Development of a Wearable Inertial System for Motor Epileptic Seizure Detection

Artemii A. Kabanov, Alexander I. Shchelkanov
Department of Radio engineering Devices and Diagnostic Systems, Omsk State Technical University Omsk, Russia

***Abstract* – Epilepsy is one of the most common and severe neurological disorders. Despite the availability of numerous antiepileptic drugs, it is often impossible to control the disease effectively. During and after seizure episodes lack of supervision and failure to provide urgent medical care may lead to a serious injury or even death.**

Therefore, developing a wearable device for epilepsy monitoring may complete the anamnesis, helping medical staff in diagnosing and treatment process, and also prevent seizure-related accidents.

The only reliable method for verifying epileptic seizures is electro-encephalography. But it is currently impractical for ambulatory monitoring. Therefore wearable devices developers focus primarily on indirect seizure detection methods.

There are a number of seizure detection systems available on the market. Still their performance is far from perfect.

This study describes a wearable device which is designed to address some issues with current seizure detection systems. Its functional block diagram and operating modes are detailed. Possible application areas of the device are also discussed.

***Keywords* – seizure detection; inertial systems; wearable biosensors; ambulatory monitoring.**

I. Introduction

EILEPSY IS A serious neurological disorder, affecting almost 1% of the world population [1]. The disease imposes huge physical, psychological and social burdens on individuals and their families. Besides, epilepsy has a dramatic impact on the health care systems' annual budgets.

One of the most disabling aspects of the disease is unpredictable nature of seizures. Abrupt episodes of muscle control loss and impaired consciousness can pose a serious injury risk and can even be life-threatening, especially if they occur while the patient is crossing a busy street, bathing or climbing stairs. Compared to a normal population, the mortality risk for patients with epilepsy is elevated by a factor of two to three [1].

Most patients can become seizure free with appropriate medication. Nevertheless, in about 30% of patients with epilepsy none of the standard therapy options can control their seizures [2]. These patients are said to suffer from refractory epilepsy.

Although the research works on predicting epileptic seizures have been carried out since 1970s [7], there are still no highly reliable and practical methods available to predict impending seizures in patients with epilepsy. That is why the development and improvement of seizure detection approaches is crucial [1]. Detection is especially important for those who are refractory to treatment and who experience particularly dangerous seizures.

II. Epileptic Seizure Detection Approaches

Epileptic seizures are defined as paroxysmal events which represent a clinical manifestation of abnormal discharges of a set of brain neurons. Thus, electro-encephalography (EEG) is the gold standard for epileptic seizures detection [3].

However, the method is uncomfortable for patients as electrodes are attached to the scalp. Furthermore, EEG analysis is labor-intensive and has yet to be automated and adapted for real-time monitoring. It is therefore usually performed in a hospital settings in epilepsy monitoring units (EMUs), for a few days at the most, and generally used to confirm the diagnosis of epilepsy, determine its type, distinguish between psychogenic non-epileptic seizures and epileptic seizures [1, 6].

Epileptic episode may manifest itself as a sudden autonomic neural system dysfunction (alterations in cardiac, respiratory or electrodermal activity), vocalizations, and also changes in sensation, state of consciousness or motor behavior. Presence of these signs and symptoms allow the use of indirect seizure detection methods: audio recording, electro-oculography, electromyography, electrodermal activity measuring etc. [1].

In about 60% of patients epilepsy spells clinically manifest as involuntary muscles contractions [2], which are called motor seizures. They can be detected by human physical activity recognition methods.

III. Brief Overview of Modern Inertial Seizure Detection Systems

A. Main Features of Inertial Systems

In recent studies the most promising sensors used in motion tracking systems are inertial ones: accelerometer and gyroscope. With their low cost and small size microelectromechanical inertial sensors gave raise to wearable devices which enable long-term ambulatory monitoring in patients with epilepsy.

These are the main advantages of the inertial systems:

- Attached to the patient, they are linked directly to movement and able to distinguish between movements of individual limbs [1].

