EEG Monitoring in Driving Using Embedded Systems

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Abstract. Epilepsy is a disease that can appear in all age groups, where many patients only have their diagnoses confirmed at more advanced ages and at different stages of their life. This disease manifests through partial and/or total seizures. To avoid more drastic consequences, an accurate diagnosis of seizures is essential to provide the correct medication to the patient. Although many patients are able to control seizures using a single drug, others need multiple medications or even complementary measures. In addition, epilepsy can make the quality of life substantially difficult due to seizures, however, it can also reduce the autonomy of patients in day-to-day tasks such as driving - in most countries, after the diagnosis of epilepsy, the patient is inhibited from driving for a period of time. This paper, through a set of chips and sensors, provides a solution to identify seizures through the study of a patient's electroencephalogram (EEG) waves, then applies several safety measures to protect the patient while driving.

Keywords: Epilepsy · Sensors · Driving · IoT · Edge Computing

1 Introduction

Epilepsy [1] is a disease in the brain, which affects both sexes and all ages and is mainly characterized by generating seizures. These seizures [2] have been defined by the International League Against Epilepsy as the transient occurrence of signs and/or symptoms as a result of abnormal, excessive, or synchronous neuronal brain activity. The root cause of these seizures currently isn't totally known, may result from trauma, hereditary disease, or an unknown cause. In this way,

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in 1989 [3], the International League Against Epilepsy proposed a classification of epilepsies and epileptic syndrome, grouping them by their symptoms (generalized or focal) and by their etiology (idiopathic and symptomatic).

However, regardless of the cause, the consequences [4] of this disease can be quite severe, including, for example, reduced life expectancy, risk of serious bodily injury, among others. There is even evidence that seizures cause brain damage, including neuronal death and physiological dysfunction. Controlling seizures is vital for the patient's quality of life to be impaired as much as possible since seizures potentially pose a serious threat to health and well-being.

One of the leading social consequences of people with epilepsy is severe driving restrictions [5]. An epileptic seizure leads to loss of situational awareness, which can have very serious consequences, particularly if such seizures occur while the patient is driving, putting the patient and other people's lives at risk. Therefore, when this disease is diagnosed, patients cannot, or at least should not, drive. Evidence shows that in the absence of seizures, the risk of accidents and injuries is reduced and tends to be close to that of the general population. However, the variability of published reports on risk led to several regulations, where each country developed its own rules on epilepsy and driving.

This paper, using a set of chips and sensors, provides a possible solution for monitoring people, diagnosed with epilepsy, while they are driving. This monitoring is performed by processing the EEC waves, using intelligent algorithms on the received data. The results of this analysis are mitigation measures in the vehicle to avoid accidents or other injuries.

The remaining of this paper is organized as follows: in Sect. 2 are described the solutions similar to the illustrated; the technical details of the proposed solution are described in Sect. 3; the preliminary results of some tests already performed are described in Sect. 4; in Sect. 5 is detailed the conclusions and directions for future work.

2 Related Work

Some solutions similar to the approach presented in this paper were found in the state of the art. In [6] is described a solution that intends to improve the emergency braking system, using the analysis of the EEG waves, however, the study of this solution makes no reference to the detection of seizures.

In [7], another approach using IoT and EEG waves is described for driver fatigue analysis. The main idea of this approach is to monitor the cerebral waves and heartbeat to identify fatigue while driving.

Adapted from the Automotive Open System Architecture (AUTOSAR) framework, the main idea of this solution [8] focuses on predicting driver performance before starting driving, based on the waves of EEG, however, as in previous solutions, there is no reference to seizures.

In [9] the authors propose an EEG acquisition and emotion classification scheme in a simulated driving environment. The scheme uses vehicle speed as a variable to simulate different danger levels and evaluate driver capability to avoid obstacles under such conditions. The approach does not focus on epileptic seizure but shares the same effort of capturing and processing the EEG signals.

In [10] is presented a review on physiological signal-based emotion recognition, an approach that among other applications, is also used in the implementation of solutions and technologies for safety driving. The review includes emotion models, emotion elicitation methods, emotional physiological datasets, features, classifiers, and emotion recognition based on physiological signals.

A literature review of the state-of-the-art of emotion recognition systems from EEG signals was published by [11]. Besides a summary of definitions and theories, the authors evaluated several deep learning and shallow machine learning approaches, considering methods, classifiers, number of classified emotions, accuracy, and datasets. It is an important work for a broader perception of what has been done recently in this area.

3 Proposed Solution

The proposal is based on a client-server architecture as can be analyzed in Fig. 1. The client component placed inside the car is an IoT module able to communicate using both LTE/NB-IoT and Bluetooth Low Energy (BLE). It also uses NeuroSky EEG biosensors to collect EEG signals, which must be coupled to the driver.

NeuroSky EEG biosensors allow accurate capture of the brain's electrical signals. It is very similar to a pair of headphones, as such, it is portable and not very intrusive, it doesn't constrain the driver's movements, its placement is easily carried out by the driver itself and it is quite affordable (when compared with traditional solutions).

NeuroSky EEG Biosensor collects the brain's EEG signals and transmits them via BLE to the IoT module. This one, using the LTE/NB-IoT sends the collected signals to the cloud through a broker. Once on the cloud, the signals are processed aiming to identify suspicious or alarming patterns. If such patterns are identified, an alert message is sent to the IoT module with the severity of the identified pattern. On the IoT module are evaluated the driving conditions, such as speed, proximity to obstacles, and other parameters may be useful to define the action to be taken. The action may involve warning the driver to stop the vehicle or a direct intervention, for example, reducing the speed or immobilizing the vehicle. It's important to note that the IoT chip must be able to inject instructions into the car controller (e.g. stop instruction).

