SeizeIT: SEIZURE victims are no longer leashed

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***Abstract*—Seizure is considered to be one of the severe and most common type of neurological disorders. Despite the availability of numerous anti-seizure drugs, it is often difficult to control the disease completely and effectively. Lack of close supervision and failure in providing urgent medical care during and after seizure episodes, leads to serious injuries or even death. On the other hand, the use of wireless sensor networks in everyday applications have rapidly increased due to decreased technology costs and improved product reliability. Therefore, developing a wearable device to monitor seizure may complete the anamnesis, help medical staff in diagnosing and acute treatment while preventing seizure related accidents. There are number of seizure detection systems available in the market. Still their performance is far from perfect. This paper explores an application of biomedical wireless sensor networks, which attempts to monitor patients in a completely non-invasive and non-intrusive manner. It describes a wearable device together with seizure prediction and alerting system, which is designed to address some issues with seizure detection systems in the market. Its functional block diagram and operating modes are detailed. Possible application areas of the device are also discussed.**

Keywords*— *myoclonic, tonic–clonic, nocturnal seizures, frontal lobe and febrile seizures

I. INTRODUCTION

Seizure is a condition that triggers a sudden surge of electrical activity in the brain due to complex chemical changes that occur in nerve cells [1]. Its condition can be seen with naked eye as repetitive convulsions, muscle spasms, loss of consciousness, abnormal sensations, emotions or (motor) behaviour. There are many causes for these kinds of changes and they vary from patient to patient. Sometimes the cause for the seizure is not clear or there is no cause. Most common causes are fever, brain injury, and abnormal levels of sodium or glucose in the blood, brain infection including meningitis, brain tumour, head injury, heart disease, stroke, malignant hypertension, and withdrawal from alcohol [1].

When consider the world population there are about 65 million people approximately affected with seizure and it dramatically impact on the patient's quality of life, the health system budget, as well as on the professional development and social behaviour[2]. In order to treat patients, the data should be gathered in everyday life while, allowing the patient to freely do their desired activities. Yet it is very difficult to adapt to analysis and procedures according to unconstrained world [2]. It is very important that the solution is easy to wear and unobtrusive since, better the wearable conditions, lessen the chances of finding a suitable excuse for not using the solution [2]. Most of devices available on the market are mainly designed for the purpose of alarming caregivers, not for seizure recording where seizure logs could significantly improve the quality of medical care and more optimal treatment to the disease where contribute to a better quality of patient's life [3].

This study focuses on solving these limitations and difficulties by proposing a seizure monitoring platform using mpu6050 and Galvanic Skin Response (GSR). Both sensors are low cost and small in size (micro electromechanical inertial sensors). However, activity recognition methods used in the study may have limitations and drawbacks which restrict to identify certain potion of the seizure purely on motor activity, skin conductance and skin temperature; since retroactive verification cannot be given for events to capture as seizure situations [4]. That leads the study to use multiple sensor networks like 3-axis accelerometers, gyroscopes along with GSR to high sensitivity and specificity of seizure detection [5].

Normally when a person is facing a threat or an emergency the person's nervous system responds to it by producing adrenaline and cortisol hormones. GSR is used to collect different conductance of the skin when a person is under stress or when not [4]. Device uses just two electrodes which are placed on the fingers and act as if they were the two terminals of one resistance [4]. It is possible and effective to detect seizures using accelerometers together with gyroscopes, and in some cases the accelerometer can detect seizures which were not clearly visible in the EEG-signal [6].

The first step of study is to identify features and they must be computed from the measured quantities; second, simple thresholding or a more extensive training process must be used with real data to determine how the features can be used to detect or predict seizures [5]. Since, when using multiple data sources, the thresholding process can provide a higher degree of resolution in detecting events [5]. In order to keep track of medical records of patient, there is a database with patient's personal information. Whenever there is a possibility for a seizure, the system is capable of making an emergency notification to make attention while, sharing those data to the medical staff [2][7]. The seizure detection mechanism and the notification process activate immediately.

