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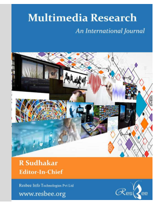

Comparison Between the Epilepsy Treatment Watch Case Study and Other Epilepsy Diagnostics

Emad Hamid Abbker
Nanoelectron Start-up, Sudan.
Emad099224@hotmail.com

Abstract: Epilepsy is a disorder in the brain's electrical activity, affecting about 3.4 million people in the United States across all ages. It can cause symptoms ranging from brief lapses of attention to severe convulsions, impacting quality of life, mental health, and social interactions. Early detection and continuous monitoring are crucial to preventing severe episodes and reducing emergency interventions. Additionally, integrating wearable technology with AI can provide personalized insights into seizure patterns, improving patient management. There is a need for a better understanding of its genetic and molecular bases, more precise diagnostic, and treatments that effectively control seizures with fewer side effects. This paper presents an artificial intelligence system integrated into a smart medical watch capable of alerting patients, families and physicians before, during, and after seizures via a smartphone application. The watch monitors heart rate, blood pressure, and hormone-related changes, provides patient location through GIS, and can wirelessly stimulate the brain with electrical pulses as a therapeutic invention. By combining accurate monitoring, alerts, and therapeutic stimulation, this wearable technology addresses key gaps in epilepsy care.

Keywords: Epilepsy, Dopamine Harmon, Aldosterone Harmon, Stimulation of the Brain, Biological Cell Voltage.

Nomenclature

Abbreviation	Expansion
EEG	Electroencephalography
BCI	Brain-Computer Interface
AI	Artificial Intelligence
BPM	Beats Per Minute
GIS	Geographic Information System
tES	Transcranial Electrical Stimulation
MAS	Multi-Agent Systems
PoMAS	Patient Observing MAS
GTCS	Generalized Tonic-Clonic Seizures

1. Introduction

Epilepsy is a neurological disorder that affects approximately 50 million people worldwide, making it one of the most common neurological diseases globally. The prevalence varies by region, with higher rates often found in low and middle-income countries. It represents a significant public health burden, not only due to the seizures themselves but also because of social stigma, reduced productivity, and healthcare costs. Epilepsy has been recognized since ancient times, with the earliest known references dating back to 4000 BCE in Mesopotamia. Throughout history, it was often misunderstood and stigmatized, attributed to supernatural causes. Despite advances in medical science, misconceptions and inadequate access to care persist in many regions, highlighting the need for improved diagnostic and therapeutic tools. To comprehend how a disease came to be, we must begin with a description of the signs and symptoms, followed by names and definitions, which are intimately tied to an understanding of the pathophysiology [7].

Sodium and potassium are the two basic elements in the formation of biological cells. These two elements are responsible for diseases. The treatment for epilepsy is through increasing or decreasing them. Initially, we have to diagnose the symptoms and provide necessary treatment to the patient. Accurate monitoring of these ions can provide early warnings and guide interventions to prevent seizure onset.

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However, Epilepsy has many types, and their symptoms also differ. Some of them include,

Focal epileptic seizures: These are seizures that result from activity in only one area of the brain.

- Generalized epileptic seizures: They affect all parts of the brain and will be the focus of this study.

Generalized epileptic seizures are divided into:

- Epileptic seizures accompanied by absence: It affects children, such as staring.
- Tonic epileptic seizures: Tonic epileptic seizures cause muscle stiffness and may affect consciousness.
- Atonic seizures: Causes loss of muscle control.
- Clonic seizures: They cause repetitive twitching muscle movements.
- Myoclonic seizures: They usually appear in the form of short twitches or spasms.
- Tonic-clonic seizures: They are previously known as grand epilepsy seizures, and they are the most difficult type of seizures. They can cause a sudden loss of consciousness, stiffness, spasms, or tremors in the body, and sometimes lead to a loss of the ability to control the bladder or bite the tongue. This type of seizure will be the scope of this study.

Tonic-clonic seizures are particularly dangerous due to the high risk of injury and complications such as status epilepticus, which can be life-threatening if not promptly managed.

Most physical activities, such as walking, running, thinking, etc., send signals from the brain in a process called action potentials. The biological cell in the brain consists of two main elements: sodium and potassium. People with epilepsy tend to have more physical problems (such as fractures and bruising from injuries related to seizures), as well as higher rates of psychological conditions, including anxiety and depression. Similarly, the risk of premature death in people with epilepsy is up to three times higher than in the general population, with the highest rates of premature mortality found in low – and middle-income countries, potentially preventable, such as falls, drowning, burns, and prolonged seizures [8]. This underscores the urgent need for preventive interventions and continuous monitoring to reduce both physical and psychological complications.