In addition, alerts may be issued to emergency contacts registered on the platform (cloud) or, if identified by the IoT module, it may request urgent intervention (in case of crash, shock, collision, ...).

The server part, hosted in the cloud, consists of:

- A set of ML algorithms that process the EEG signals coming from the client, aiming to identify possible indications of an epileptic seizure.
- A web platform to monitor and validate the received signals and their results produced by the ML algorithms.

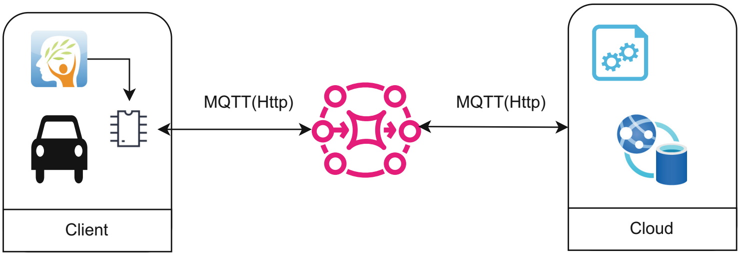

Fig. 1. Architecture of the proposed solution

– An alert system that will inform not only the driver, but also doctors, and possible emergency contacts.

4 Results

In general, the proof of concept was carried out, by collecting the data and sending it to the cloud. A pattern recognition process was simulated in terms of processing time and sending messages to the module. The reason why this was simulated is that we simply do not have data to create the recognition model (that replicates the brain signals we want to identify).

Decision-making by the IoT module on the action to be carried out and the respective action on the vehicle was also not included. This is because there is still work to be done here on what could be the inputs of the decision model, but mainly because we do not have, at least for now, the means to act on the vehicle.

Thus, even considering that there is a lot of work to be done and that some of it will be difficult to complete due to existing constraints, it has nevertheless been possible to validate the architecture operation model and, communication and processing latencies. The initial tests were performed in an ideal scenario, where the NB-IoT signal was strong and stable, minimizing possible impacts caused by data transmission. A latency of about 2% was obtained, however, the scenario used was not close to the real one (with the car in progress), which indicates that this latency can worsen, as the moving car crosses several zones that may have better and/or worse signal for data transmission.

We have no idea whether this latency is, or is not, critical for timely action. The impact of this latency is directly related with the time that goes from the moment that occur the alarm pattern and moment that the driver shouldn't be driving the vehicle. If this is very short, in the order of milliseconds or even a few seconds, than the latency will be very critical. If it take more time, like several seconds or even minutes, the latency might not be relevant. We will only be able to answer this question when we have real data of epilepsies episodes.

In either case, an alternative architecture has already been devised, based on edge computing, in which pattern recognition is carried out directly in the

IoT module. This eliminates communication latencies but also ensures that the solution works, even if there is no communication with the cloud. On the other hand, it is necessary to test which modules (processing units, memory, and the like) are capable of performing this function in a timely manner.

Furthermore, in the authors' opinion, the concept and the idealized architecture are already contributions that should be put up for discussion by peers.

5 Conclusion

This paper presents promising contributions to ensure the solution for patients with epilepsy while driving. The creation of this type of solution enables better control and monitoring of possible crises while driving, allowing one to take mitigation measures to reduce the existing risks of a possible crisis while driving, increasing the safety of the epilepsy patient and the people around him. In addition, as previously mentioned, after the diagnosis of the disease, patients are required by law to comply with a period of driving inhibition. Driving inhibition nowadays easily becomes a problem because it limits and reduces the quality of life of patients with epilepsy since they become dependent on others to perform their daily tasks. Thus, solutions similar to that presented in this paper may contribute to reducing this period of inhibition, or even in some cases cause it to cease to be mandatory.

However, despite the advantages there are still a set of limitations identified during the development process. At the cybersecurity level, a new attack vector is available, as this type of solution needs to inject instructions into the car controller in cases of seizure detection. In addition, it is also necessary to work on the circumstances in which the vehicle is stopped, as an abrupt stop calls into question the safety of other vehicles on the road.

In terms of seizure detection, it should be noted that there is a varied set of epilepsy [12] with very small variations that do not allow ML algorithms to be identified without the help of a health professional. Finally, data transmission is another point that can be problematic since the system is reactive and needs coverage either LTE or NB-IoT [13] to send data and receive responses. Thus, it is necessary to think of a better solution to ensure detection in areas without network coverage in order to ensure a similar level of security or explore the alternative architecture, based on edge computing.

5.1 Future Work

Despite the potential of the solution, the current state of development does not allow to evaluate the solution under real scenarios yet. The following points were left for future work: evaluate the feasibility and adequacy of the distinct communication technologies (LTE/NB-IoT or other); evaluate how far ML algorithms are able to detect the various types of epilepsy; mitigate the attack vector resulting from the need to take control of the car in the event of an epilepsy episode;

study the best approach to immobilize the vehicle, ensuring the safety of everyone - patients, passengers, and other drivers and passersby; and carry out a comparative analysis of the two approached architectures: cloud and edge computing, namely its suitability given cloud access limitations and computational demands of the ML algorithms.

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