Low-Power Implantable Seizure Detection Processor

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***Abstract*—The detection processor is a part of an implantable integrated device used for detection of an electrographic seizure onset. The system is supposed to acquire the neural signals from 1024 electrodes implanted in the brain tissues, amplify the acquired signals, and then process them using the seizure detection processor to detect the occurrence of a seizure. Based on the decision of the processor, a stimulation signal can be applied to a number of the implanted electrodes to block the seizure progression.**

I. INTRODUCTION

Over 50 million people worldwide suffer from epilepsy. Approximately one-third of those with epilepsy do not react well to currently available pharmacological treatments such as antiepileptic drugs. Thus, researchers are looking for other alternative treatments, such as implantable devices delivering stimulation signals upon automated detection of electrographic seizures. The stimulation needs to be responsive, not continuous, in order not to cause damage to the brain tissues.

So we only apply stimulation to the neurons when a seizure is detected. Also if the stimulation pulses are applied continuously and periodically, it can result in suboptimal treatment efficacy, shorten the battery life and increase the cost of the therapy as additional surgical operations are required for battery replacement.

II. THE SYSTEM ARCHITECTURE

A. Overview Of The System Architecture

Fig. 1 shows the architecture of the implantable device and the location of the seizure detection processor. The purpose of integrating the detection processor within the implantable chip is to reduce the power consumption by reducing the needed rate of wireless EEG data transmission. Despite the fact that the processor will consume more power, yet the power needed for transmission will decrease. This is because we don't need to transmit the data from all the channels; we only transmit channels with a detected seizure. Therefore, the power consumption of the overall system will decrease.

The detection processor is a part of an implantable integrated device researched by our research group at Cairo University. The system consists of four parts: the acquisition system, the detection processor, the wireless transmission system and an energy harvesting system.
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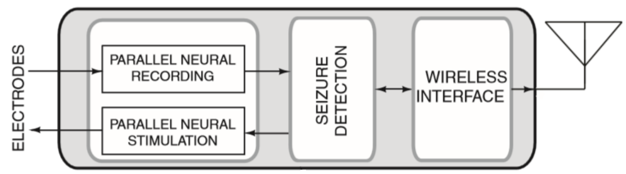

Fig. 1. System for neural monitoring and stimulation based on seizure detection

For every channel of the system, there is a detection processor after digitizing the neural signals using the ADC. The algorithm is executed simultaneously on neural signals in a window of time.

The detection algorithm purpose is to extract a feature from the neural signal and then we can compare the extracted feature with a threshold that is determined experimentally. If the extracted feature exceeds this certain threshold, then a seizure is detected.

B. Detailed View

Fig. 2 shows a detailed view of the seizure detection processor and its interfacing with the data acquisition system and the wireless communication system for one channel.

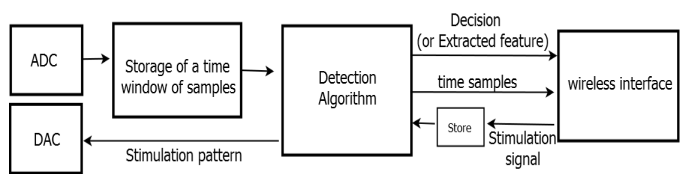

Fig. 2. Detailed view of the interfacing between the detection processor, the ADC and the wireless system

The figure shows the two paths, the recording path and the stimulation path. The recording path comes from the ADC; therefore we need to store the neural signals for a certain window of time. The window size can vary according to the type of algorithm. After processing, the decision is made and the decision is sent wirelessly. In case of a detected seizure, we also transmit the time samples of this channel, so we need storage as well before transmitting.

For the stimulation path, we get three specifications from the wireless system, the frequency of current pulses, the pulse width and its amplitude. These specifications are then stored and the stimulation pattern is constructed.

III. DETECTION ALGORITHMS

There are many types of algorithms used in literature. They can be classified into two types. The first type is Univariate algorithms, which involve computations on a single input as in [1]. The second type is bivariate algorithm, which operate on two inputs as in [2].

A. *Performance Metrics of the processor*

1- **Sensitivity vs specificity:**
The sensitivity is defined as to how accurately we identify the onset of a seizure. It can be measured as the true positive rate, which is the rate of true detected seizures. The specificity is to reject any "seizure-like" events that could lead to unnecessary stimulation. It can be measured as the true negative rate.

2- **Average detection to seizure onset:**
In order to permit therapeutic intervention, a minimum window of time, between the alarm raised by the prediction method and the beginning of the seizure occurrence, is required. This window is called the seizure prediction horizon.
Seizure detections are classified as false positive (FP) if they are recognized by the algorithm but not by the visual scorer and as false negative (FP) in the opposite case.

So when comparing algorithms and their implementation, we have to take these two performance metrics into account, besides the power consumption and area. Table I shows a comparison between two algorithms used in [1] and [2].

TABLE I
COMPARISON OF LATEST LOW-POWER SEIZURE DETECTORS

Seizure Detection Algorithm	TPR(%) For 1FPR/h and SOP= 30 min.	Average Detection to seizure onset	Power
Event threshold [1]	94%	8.5 sec.	350 nW/channel
Phase locking value [2]	66%	59 sec.	3.6 µW for a pair of channels

TPR: true positive rate, FPR: false positive rate, SOP: seizure occurrence period.

B. *Algorithms optimization*

We have two degrees of freedom that should be optimized to get maximum possible sensitivity and specificity.

1- **Threshold value:**
All algorithms eventually have to compare their extracted feature with a threshold value. This value should be chosen carefully in order to get best sensitivity and specificity. The best threshold value can differ from one patient to another. It should be optimized experimentally. If the value is too low, then the system will be highly sensitive and has no specificity so it will detect a seizure most of the time, so we get high false positive rate. If the value is too high, then the system will have high specificity, so we might not be able to detect a seizure and we get a high false negative rate.

2- **Time window:**
The window, over which we are computing our algorithm, is the second degree of freedom. For example, if we are detecting the energy contained in a window, if the window size is too short, the algorithm might consider any spike as a seizure which increases the false positive rate. A longer window results in lower false positives at the expense of a larger detection delay.

IV. CONTRIBUTIONS

A. *Component specification*

In our research up till now, we were able to specify some parameters of the system such as:

- **Specification for storage of the neural signals:**
The algorithm is executed on the neural signals from the 1024 channels simultaneously for a certain window of time. Therefore, we need to store the neural signals coming from the ADC first, and then we can process them by the seizure detection processor. The data rate coming from the ADC is around 20 kSample/s and the ADC resolution ranges between 8 to 12 bits. The algorithm is executed over a window of time at least 2 seconds. Therefore the memory size needed is around 60 kbytes per channel.

B. *Expected contributions*

The project aims at comparing the different algorithms to implement an algorithm that improves the performance metrics of the detection processor to have better sensitivity, specificity and smaller detection delay with low power consumption and area. This can be achieved by using a hybrid of different algorithms and by optimizing the algorithm performance on the experimentation level. The next stage of our research is to start the simulations on MATLAB to evaluate the performance of the different algorithms.

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