While EEG is a well-established, non-invasive method widely used for diagnosing epilepsy, polarization depolarization techniques offer detailed insights at the cellular level, albeit often involving more invasive or specialized procedures. These techniques allow precise modulation of ion concentrations, potentially providing both diagnostic and therapeutic benefits. It is invasive or non-invasive with varying degrees of patient risk.

In this paper, we proposed polarization and depolarization methods using an epilepsy watch. The watch contains four different sensors to monitor the ion detection in the patient's body and send signals to the detector. When the seizure is detected, the watch stimulates the ion electrically with the standard voltages and frequencies of tissue resistance of 100 ohms, which helps the patient to become normal. The stimulation of the brain in the watch is of two types: one is all the time stimulating the second is critical stimulation during the seizures to inhibit epilepsy. A notification is sent to the patient's caretaker and physicians in emergencies through GIS and a smart mobile app. The integration of real-time monitoring with automated intervention offers a novel approach to reducing seizure severity and improving patient safety.

The main contribution of the project is

- Prevent the depolarization process that causes unwanted movement by reducing the sodium concentration inside the cell during, before, and after epileptic status by wireless electrical stimulation of the brain.
- Address the critical gaps in epilepsy care by providing accurate results, automatic care, and timely notifications to caregivers, thereby improving the overall management of the condition and enhancing the quality of life for epilepsy patients.
- Incorporates GIS technology to provide the patient's location to facilitate a quicker response in case of a seizure.

Overall, this system combines monitoring, therapeutic stimulation, and location tracking to deliver a comprehensive, patient-centered approach to epilepsy management.

The rest of the paper is organized as follows: Section 2 covers the literature review, Section 3 elucidates methodology, Section 4 covers materials used, Section 5 explains the results and Discussion, Section 6 mentions advantages and disadvantages, and Section 7 concludes the paper.

2. Literature Review

In 2014, Constantin Ungureanu *et al.* [2] developed an app to detect night epilepsy during sleeping. It used the VITRUVIUS sensor platform and smartphone for notification. The sensors are used for detection and sent to a seizure detector application that has an online classifier that triggers an adaptable cumulative sum algorithm. If epilepsy is detected, then an alert message is sent to the seizure monitor application or the caregiver's phone. This approach demonstrated the potential of combining wearable sensors with mobile technology to enable timely interventions, particularly during high-risk periods such as sleep. The evaluation result achieved high sensitivity and predictive value.

In 2017, Bianca A. Simonsmeier *et al.* [13] investigated the use of tES, a noninvasive method involving a weak electrical current applied to the brain, to enhance physiological and cognitive processes. They present the first metallic analytic test of the hypothesis that tests in a learning phase are more effective than tests in an assessment phase. Although promising for cognitive enhancement, this method highlights the limitations of traditional electrode-based stimulation, which can be cumbersome and less practical for continuous use. They achieved good results, but stimulating the brain by using electrodes is an old way.

In 2023, Habtamu *et al.* [12] designed and developed a wearable device for the automated real-time detection of epileptic seizures. The designed device integrated different sensors like an accelerometer, pulse oximeter, and vibration sensor to monitor body movement, heart rate variability, oxygen levels, and jerky movements for real-time seizure detection. The study emphasizes the growing trend of low-cost, sensor-based wearables for continuous monitoring, which can enhance patient safety outside clinical settings. Through testing and iterations, the prototype demonstrated acceptable accuracy levels for sensor measurements at a low cost, below $40, excluding other expenses.

In 2023, Carlo M. Bertoncell *et al.,* [9] focused on the development and implementation of a healthcare system named PredictMed-MHS, utilizing a deep-learning module for epilepsy prediction and seizure detection in children with Developmental Disabilities and Cerebral Palsy. The development and implementation of a MAS encapsulating the PredictMed-Epilepsy module, enhancing real-time detection of patient-related events through a module called PoMAS. This study illustrates the integration of multi-agent systems with deep learning to improve real-time monitoring and predictive analytics in complex patient populations. Finally, the Machine-learning model PredictMed is employed to analyze the collected data and determine associations with epilepsy, achieving an average accuracy in prediction.

In 2022, Nicholas M. Gregg *et al.* [4] focused on seizure unpredictability in people with epilepsy. The wearable devices can detect these cycles of seizure risk and compare the performance of wearables with concurrent chronic brain recordings. Fourteen subjects underwent long-term monitoring using a multimodal wrist-worn device and an implanted responsive neurostimulation system to measure various physiological parameters. Wavelet time-frequency analyses identified circadian and multiday cycles in both wearable and brain recordings, and circular statistics were used to assess seizure phase locking to these cycles. This work highlights the importance of understanding temporal seizure patterns, which can inform personalized monitoring schedules and early-warning systems. Results showed that long timescale cyclical changes in wearable recordings are common in epilepsy, with seizures occurring at preferred phases of these cycles for many individuals.

