

A computational platform for continuous seizure anticipation, monitoring and clinical evaluation

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Abstract. The development of platforms that are able to continuously monitor and handle epileptic seizures in a non invasive manner is of great importance as they would improve the quality of life of drug resistant epileptic patients. In this work, a device and a computational platform is presented for acquiring low noise electroencephalographic signals, for the detection/prediction of epileptic seizures and the storage of ictal activity in an electronic personal health record. In order to develop this platform, a systematic clinical protocol was established including a number of drug resistant children from the University Hospital of Heraklion. Dry electrodes with innovative micro-spike design were proposed in order to increase the signal to noise ratio of the recorded EEG signals. A wearable low cost platform and its corresponding wireless communication protocol was developed focus on minimizing the interference with the patient's body. A computational subsystem with advanced algorithms provides detection/anticipation of upcoming seizure activity and aims to protect the patient from an accident due to a seizure or to improve his/her social life. Finally, the seizure activity information is stored in an electronic health record for further clinical evaluation.

Keywords. Seizure detection, seizure anticipation, EEG, dry EEG electrodes, wearable device, WBAN, EEG analysis, electronic health record

1. Introduction

Seizure detection/prediction and probably seizure control are of great importance for the improvement of the epileptic patients' quality of life. Even if in many cases seizures are

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controlled by anti-epileptic medication, there is a notable percentage of patients that remains exposed to the experience of seizure outbreaks [1]. The unpredictability of an upcoming seizure is what causes the major problems either because it can lead to accidents or because it deteriorates the patients' professional, social and personal life, often resulting in social isolation and personal depreciation.

Low cost EEG devices that can be used on a daily basis at home, face the problem of noise contaminating the captured EEG signals due to the patient's body activity. Dry microneedle electrodes give promising results towards reducing such artefacts, the fabrication of which includes a simple technique of photolithographic process on a SiO₂ wafer, in order to obtain the microneedles at a low cost, with a high sensitivity and low resistivity compared to the conventional electrodes. Using this type of electrodes, the mounting procedure becomes simple with no need of skin preparation and conductive paste. Considering the device itself, a wireless communication protocol for the duplex information transmission and a compact size, minimizing disturbance of the patient is a prerequisite for the application domain.

A computational subsystem extracts features related with epileptic activity in order to anticipate or even predict the occurrence time of an upcoming seizure. Although there are great advances in the area of epilepsy monitoring systems and brain signal analysis, the problem of seizure prediction has not found yet a consistent and reproducible solution. On the other hand, seizure anticipation for a short time period, before the seizure onset, is still very valuable for improving patients' everyday life.

2. The predictES platform

The predictES platform aims to support long-term seizure monitoring and warning of patients' upcoming seizures. In addition, it transmits any epileptic activity event information to the caring clinician and stores the respective data in a customized patient's electronic database record. The platform consists of the following subsystems:

- dry electrodes subsystem
- wearable device
- middleware for body monitoring
- seizure detection/prediction algorithms
- platform portal (electronic health record)

The workflow of the platform is shown in Figure 1.

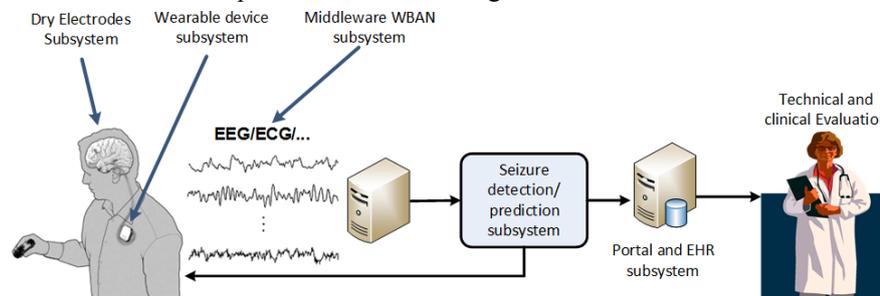


Figure 1. Workflow of the predictES platform

2.1. Novel sensor design: a dry electrodes subsystem

This subsystem contains the prototype dry, metal coated SU8 based, microneedle electrodes [2] that were developed for the purposes of this work. The microneedles are cone-shaped with a height of 500 μm and a base of 100 μm in diameter. The tip is smaller than 30 μm as shown in Figure 2.

