems showed that the EEG system was able to accurately detect 92% of seizures and 0.2 ± 0.7 false alarms per hour [2].

III. Electrodermal systems

The first analysis of reliability is based on the data obtained in an experiment published in the paper: Continuous Monitoring of Electrodermal Activity During Epileptic Seizures Using a Wearable Sensor. The study's results showed that the wearable sensors were able to detect seizures through EDA accurately and the data also differentiate GTCS and CPS. The statistical comparison of EDA during CPS and GTCS was done using the Wilcoxon rank-sum test, p values < 0.05 were identified as important.

As a consolidated conclusion of the analysis of the reliability of the most commonly used wearable sensor systems, I felt it necessary to include the table below, which is from the paper 'Seizure Diaries and Forecasting With Wearables: Epilepsy Monitoring Outside the Clinic,': [3].

Table 1.

Study	Device	Signal(s)	Environment	Seizure type	Patients (seizures)	Sensitivity (%)	False alarms per day
Beniczky (56)	IctalCare EDDI	EMG	EMU	GTCS	71 (32)	93.8	0.67
Halford (57)	BrainSentinel SPEAC	EMG	EMU	GTCS	199 (46)	76	2.52
					149 (29)[a]	100[a]	1.44[a]
Onorati (49)	Empatica E4	ACC,EDA	EMU	GTCS	69 (22)	94.5[b]	0.2[b]
Vandencasteele (58)	180° eMotion Faros	EKG	EMU	CP (FT)	11 (47)	70	51.6
	Empatica E4	PPG				32	43.2
Johansson (59)	Shimmer3, custom device	ACC	EMU	TCS	8 (10)[c]	100[b]	1.2[b]
Heidberg (51)	Empatica E3	ACC, EDA	EMU	Multiple	8 (55)	89.1[d]	18.1[e]
Jeppesen (60)	ePatch	EKG	EMU	Focal, GTCS	43 (125)[f]	93.1[f]	1.1[f]

Conclusion

Research has shown that the initial hypothesis that the wearable sensors used in epileptic seizure monitoring are not very reliable is untrue. The wearable biosensors available are shown to have good accuracy rates and have significantly aided the providence of good healthcare. Wearable biosensors are not only enabling around the clock monitoring but also improving quality of life and possibly even reducing chances of SUDEP.

However, if we apply the false-positive rates to real-life numbers there are still a lot of discrepancies and the number of patients not receiving reliable data is still high. Accelerometric is efficient and accurate, but it does not differentiate between seizures or help with locating origin either. EEG & ECG systems and EDA monitoring systems do not allow for as much mobility. Technological advancements should be encouraged through funding.

Even though similar data was gathered from each of the wearable sensor systems we must note that there is no standardization in the way we can analyse reliability. It is easy to evaluate an individual system's reliability, but hard to compare it with the reliability of other. The checklist provided at the conclusion of the paper 'Recommendations for Assessment of the Reliability, Sensitivity and Validity of Data Provided by Wearable Sensors Designed for Monitoring Physical Activity should be considered for standardization.

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