In 2024, Lydia Wheeler *et al.* [14] developed and implemented a mobile platform and ARTiE Watch to facilitate standard and objective assessments of behavioral responsiveness during and after seizures. The ARTiE Watch enables remote activation of standardized assessment through 18 command prompts, testing behavioral responsiveness across the motor, language, and memory domains. The integration of cloud-based analytics allows for real-time data aggregation and remote monitoring by clinicians. The ARTiE Watch behavioral testing, deployed via a cloud-based platform, proved to be feasible, providing standardized, objective behavioral responsiveness assessments during seizures.

In 2022, Salah Eldeen *et al.* [15] developed a wearable device for epilepsy seizure detection, with a particular emphasis on detecting GTCS. The methodology involves the development of a wearable belt equipped with an Arduino processor that constantly acquires data from four different sensing modalities: heart rate sensor, electromyography sensor, blood oxygen level sensor, and accelerometer. Higher-than-normal threshold levels are established for each sensor, and if two or more signal measurements surpass the corresponding threshold value for a specific time interval, a seizure alarm is triggered. This approach demonstrates the effectiveness of multimodal sensing in improving detection specificity and reducing false alarms.

In 2022, Gaurav *et al.* [16] focused on developing a classifier for seizure detection using machine learning models. It used data acquisition from the E4 smartwatch, preprocessing of acquired signals, and feature extraction from these signals. It included the E4 smartwatch for data collection and machine learning models such as SVM-RBF, decision tree, and logistic regression for classification. The study underscores the role of wearable technology combined with machine learning for individualized seizure prediction and early intervention. The evaluation of different machine learning models, including SVM-RBF, decision trees, and logistic regression, showed promising results for seizure detection and classification.

2.1 Review Table

Author	Methodology	Technology	Advantage	Disadvantage
Constantin Ungureanu *et al.,* [2]	Cumulative Sum Algorithm	Smartphone, sensor, and Bluetooth	• Detect major nocturnal convulsion seizures in real time. • The monitoring app and seizure detection can be installed on Android and regular apps. • Customized algorithm parameters were easily downloaded based on the patients. • Simple with maximum functionalities.	• The detection algorithm has to be improved by combining multiple sensors. • Have to reduce false positives.
Bianca A. Simonsmeier *et al.,*	tES	tES	• Provided a comprehensive meta-analytic assessment of the effects of tES on language and mathematical competence. • The noninvasive brain stimulation technique was used to enhance long-term synaptic plasticity and learning outcomes.	• Limited to the effects of tES on language and mathematical competence and excluding other cognitive domains. • The results were limiting the generalizability of the findings to broader cognitive functions. • Doesn't discuss the optimal dosages or potential adverse effects that could arise from tES application.
Habtamu et al.,	Multiple Sensors	Wearable device, smartphone, mobile app, and Bluetooth	• This cost-effective approach enhances the device's accessibility and affordability for wider utilization.	• Multiple sensors potentially increase the complexity of the system, leading to more intricate calibration and maintenance. • There was a need for continuous validation and calibration of the sensors to ensure accurate data collection and seizure detection.
Carlo M. Bertoncell *et al.,* [9]	PredictMed-MHS	Embrace the smartwatch and Brain Sentinel EMG device	• Facilitating early evaluation and management of epilepsy. • PoMAS with real-time event detection mechanisms adds a layer of sophistication to patient monitoring systems.	• Focused only specific population of children with Developmental Disabilities and Cerebral Palsy. • The model's performance metrics were not extensively discussed, which could raise concerns about the validity and reliability of the predictions.
Nicholas M. Gregg et al., [4]	Long-term ambulatory monitoring	Multimodal wrist-worn device	• Enables a better understanding of when seizures are more likely to occur for individuals with epilepsy. • The extended monitoring duration contributes to a more thorough analysis of seizure risk factors.	• This is a relatively small cohort; however, the long recording durations bolster the reliability of results. • The use of circular statistics to assess seizure phase locking to physiological cycles may introduce complexities in data analysis and interpretation.
Lydia Wheeler *et al.,*	BrainRISE platform	ARTiE Watch and mobile application	• Convenient and non-intrusive method for monitoring and assessing behavioral responsiveness. • Enables remote activation of assessments during different	• Used only a relatively small sample size. • ARTiE Watch needs further standardized behavioral responsiveness testing.

			periods of monitoring, enhancing the efficiency and effectiveness of behavioral responsiveness testing.	
Salah Eldeen *et al.,*	GTCS	wearable belt, GPS, SMartphone	• Continuous real-time monitoring minimizes false alarms. • Ensure timely assistance during a seizure event.	• Clinical trials were not conducted during this initial system development phase, limiting the evaluation of the device's effectiveness in real-world scenarios.
Gaurav *et al.,*	Machine Learning	E4 smartwatch	• Provided a systematic approach to seizure detection using wearable technology and machine learning. • Machine learning models allow for accurate classification of seizure vs. non-seizure and pre-seizure vs. non-seizure events.	• One potential limitation could be the generalizability of the results to a larger population, as the research was conducted on a specific group.