978-1-5386-7054-5/18/$31.00 ©2018 IEEE

- Compared with EEG, signal analysis algorithms in inertial devices might be less complex and require less power for automated analysis [1].

However, activity recognition methods carry a number of drawbacks:

- They cannot provide retroactive verification for events that are logged as seizures.
- These approaches can only be used in a select portion of seizures that have well defined motor activity, namely myoclonic, tonic–clonic, clonic and nocturnal seizures [5]. It is worth noting that it is nocturnal and tonic–clonic seizures that deserve special attention since the former are often refractory to treatment and the latter can lead to status epilepticus, which can be fatal [1].
- They tend to have high false-positives rates, because many sudden repetitive movements, such as toothbrushing, may be similar to seizure movements [4].

B. Wearable Devices Available in the Market

There are several commercially available wearable seizure detection systems, such as EpiLert (BioLert, Israel), SmartWatch (Smart Monitor Corp., US), Epi-Care Free (Danish Care, Denmark), and also devices currently under clinical evaluation.

Overview of these systems has revealed that most of them are not customizable. The possibility of making user-specific adjustments is important since clinical manifestations of epileptic episodes vary among patients and a given patient may have different seizure types [1]. Enabling seizure detection system modifications based on the features of particular seizure types can improve seizure recognition and minimize false positives. It should be possible to customize devices not only to the user's seizures but also to the caregiver's preferences.

The second issue is that the devices presently available on the market are designed primarily for alarming caregivers, not for seizure recording. Meanwhile, it is obvious that objective seizure logs could significantly improve the quality of medical care. Neurologists often make clinical decisions about medication adjustments relying heavily on patient's seizure diary [2]. Unfortunately, since consciousness can be impaired both during and following epileptic episodes patients fail to report 30-50% of daytime seizures and more than 85% of nighttime seizures [4]. Thus, inaccurate seizure reports can lead to ineffective therapy.

Our work aims to design a wearable device to address the both issues.

IV. The Proposed Device Description

A. Design Features

The device is based on AMega128 microcontroller which uses 16 MHz crystal oscillator as its clocksource. GPRS-GSM and the GPS antenna of SIM-900 (SIMCom) module are attached to UART0 and UART1 lines of the microcontroller respectively. In SIM-900 the MIC input and the SPEAKER output are available for audio communication with the patient.

The SIM card of a chosen service provider's is inserted into 6-pin SIM card holder.

4200 Hz piezo buzzer is used to provide sound alert.

The system employs two inertial sensors: accelerometer ADXL345 and gyroscope ADXRS453 (Analog Devices). Since I2C function is not supported in the standard SIM-900 firmware and SPI is for memory card and LCD display attaching, the respective protocols using GPIO lines for interfacing ADXL345 and ADXRS453 sensors have been designed.

Algorithm for inertial sensors signals processing is developed with consideration of the error caused by changes of accelerometer's measurement axes with respect to the gravitational acceleration vector.

For the measurement data recording SD memory card up to 32 GB can be used. It communicates with the microcontroller via the SPI interface. The information stored on the SD card can be processed externally by a PC.

Functional block diagram of the device is given in Fig.1.

B. Operating Modes of the Device

There are two modes in which the system can operate.

1) *Creating patient-specific seizure template using parameters of the epileptic spell*. This process includes:

a) *Collecting the data over a period of the user's motor activity monitoring*. The data obtained represent a time sequence of the instantaneous accelerations experienced by the sensor.

b) *Analyzing the data collected to determine parameters characterizing the abnormal oscillatory motion*.