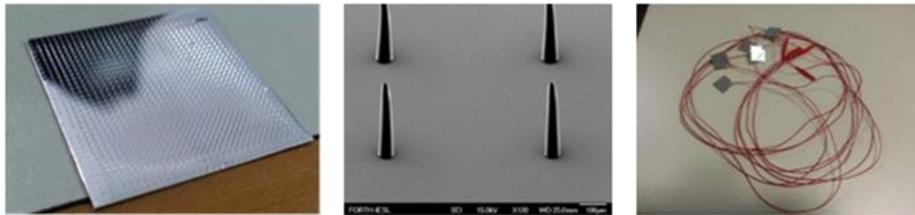


Figure 2. Micro needles electrodes

The dry electrode consists of a tetragonal array of microneedles spaced 650 μm apart. The chosen pitch allows for a large enough areal density of microneedles to secure higher sensitivity compared to conventional wet ones. The microneedle fabrication process of FORTH is an elegant but simple technique that employs a fine tuned photolithographic process of SU8 on a glass wafer. This approach produces mechanically reliable microneedles at a competitive cost due to the low complexity of the fabrication process coupled with its potential for mass production. The dry microneedle electrodes were initially tested with a commercial EEG system from the University General Hospital of Heraklion in Crete on 3 volunteers.

The tests were performed without any skin preparation or conductive paste and the results were compared to those obtained on the same persons with commercial electrodes. The EEG testing recordings, clearly showed that the dry microneedle electrodes presented low resistivity and enhanced sensitivity compared to commercial electrodes. Typical results are shown in Figure 3a for electrodes placed at sites FP1 and Cz. Following the removal of the microneedle electrode pad from the human skin, noticeable spots confirmed penetration of the outer skin (stratum corneum).

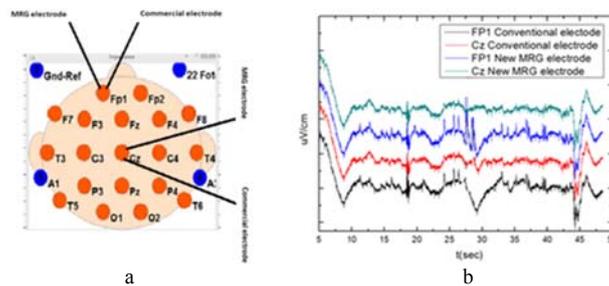


Figure 3. EEG recording for Microneedle electrodes and Conventional ones

From Figure 3b it transpires that the microneedle electrodes offered the additional advantage of being less susceptible to signal artifacts thus being able to operate with lower noise levels.

2.2. Wearable device subsystem

This subsystem contains an eight channel EEG wearable prototype device that was developed for the purposes of this work.

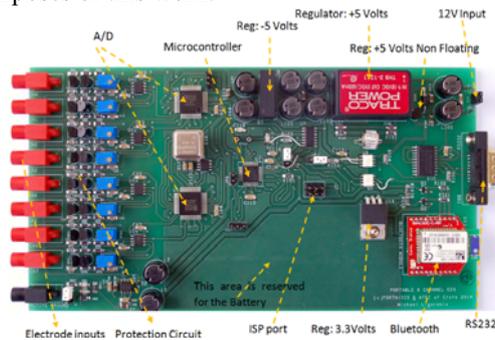


Figure 4. PCB overview of the wearable device that is connected wirelessly to a laptop via Bluetooth

The device is capable of collecting and transmitting data, via Bluetooth, from eight channels simultaneously at a sampling rate of 256Hz/channel. The signal amplitude is within the range of ± 3 Volts and the signal frequency ranges from 0 to 1000Hz. A protection circuit prevents the device from damages due to power surge.

2.3. Middleware for body monitoring WBAN subsystem

The purpose of this subsystem is to design, implement and test a software module that will act as an interface between the body sensors and the computational subsystem. The MCU packetizes the data of the eight channels and then transmits the data in blocks of 6148 bytes. This is performed as soon as the system is powered up regardless of the number of the electrodes connected to the system. The block size is calculated as follows: there are three bytes for each channel at 256Hz, multiplied by four sync bytes, which results in total 6184 bytes.

The communication protocol chosen for the data transfer between the sensors and the middleware is Bluetooth as it is a reliable wireless technology used for exchanging data over short distances (using short-wavelength UHF radio waves in the ISM band from 2.4 to 2.485GHz). The data rate specification of the protocol is satisfactory enough for the requirements of the PredictES system.

The middleware module is implemented in C programming language, reassuring the system's interoperability and providing fairly fast execution times for the PredictES subsystem and reassuring the system's interoperability. The main module is comprised of three submodules: a) Data receiving submodule, which is responsible for reading the communication channel, b) Data regeneration submodule, for making all the necessary calculations in order to transform raw incoming data (binary format) to signal values (decimal format), c) EDF writer submodule, for creating and writing the signal values in compliance with the European Data Format (EDF), a simple and flexible data format for the exchange and storage of multichannel biological and physical signals.

2.4. Seizure detection/prediction computational subsystem

This subsystem is in charge of processing and analyzing the acquired EEG signals in order to extract features relevant to epileptic activity. The first step is the preprocessing of the EEG signals in removing noise and artifacts produced from subject's activity (eye blinks, head movements or chewing). Then, linear and nonlinear features are calculated based on literature review of their anticipation performance [3]. Finally, a threshold or/and classification rule is applied in order to identify whether the segment under investigation belongs to an ictal or pre-ictal period or not. A flowchart of the whole procedure is shown in Figure 5.