2.2 Research Gap

- In paper [2], detecting epilepsy seizures is not effective because it only works for night seizures, but the epilepsy treatment watch works effectively at all times. This highlights the need for continuous, real-time monitoring across day and night to ensure patient safety at all times.
- In paper [1], the methodology is not better for patients because the method uses ECG for detection only, and treatment is only done through surgery. Non-invasive alternatives with immediate intervention capability are required to reduce risks and improve patient comfort. A better version is needed to detect and treat the patients through wireless electrical stimulation without surgery.
- The paper [12] used an innovative smart real-time sensor, but the alarms are not timely. When the seizure increases, it should be reported immediately to the caretaker. Timely notifications are crucial to prevent injuries and facilitate rapid medical response.
- Commonly, epilepsy seizures are diagnosed by the neurologist in the neurological clinic. It is difficult to transfer the affected patient from that spot to the hospital. This gap underscores the importance of portable, wearable devices that can detect and manage seizures on the spot, improving patient outcomes and reducing emergency transport delays. However, there is a need for technology to treat patients on the spot.

2.3. Research Hypothesis

Traditionally, Epilepsy was diagnosed using brain waves through EEG, a method where the neuronal activities in the brain are translated into EEG signals by utilizing a BCI system with wearable headsets. EEG signals captured by multiple electrode sensors attached to the scalp can indicate abnormalities or patterns associated with epilepsy when fluctuations in voltage are observed during specific brain activities. However, EEG signals are often affected by external noise, patient movement, and inconsistent electrode contact, which can reduce diagnostic accuracy. The EEG signals were quantized based on their frequency ranges from 0.5Hz to 28Hz, as each frequency range has unique biological significance and correlation with distinct brain functions. EEG signals with different frequencies can be crucial for recognizing activities like epilepsy, as neglecting specific frequencies may hinder accurate diagnosis. Advanced signal processing and feature extraction techniques can enhance the reliability of EEG-based diagnosis, particularly when integrated with machine learning models. In the diagnosis process, the quality of EEG signals plays a vital role in determining the distinctive power of extracted features, as the signals are acquired via sensors placed over the skull, leading to noise and variations in strength [11] which is clearly shown in Figure 1.

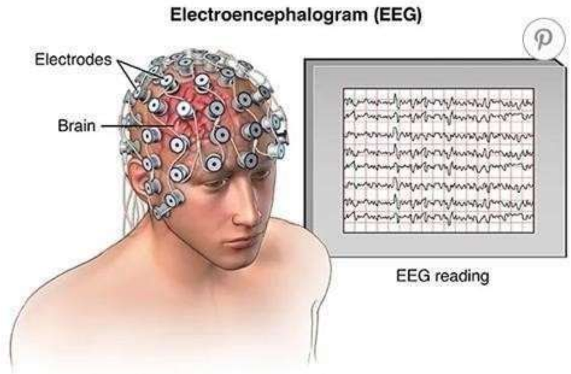

Fig. 1. *Diagnosis of Epilepsy through EEG*

The proposed method is based on polarization and depolarization in diagnosing and alerting in the event of epilepsy. These techniques provide more direct insights into neuronal activity and can enable both early detection and real-time therapeutic intervention. These techniques offer detailed insights at the cellular level, albeit often involving more invasive or specialized procedures.

3. Methodology

The design relied on theories of electronic circuits and some electronic sensors. Figure 2 illustrates the conceptual framework of the proposed approach. The proposed method diagnoses epilepsy through a smart medical watch using AI to notify of epilepsy occurrences before, during, and following occurrences. This watch effectively tracks epileptic patients and notifies their families and physicians using a smartphone app. The integration of AI enables predictive analytics, which can anticipate seizures based on real-time physiological data and historical patterns. Furthermore, the watch also uses the Geographic Information System (GIS) to provide the patient's location. This feature ensures rapid emergency response and enhances patient safety, particularly when the patient is alone or in public spaces.