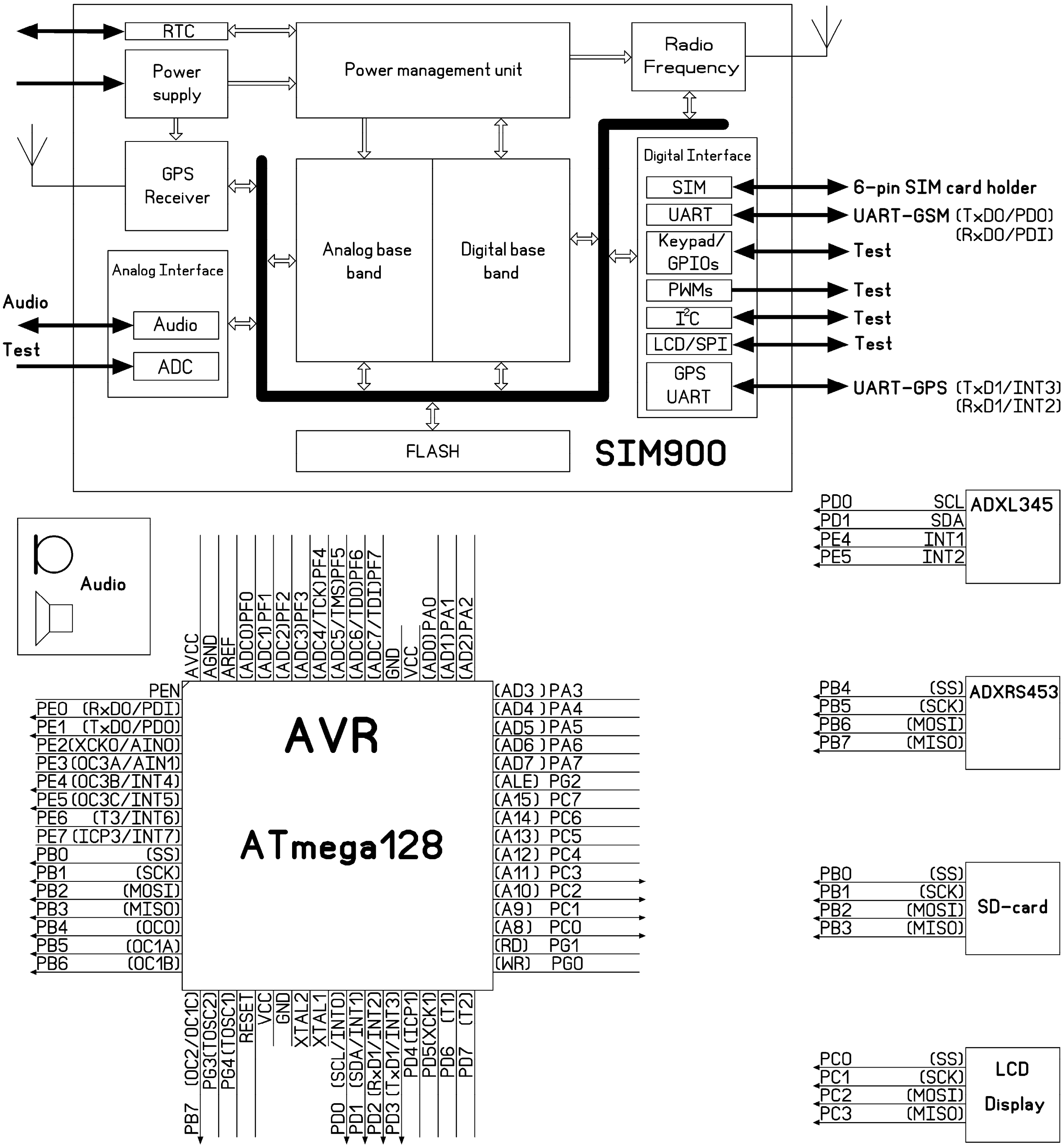

Fig. 1. Functional block diagram of the proposed device.

c) *Defining the signature of a particular seizure type in an individual patient by checking the motion patterns against verified epileptic spells.*

d) *Setting thresholds for oscillatory motion parameters (frequency of jerks, magnitude of acceleration or root mean square of acceleration) in order to allow rules-based seizure detection.* These values are stored in microcontroller memory, so that the user does not need to input the parameters every time the system is turned on.