The ultimate goal of the study is to detect a seizure in the initial stage, make aware the medical assistants or caregivers in the earliest possible state to avoid any complications and assist the patient in the difficult times. The notification for caregivers also aid to decrease the death amount in the world due to sudden seizures. As well as patient logs on seizure activity will help to improve the individual patient's medication as well the entire seizure community in advance

II. Brief Overview Of Modern Seizure Detection Systems

A. Main Features of Modern Seizure Detection Systems

In recent years many researches have been focused on automating seizure detection processes. The timely detection, monitoring and early remediation and prevention of seizure are the utmost priority of these modern seizure detection systems. Further, these systems are mainly focused on development of the multi-task novel biosensing components. Moreover, these smart seizure diagnostic systems provide bio-information needed to understand timely seizure progression and therapy optimization.

In recent studies most propitious biosensors used in modern seizure detection systems are inertial and tactile ones: thermometer, GSR sensor, accelerometer and gyroscope, which enables long-term ambulatory monitoring in patients with seizure.

However, currently available seizure recognition methods carry a number of drawbacks:

- They cannot provide retroactive verification for events that are logged as seizures.
- Most of them are not patient-friendly, as many seizure diagnostic biosensors are directly attached to the patient's body (EEG electrodes are attached to the scalp.) An automated and real-time method for measurement of EEG signals is yet to be found.
- These approaches can only be used in a selected portion of seizures that have well defined motor activities namely; myoclonic, tonic–clonic, clonic and nocturnal seizures [8]. It is worth identifying nocturnal and tonic–clonic seizures that deserve special attention since the forms are often refractory to treatment and the latter can lead to status epilepticus, which can be fatal [9].
- They tend to have high false-positives rates, because many sudden repetitive movements, such as tooth brushing, may be similar to seizure movements [10].

B. Wearable Devices Available in the Market

Few commercially available wearable seizure detection systems like EpiLert, SmartWatch (Smart Monitor Corp.), Epi-Care Free (Danish Care, Denmark), Medpage MP5 and Embrace. These devices are currently under clinical evaluation. Overview of these systems has revealed that most of them are not customizable.

The potentiality of making user-specific modifications is important since clinical manifestations of seizure vary among patients and a given patient may have different seizure types [9]. Enabling seizure detection system modifications based on the features of particular seizure type 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. Another issue is that the devices currently available on the market are designed primarily for alarming caregivers, not for seizure recording.

Meanwhile, it is obvious that objective seizure logs could significantly enhance the quality of medical care. Neurologists often make clinical decisions about medication adjustments relying heavily on patient's seizure diary [11]. Unfortunately, since consciousness can be impaired both during and following seizure episodes patients fail to report 30-50% of daytime seizures and more than 85% of nighttime seizures [10]. Thus, inaccurate seizure reports can lead to ineffective remedy. Our work pursuits to develop a reliable, wearable, and comfortable seizure detection device to address the both issues.

III. The Proposed Device Description

SeizeIT is a multimodal, wearable, clinically-accurate seizure detection device. The prototype captures the majority of clinically meaningful seizures, in a socially-acceptable form factor (on the bicep).

In addition, SeizeIT is a multimodal system, allowing several biosignals to be measured simultaneously, by using different type of bio sensor modules (Fig. 1): thermometer to detect patient's core body temperature, Galvanic Skin Response(GSR) sensor to measure skin conductance, accelerometer to measure the muscle's acceleration and Gyroscope to measure angular velocity (rotational motions of the muscles). Further, these biosensors can be easily incorporated in the SeizeIT system to improve the accuracy of the seizure-detection algorithm.

High-quality biosignals measurements are key to the SeizeIT for reliable seizure detection. The data acquired by the SeizeIT prototype closely resembles the data recorded with the standard hospital equipment. The seizure detection algorithm, which engaged with SeizeIT use bio signal data acquired by the sensors, in order to enable patient specific an effective seizure detection and prediction method.