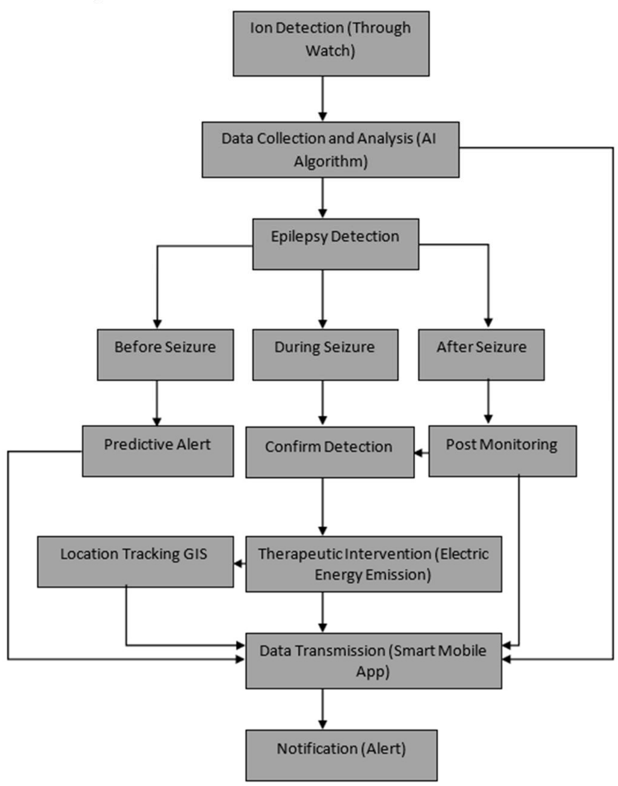

Fig 2. *Conceptual framework*

Polarization and depolarization are fundamental processes in the functioning of neurons and play a crucial role in the occurrence and propagation of epileptic seizures. The detailed process is explained diagrammatically in Figure 3. Understanding these processes is essential for developing electrical stimulation protocols that can mitigate or prevent seizure activity.

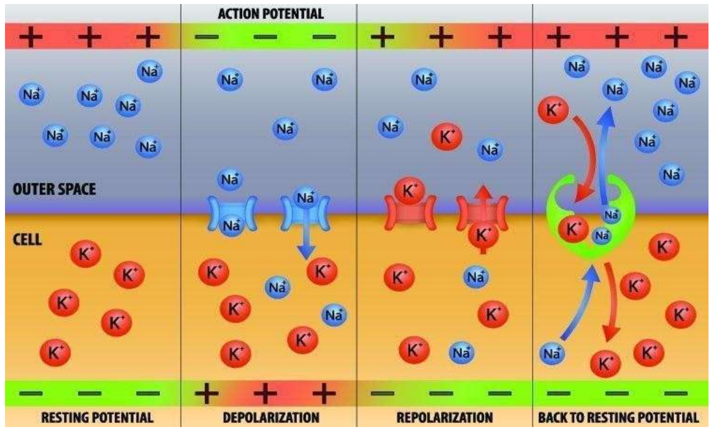

Fig 3. *Action potential*

3.1 Polarization

Polarization and depolarization refer to the electrical state and activity of neurons in the brain. When the cell is resting, neurons are polarized. This means that there is an electrical charge difference across the neuron's membrane. The inside of the neuron is negatively charged relative to the outside. This charge difference is maintained by the distribution of ions (such as sodium, potassium, chloride, and calcium) inside and outside the cell. Proper maintenance of polarization is crucial for normal neuronal function, and deviations can increase the risk of abnormal firing, such as in epilepsy. The percentage of potassium inside the cell is greater than the percentage of sodium, i.e., the resting membrane potential is typically around -70 millivolts (mV) to -55 millivolts [10]. The normal concentration of

potassium (K^+) inside a cell is typically around 140 to 150 millimoles per liter (mM), and extracellular potassium that is found outside the cell is approximately 3.5-5.0 mM in the blood plasma. Monitoring potassium levels in real time can provide early warning signs of neuronal excitability and impending seizures. The intracellular concentration of potassium is essential for maintaining the cell's resting membrane potential and proper cellular function.

3.2 Depolarization

When a neuron is activated, ion channels open, allowing positive ions (mainly sodium) to flow into the cell. This influx of positive ions causes the inside of the neuron to become less negative (or more positive) relative to the outside, reducing the membrane potential. If the depolarization reaches a certain threshold from -70 to -55 millivolts, it triggers an action potential, an electrical impulse that travels along the neuron [3]. This action potential is essential for neuronal communication. In epilepsy, abnormal synchronization of depolarization events across neurons can lead to uncontrolled firing, resulting in seizures. During external stimulation, the nerve cell begins making a movement or activity. The potassium levels begin to decrease inside the cell until the cell voltage becomes +40 volts, which is the highest value of the action potential wave. Then it begins and gradually decreases until it reaches zero, then to -70 millivolts, which is the normal situation. By applying controlled electrical stimulation at the right moment, it is possible to restore normal polarization and prevent excessive neuronal firing. For the effort of comfort. It is represented diagrammatically in Figure 4.