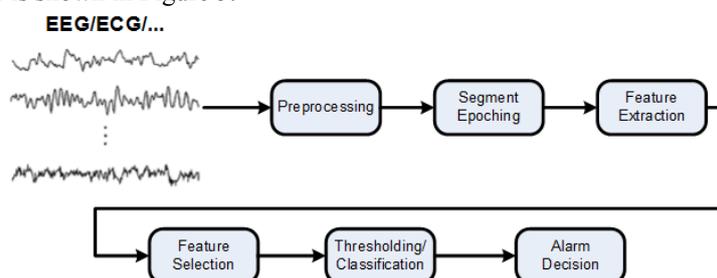


Figure 5. Flowchart of seizure detection/prediction system

The evaluation of the procedure was based on epileptic activity data, provided by the University General Hospital of Heraklion and produced promising results regarding seizure anticipation accuracy. As there are different types of seizures (in most cases each patient has a specific type of seizure), some algorithms achieve high performance for certain patients while their performance in other patients/seizure types is mediocre. It was observed that, especially in focal seizures, seizure types under investigation affect algorithms performance. Thus, a patient specific approach for adjusting algorithms' parameters is proposed as more effective in seizure anticipation.

2.5. Platform Portal (electronic health record) subsystem

For the needs of the portal, an Electronic Health Record (EHR) was designed and developed. The system encloses most of the essential components of the EHRs, such as administrative processes, health information and data, communication/connectivity and results management [4]. The EHR was installed at University General Hospital of Heraklion and till now 316 patient records have been registered.

The system provides dynamically generated forms, used for effectively storing patients' clinical, diagnostic, demographic and examination data along with the classification of the epileptic syndrome and seizures, substance administration, informed consent and EEG signal data. For each patient, a diagram representing his/her seizure events with respect to his/her substance administration per month is made available, which provides to clinicians an intuitive picture of the patient's health and treatment timeline. Furthermore, searching capabilities and customizable filters were considered very useful for the clinical evaluation.

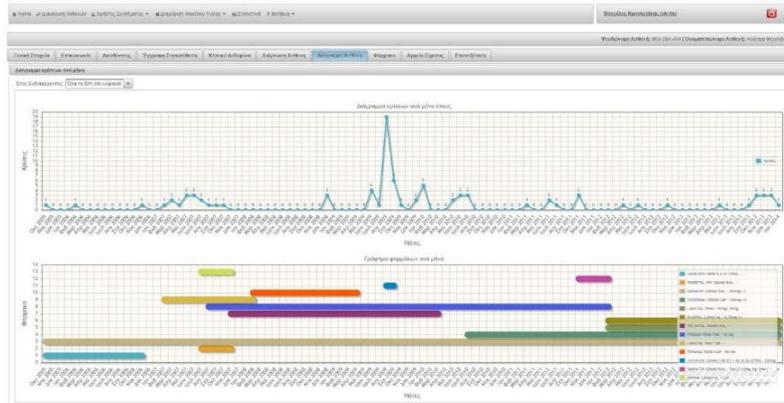


Figure 6. Graph showing patient’s monthly number of seizures with respect substance administration.

The security framework provides an organization wide control process for managing information technology assets while maintaining the desired level of security, by adopting a custom designed Role Base Access Control (RBAC) model. Moreover, encryption/decryption mechanisms were used for ensuring privacy and confidentiality of patients, which is considered quite crucial for health care organizations.

3. Conclusions

This platform provides promising results regarding seizure anticipation, facing many technical challenges such as keeping the cost low in comparison with commercial devices. In addition, initial in vivo tests produced good results since the micro needle electrodes were more sensitive in relation to commercial ones, which in combination with the low cost for the fabrication and the missing need for any contacting paste, seems to be the future for EEG recordings.

Acknowledgement

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References

- [1] P.N. Banerjee, D. Filippi, and W.A. Hauser, The descriptive epidemiology of epilepsy—a review, *Epilepsy Research* **85** (2009), 31-45.
- [2] G. Stavrinidis, K. Michelakis, V. Kontomitrou, G. Giannakakis, M. Sevrisianos, G. Sevrisianos, N. Chaniotakis, Y. Alifragis, and G. Konstantinidis, SU-8 microneedles based dry electrodes for Electroencephalogram, *Microelectronic Engineering* **159** (2016), 114-120.
- [3] G. Giannakakis, V. Sakkalis, M. Padiaditis, and M. Tsiknakis, Methods for seizure detection and prediction: an overview, in: *Modern Electroencephalographic Assessment Techniques: Theory and Applications*, Springer, 2015, pp. 131-157.
- [4] C. Seckman, Electronic health records and applications for managing patient care, in, Elsevier and typesetter Toppan Bes, 2013.