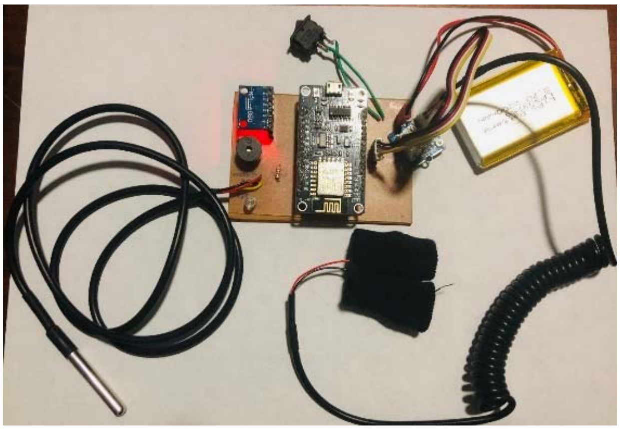

Fig.1 Hardware components of the device

A. Design Features

The SizeIT is based on NodeMCU microcontroller which is an open source IOT platform consisted with both firmware and hardware platform. The firmware runs on the ESP8266 Wi-Fi SoC and hardware platform is based on the ESP12 module. In built Wi-Fi module in the micro

controller unit enable to send the acquired bio signal data to the system main database. further, system employs three main sensors: MPU6050 sensor contains a MEMS accelerometer and MEMS Gyroscope. SCL and SDA pins of Mpu6050 connected to D_5 and D_7 pins of NodeMCU. GSR sensor connected to the NodeMCU through A_0 pin. A_0 port reads GSR senor data as an analog signal. Thermometer data line pin connected to the NodeMCU via wire bus pin and 4.7KΩ resistor. The 4.7KΩ resistor use to control the device voltage and to get the accurate sensor data readings from the bio sensors.

Algorithm for tactile and inertial biosensors signals processing is developed with consideration of the error caused by changes of accelerometer’s measurement axes with respect to the gravitational acceleration vector and GSR sensor ‘s skin conductance values measurements respect to the body temperature measurements of thermometer.

For the measurement data recording SD memory card up to 32 GB can be used. It communicates with the microcontroller via the SPI (serial Peripheral interface). The information stored on the SD card can be processed externally by a PC. Moreover, 4200 Hz piezo buzzer is used to provide sound alert when there is any error occurrence in the device and buzzer connected to the NodeMCU via D_6 pin. In addition, there is a LED bulb connected to the NodeMCU via D_1 pin. Which is used to indicate the data transit and Wi-Fi connectivity status of the device. The functional block diagram is shown in Fig. 2.

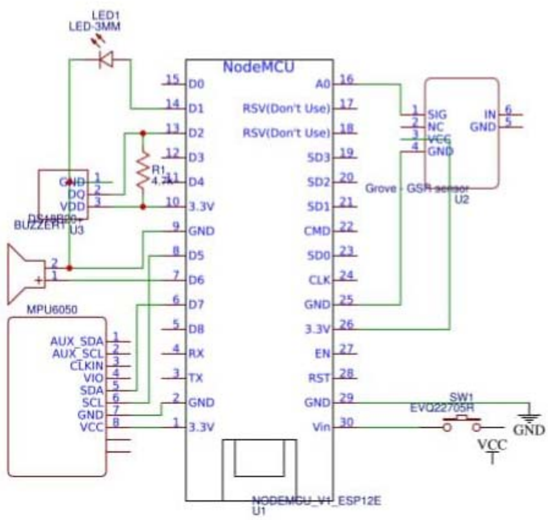

Fig. 2 Functional block diagram of the device

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 seizure spell. This process includes:

- Assembling the data over a period of the patient’s motor activity, body temperature and skin conductance. The data obtained represent a time sequence of the instantaneous stimulations experienced by the sensors.
- Analyzing the collected data to determine the abnormal deviations of seizure parameters.
- Defining the signature of a particular seizure type in an individual patient by checking the motions, EDA and body temperature patterns against verified seizure spells.
- Setting thresholds for oscillatory seizure parameters (frequency of EDA, persistence of body surface temperature and 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) Seizure pattern recognition.
This method is performed via an algorithm executed within the processor. If seizure parameter values obtained from the patients are greater than the thresholds, then the patient’s status is considered to be a critical seizure state. In an embodiment, after the processor generates an indication of abnormal deviation there are 2 options available:

a) Alerting caregivers to ongoing seizures via notification message. The message may include data from a current episode of abnormal seizure parameters.
b) Recording of biosensors data on SD card. The data 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 for the future seizure prediction purpose. 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.