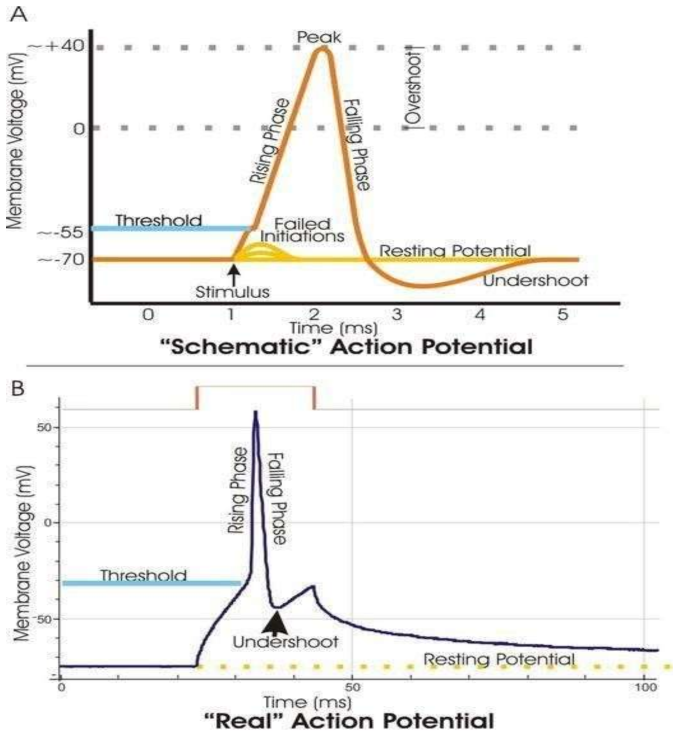

Fig 4. *Potential waveform*

3.3 Epileptic Seizures

In cases of epilepsy, the cell depolarizes to produce an action potential in a random, involuntary manner due to an epileptic seizure. Quantities of sodium are pumped into the cell, amounting to 55 mmol to the power of 5, and the potential difference in the cell reaches +20 volts, while the percentage of potassium in Blood or outside the cell to +12 mmol raised to the power of 2 here as a result of the sudden increase in the proportions of chemical elements inside and outside the cell. These rapid ionic changes create abnormal neuronal firing patterns, which are the physiological basis of epileptic events. The increase in potassium outside the cell leads to an increase in the dopamine Harmon, which leads to an increase in heart rate, which is the first mechanism used in diagnosis. Monitoring both potassium levels and dopamine fluctuations can provide early indicators of seizure onset before clinical symptoms appear.

At the onset of epilepsy and when potassium increases in the blood, it leads to a decrease in the Aldosterone Hormone, which leads to a decrease in blood pressure, which prompts the aldosterone pumps to pump more of the hormone to equalize the percentage of potassium in the blood and regulate blood pressure until blood pressure rises. Tracking these hormonal changes in real time allows for a more comprehensive understanding of seizure physiology and can improve prediction accuracy. The values for the ions during rest and peak are given in Table 2.

Table 2. *Chemical elements rates [6]*

	Typical rest			Typical peak during seizure			
ion	$[ion]_i$	$[ion]_e$	E_{ion}	$[ion]_i$	$[ion]_e$	E_{ion}	Reference
K^+	96 mM[1]	4 mM	–85 mV	94 mM	12 mM[2]	–55 mV	Jiang and Haddad (1991) and Dreier and Heinemann (1991)
Na^+	10 mM[3]	145 mM[4]	+71 mV	55 mM[5]	139 mM[4]	+25 mV	Dietzel et al. (1982), Diarra et al. (2001) and Rose and Konnerth (2001)
Ca^{2+}	70 nM	2 mM	+137 mV	700 nM[6]	100 µM[7]	+66 mV	Pumain et al. (1985) and Pal et al. (1999)
Cl^-	7 mM	145 mM	–80 mV	26 mM[8]	152 mM[4]	–47 mV	Raimondo et al. (2013) and Ellender et al. (2014)
pH/HCO_3^-	7.2/15 mM	7.4/24 mM	–13 mV/–13 mV	7.05[9]/10 mM	7.405[10]/25 mM	–25 mV/–25 mV	Caspers and Speckmann (1972) and Raimondo et al. (2012a)
Receptor	Relative Permeability		$E_{receptor}$			$E_{receptor}$	
AMPAR	K^+:Na^+/1:1		9.1 mV			0.4 mV	
$GABA_AR$	Cl^-:HCO_3^-/4:1		–70.6 mV			–45.8 mV	

$[ion]_i$ and $[ion]_e$ indicate the intracellular and extracellular, free ion concentrations, respectively. E_{ion} and $E_{receptor}$ indicate the reversal potentials for ion species and neurotransmitter receptors, respectively. In calculating HCO_3^- concentrations and $E_{HCO_3^-}$ we have assumed that carbon dioxide is equilibrium distributed across the plasma membrane and that the CO_2 hydration reaction inside and outside the cell is under equilibrium. Values in gray have been estimated where data is not available.