2) *Movement pattern recognition.*

It is performed via an algorithm executed within the processor. If values obtained during patient's physical activity are greater than the thresholds, then the motion is considered to be a seizure.

In an embodiment, after the processor generates an indication of abnormal motion there are 2 options available:

a) *Alerting caregivers to ongoing seizures via local in-device sound signal and/or SMS message*. The message may include data from a current episode of abnormal motion and patient's location.

If the system activates alert, but the patient is fine, he or she can press a button to ignore the alarm. It is possible to set the alarm delay at different interval times.

b) *Recording of motion sensor data on SD card.*

They can be reviewed later by a medical professional for further analysis.

The system may provide two adjustable sets of thresholds. One set of thresholds is for sending an alert and the other one is for recording events that have seizure-like characteristics.

There may be also two levels or thresholds each indicating a different degree of danger or indicating a different degree of certainty that a seizure occurred.

V. Application Areas Of The Seizure Detection System

The seizure detection system we propose can be used in both diagnostic and care settings.

In the first scenario analysis of the data obtained is done after a period of monitoring. Then based on the information on seizure type, frequency and distribution during day and night, neurologists make decisions about drug therapy.

In care settings the instantaneous epileptic seizure detection triggers an alarm system and thereby increases person's chances of receiving prompt assistance. In view of this, the device can be used for accident prevention and offering reassurance to patients and their families.

Conflict Of Interest Statement

None of the authors has any conflict of interest to disclose.

References

[1] A. Van de Vel, K. Cuppens, B. Bonroy, M. Milosevic, K. Jansen, S. Van Huffel, et al, “Non-EEG seizure-detection systems and potential SUDEP prevention: State of the art,” Seizure, vol. 22(5), pp. 345 – 355, June 2013.

[2] National Institute for Health and Care Excellence (NICE). The Epilepsies: the diagnosis and management of the epilepsies in adults and children in primary and secondary care. CG137. NICE: London, 2012.

[3] G. Rubboli, S. Beniczky, S. Claus, M.P. Canevini, P. Kahane, H. Stefan, et al, “A European survey on current practices in epilepsy monitoring units and implications for patients' safety, ” Epilepsy Behav., vol. 44, pp. 179 – 184, Mar 2015.

[4] J. Bidwell, T. Khuwatsamrit, B. Askew, J.A. Ehrenberg and S. Helmers, “Seizure reporting technologies for epilepsy treatment: review of clinical information needs and supporting technologies,” Seizure, vol. 32, pp. 109 – 117, Nov 2015.

[5] J. Gubbi, S. Kusmakar, A. Rao, B. Yan, T. O'Brien and M. Palaniswami, “Automatic detection and classification of convulsive psychogenic non-epileptic seizures using a wearable device,” IEEE J. Biomed. Health Inform., in press.

[6] S. Beniczky, I. Conradsen, M. Moldovan, P. Jennum, M. Fabricius, K. Benedek, et al, “Automated differentiation between epileptic and non-epileptic convulsive seizures,” Ann.Neurol., vol. 77, pp. 348 – 351, Feb 2015.

[7] S.S. Viglione and G.O. Walsh , “Proceedings: Epileptic seizure prediction,”Electroencephalogr. Clin. Neurophysiol., vol. 39(4), pp. 435 – 436, Oct 1975.

Artemii A. Kabanov was born in 1993 in the Republic of Kazakhstan. He graduated with honors from Omsk State Technical University, with a bachelor's degree in 2016, his specialty was Information Measurement Technology. After graduating from the university in 2016, he entered on a master program of Omsk State Technical University for the same specialty. He also began his career at the university as an engineer. He has a number of scientific interests such as, data acquisition systems, digital signal processing, automation and biophysical signals.

Alexander I. Shchelkanov was born in Omsk in 1957. He graduated from Omsk State Technical University in 1980. He is Candidate of Engineering Sciences, he work is an Associate Professor of the Department of Radio Engineering Devices and Diagnostic Systems since 2012. Has a number of scientific interests such as, data acquisition systems, linearization of nominal static characteristics.