Fig. 3 SizeIT placement on subject bicep

IV. Method

The datasets of the seizure patients are acquired from the Sirimavo Bandaranaike General Hospital Peradeniya. The device is attached to the bicep of the patient (Fig. 3) which includes:

1. MPU6050 sensor with inbuilt micro-electromechanical systems (MEMS) 3-axis accelerometers and 3-axis gyroscopes to monitor the hand movements
2. GSR sensor to capture the modulation in skin conductance.
3. Thermo sensor to trace the body surface temperature.

The device consisted of a 3D accelerometer with a sensitivity of ±2g and 3D gyroscope with sensitivity of ±250deg/s. Based on the scale used, the raw data was be shared by using this formula:

$$A_{axis} = \frac{Scale}{A\ raw_{axis}} \quad (1)$$

$$G_{axis} = \frac{Scale}{G\ raw_{axis}} \quad (2)$$

After the data is calculated based on the scale, the magnitude value of the xyz axis data on the accelerometer is calculated by using the following formula:

$$\text{ATt} = \sqrt{aX^2 + aY^2} + aZ^2 \quad (3)$$

Beside the magnitude value, the slope of the accelerometer is also used as an additional feature or often called pitch roll and yaw. The following formula is used to calculate the slope

$$\text{arx} = \frac{180}{\pi} * \text{atan}\left(\frac{ax}{\sqrt{ay^2+az^2}}\right) \quad (4)$$

$$\text{ary} = \frac{180}{\pi} * \text{atan}\left(\frac{ay}{\sqrt{ax^2+az^2}}\right) \quad (5)$$

$$\text{arz} = \frac{180}{\pi} * \text{atan}\left(\frac{ax}{\sqrt{ay^2+az^2}}\right) \quad (6)$$

Signals are sampled at 250 Hz [12]

Furthermore, the device has a skin temperature sensor (a calibrated thermistor) with an accuracy of ± 0.1°C. The sensor continuously monitors the skin temperature for any sudden increase or decrease in value. GSR captures skin conductance using skin electrodes with a sampling rates between 1 – 10Hz and is measured in units of micro-Siemens (µS).

The datasets are acquired during the night as there is a reduced supervision of the patient by the caregivers. Furthermore, the acquired data is not much influenced by noise sources such as voluntary movements, EDA and Body temperature. Four datasets of four different patients between the age of 5 years and 11 years who suffer from frontal lobe and febrile seizures which results in marked motor manifestations and EDA deviations are acquired.

A smart application was developed to continuously record sensor data with a time stamp. The device is firmly strapped on patient such that the device is in contact with the dorsal side of forearm. A preprocessing step is executed on the raw data. This step has two goals: first it reduces the amount of data significantly, second it divides the data into separate movement, EDA and body temperature epochs which are further used to classify as a abnormal or a normal activity.

The first preprocessing step is data reduction. Motion data being filtered with a cut-off frequency of 47 Hz. To avoid the phase distortion introduced by the filter, we processed the input data in both the forward and reverse directions, which results in a zero-phase filtering. The cut-off frequency is chosen such that the filter cancels out the aliasing effect [6].

After this data reduction step, the epochs without movement are discarded. To discriminate between movement and non-movement, the standard deviation of a sliding window of two seconds is calculated. If the standard deviation crosses a certain threshold, the epoch is considered as a movement, otherwise the epoch is discarded.

The threshold is determined by a simulation where it is detected by the algorithm. This resulted in a threshold of 10 mg. After this step, the data is clustered. Epochs within 30 seconds are clustered together and are considered as a single movement epoch. Ten to twenty percent of the datasets are considered as movement events. Considering all the preprocessing steps, this means that only about 1.5% to 3% of the original has to be processed, which is a considerable reduction.

Change in skin conductance during a session was calculated by subtracting the mean skin conductance level for the first 2 min and for the last 2 min and by calculating the percentage of variation compared with the first 2 min. Percentage change in skin conductance was averaged for each patient over the 12 biofeedback sessions. The normal body temperature ranges from 36.5˚C to 37.2˚C.