3.4 Epilepsy Treatment Mechanism

Usually, cases of epilepsy are treated electrically with deep-brain stimulation by placing a device in the chest of the person suffering from epilepsy through surgery. The device is connected to the internal vagus nerve of the neck (Fig. 5). When the device is opened and the electrical circuit is closed, electrons flow to the brain, which leads to the occurrence of an electric field where the electrons are attracted and it will be released from the device into sodium ions, the sodium turns from an ion into an inactive atom. In this way, we have reduced the percentage of sodium in the cell and treated epilepsy. This method depends on heart rate just for diagnosing epilepsy. Although effective, this invasive approach carries risks such as infection, surgical complications, and limited adaptability for real-time monitoring.

However, it is not effective because some patients have heart disease and epilepsy. This limitation highlights the need for non-invasive and adaptable methods that can simultaneously monitor and treat seizures without relying solely on cardiovascular indicators.

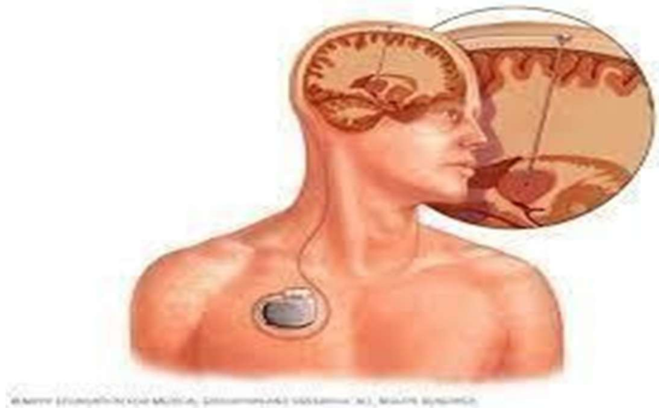

Fig. 5. *Deep-brain stimulation by surgery*

In the proposed method, the smartwatch continuously monitors the ion activity of neurons to detect any anomalies that may indicate an impending seizure. The collected data is processed by an AI algorithm that analyzes patterns and identifies potential epileptic activities. The AI algorithm is trained using historical patient data and physiological markers to improve predictive accuracy and reduce false alarms. The system is designed to detect epilepsy in three stages:

- Before Seizure: Identifies early warning signs based on ion activity patterns. Early detection allows caregivers to take precautionary measures and prevents injuries.
- During Seizure: Detects active seizure events through significant changes in ion activity. Real-time detection ensures immediate therapeutic intervention, minimizing seizure duration and severity.
- After Seizure: Monitors the ion activity post-seizure to assess recovery. Post-seizure monitoring helps track patient recovery and informs future treatment adjustments.

If the AI algorithm predicts an impending seizure based on the data, it sends a predictive alert to the patient, family, and physician. The system confirms the occurrence of a seizure by analyzing real-time data during the seizure. Continues to monitor the patient's condition after the seizure to ensure their safety and well-being. During a seizure, the watch can emit electrical energy through wireless electrical stimulation of the brain as a therapeutic measure to help manage the condition and return the patient to a normal state. This avoids surgery. Wireless stimulation is tailored based on the patient's current ion levels and seizure intensity, enhancing safety and efficacy. Electrical stimulation of the brain has contributed to reducing cases of epilepsy by 40% [1].

The GIS in the watch tracks the patient's location to provide accurate information to family members and healthcare providers in case of an emergency. This real-time location tracking is particularly valuable for patients at risk of injury or in unfamiliar environments. The watch transmits all collected data to a smart mobile app, which records and stores the patient's information for continuous monitoring and analysis. The system sends notifications to the patient's family and treating physician through the smart mobile app, alerting them to the patient's condition and any necessary actions. The mobile app also allows healthcare providers to remotely adjust stimulation parameters and monitor long-term trends in seizure activity.

4. Materials Used

The proposed method used an STM32 microcontroller that is programmable in the C language using the

CubeMx program. Figures 6 and 7 represent the pictorial view of the epilepsy watch and STM32 microcontroller. The STM32 microcontroller allows real-time processing of data from multiple sensors simultaneously, enabling rapid seizure detection and immediate therapeutic response.

Fig. 6. *Epilepsy watch*

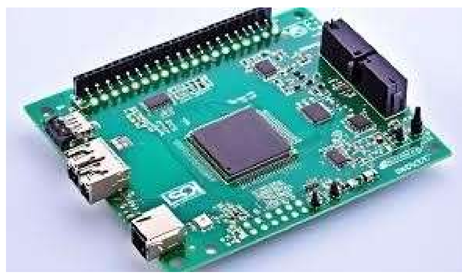

Fig. 7. *STM32 microcontroller*

4.1 Sensors

Sensors detect and respond to various types of input from the body. The sensors are located on the epilepsy watch. Through the sensor, heartbeat, blood pressure, vibration, and tilt are identified. The sensors convert the input into signals to measure and record data. By integrating multiple sensors, the watch ensures higher reliability and reduces false positives in seizure detection. The various sensors used in the device are explained as follows.