V. Application Areas

Seizure detection system is applicable in both diagnostic and care settings. Which is important specially in aiding patients with epilepsy. The data obtained from the analysis helps neurologists to make decisions based on the identifications like; the seizure type, frequency and distribution during day and night about drug therapy. Also helps to discover new therapies and medications. The alarm or notification system increases patient's chances of receiving prompt assistant where same theory can be used for accident prevention and offering reassurance. The device can be used as a stress level monitor with the active GSR sensor to help emotion regulation issues or autism. GSR used to measure skin surfaces unopposed action of sudomotor sympathetic nerves where it increases electrical conductance. Which helps the device to detect the early stages of the seizure through sweat and skin temperature drops or rises. This activity can used in future work to develop lie detectors or else know as truth meters. Also the device can be altered for athletic purposes to detect heat strokes, abnormal heart pulses etc. Also the active sensors accelerometer and GSR contribute to identify Parkinson's abnormalities when customized and trained.

VI. Discussion

The main aim of this study is to identify possibilities of seizure and immediately notify the caregivers to assist when difficulties occur. This study was about how effectively the mpu 6050 and GSR can be used to determine seizure threat effectively. The devices in the market uses mostly the electroencephalography (EEG), electrocardiography (ECG), electrodermal activity (EDA), and surface electromyography (sEMG) or video monitoring where patient needs to wear scalp electrodes all the time. Also, most of the devices available in the market are not customizable according to the individual patient's condition, where the system is customizable according to individual patient. Thus, it leads to stigmatization, labour-intensive impractical and discomfort to patient. While the device in the study focus more on physical changes like skin conductance, muscle accelerate and angular velocity. With the sensors used there will be less difficulty for the patient, more portability more comfort and low cost. The expected results of the study fulfil immediate notification system and accurate and more sensitive seizure detection. Considering the results turned out, hypothesis will be as the system enhance the patient's assistance in difficult seizure times which will eliminate the risk for life treats. In long terms when a patient is wearing the device and triggers a seizure, his/her own self can determine what causes for sudden seizure (emotions, proactive actions, mental stability). Even the system is able to identify jerk moments alongside with skin conductance, device may capture irrelevant motions sometimes as seizure situations since a patient may go through many kinds of proactive activities during a day. Mostly the device identifies running, dancing activates as abnormal motions since the patient may experience sweat and temperature change during these activities as well. The quality of the predictions improved through continuous data captured through the device and fed into machine learning algorithm in long term. Over e benefits found in device there are limitations as well. Motion measurement accuracy is a main concern with patients' proclivities, signal processing barriers, using redundant sensor arrays to improve the performance of the system and sudden system errors are some of the main limitations. These tasks take considerable amount of time and labour to predict accurate seizure situations.

VII. Conclusion

Considering the seizure detecting devices available in the market, most of them are focus on a single modality of detection and doesn't consider multiple parameters that helps to determine seizure more sensitively. Also most of the devices provide the facility of detecting the seizure yet not notifying caregiver. Considering the need for a device with multiple modality of detections which are more comfortable, low cost, portable and efficient the study focused to cover them all with a seizure detection and prediction system. The study proposes the design, develop and validate a bicep worn device that detect seizure efficiently and over time it can also predict a seizure in the initial stage. The seizure detection through motions and skin conductance is accurate when there are no proactivity, since the physiological status of a person changes according to time and the situations. In order to trigger more accurate seizure motions, system is trained with large number of individual patient data for a considerable amount of time where system identify small deviations of emotions due to external factors, mental stability changes, physical activities carries out during day. So that it can omit similar kind of motions and skin conductance arrays and focus on more impotent and real abnormalities. The system is capable of detecting convulsive seizures with duration ≥ 1 min. Future work will optimize the algorithm and system in detecting other neurological disorders.

For the future study of the device requires more powerful study designs providing valuable insight for clinical trials. The seizure detecting system has big pool of possibilities to improve and used as a medical too assist in many neurological disorders. Among them Parkinson, epilepsy, Autism are some highlighted diseases. In order to improve the existing system, additional sensors or tools can be added to the device. A micro speaker is an effective tool to be include in the existing device to increase the accuracy of the epileptic seizures through patient's aurora. The device can be improved to be used as tele-health gadget where the patient's neurological abnormalities will be record for a period of time and transferred to medical officers for medical analysis, it will broad the access to information and reduce cost, enabling delivery of an effective non-drug treatment in pharmaco-resistant epilepsy. This is a viable alternative to face-to-face therapy, meeting experts in medicine, travelling cost and difficulties. Device can be generalized to other effects on anxiety disorders, depressive disorders and stress on TLE patients as well with specialized datasets trained over a period of time

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