4.1.1 Heart Rate Sensor

Heart rate sensors measure the heart's activity and can play a crucial role in epilepsy monitoring systems by detecting autonomic changes associated with seizures. While they do not directly detect epilepsy, they contribute to a comprehensive monitoring system that improves the accuracy and timeliness of seizure detection and response. The sensor uses light to measure blood flow. The photodiode detects the amount of light either transmitted or reflected. The heartbeat of a healthy person is 100-160 BPM. When the blood volume changes in the microvascular tissue, the change affects the amount of light absorbed or reflected, allowing for detection of the pulse. When the heartbeat increases from 180-120 BPM, it indicates the presence of epilepsy. Continuous heart rate monitoring enables the AI algorithm to detect abnormal autonomic responses even before a seizure manifest clinically.

4.1.2 Blood Pressure Sensor

Blood pressure sensors contribute to a holistic approach to monitoring and managing seizures. Integrated into multimodal monitoring systems, blood pressure sensors provide valuable physiological data that enhances the understanding of seizure-related autonomic responses and supports timely intervention strategies. It works by measuring changes in pressure oscillations caused by the pulsations of blood flow. The blood pressure of a healthy person is 120/80 mmHg. When the blood pressure decreases, potassium is pumped out of the cell into the blood, and it heralds the beginning of an epileptic state. So the microprocessor starts comparing with the rest of the sensors, and the aldosterone hormone begins to flow, which leads to an increase in blood pressure, which confirms the presence of status epilepticus, and blood pressure in case of epilepsy is 140/90 mmHg. In combination with heart rate data, blood pressure trends improve the predictive capability of the system.

4.1.3 Vibration Sensor

Vibration sensors (accelerometers) detect acceleration forces and vibrations, providing valuable data on movement patterns and activity levels. In epilepsy monitoring, these sensors contribute to seizure detection, motion analysis and fall detection, enhancing the overall management and safety of epilepsy patients. Integrated into multimodal monitoring systems, vibration sensors play a crucial role in real-time seizure detection and response strategies. When the accelerometer experiences acceleration or vibration, the mass inside the sensor moves relative to the sensor body. This movement causes a change in the electrical properties of the sensor, which is measured and converted into an output signal. The output signal typically represents acceleration or vibration amplitude along one or more axes (x, y, z). Vibration sensors can detect both transient (sudden) and continuous vibrations, providing real-time data on movement and activity. This diagnosis is useful for epilepsy patients who have diseases other than epilepsy that involve blood pressure and heart rate. This will certainly be more accurate than relying on diagnosing blood pressure and heart rate only. Vibration data can also help differentiate between epileptic seizures and other non-epileptic movements, reducing false alarms.

4.1.4 Tilt Sensor

The tilt sensor works along with gravity, providing data on tilt angles and posture changes. They have potential applications in detecting posture changes, fall detection, and positional analysis related to seizures. Here, the sensor detects whether the patient fell or not and compares the result, and there is also an increase in the accuracy of diagnosis [2]. Incorporating tilt sensors ensures that sudden falls or changes in body orientation, which are common during seizures, are captured accurately.

4.2 Wireless Electrical Stimulation of the Brain

The flow process of Figure 8 in the epilepsy watch involves the utilization of different sensors to monitor specific physiological parameters for detecting the presence of epilepsy. The output electrical signals from the sensors are passed through a threshold detector that converts a series of pulses that represent the frequency of the input signal. Then it is fed into a gate. The opening and closing of the gate are controlled by the gate flip-flop, which is in turn controlled by the accurate timebase/clock. When the gate is open, the pulses from the input signal pass through to the counter. The counter counts the number of pulses that pass through during the gate open period. The latch stores the count value when the gate closes, ensuring that the count can be displayed even while the next measurement cycle is occurring. The stored count value is sent to the display, where it is shown as the measured frequency of the input signal. This provides a stable and accurate clock signal that defines the measurement period. It ensures that the gate opens and closes at precise intervals, typically one second, to ensure accurate frequency measurement. These divide the clock signal into smaller, precise time intervals. They provide the timing signals to the gate flip-flop to control the measurement period. This flip-flop is controlled by the divided clock signal from the decade dividers. It toggles the gate open and closed, controlling when the pulses from the input signal can reach the counter. This timing mechanism ensures synchronization between data acquisition and electrical stimulation for precise intervention.

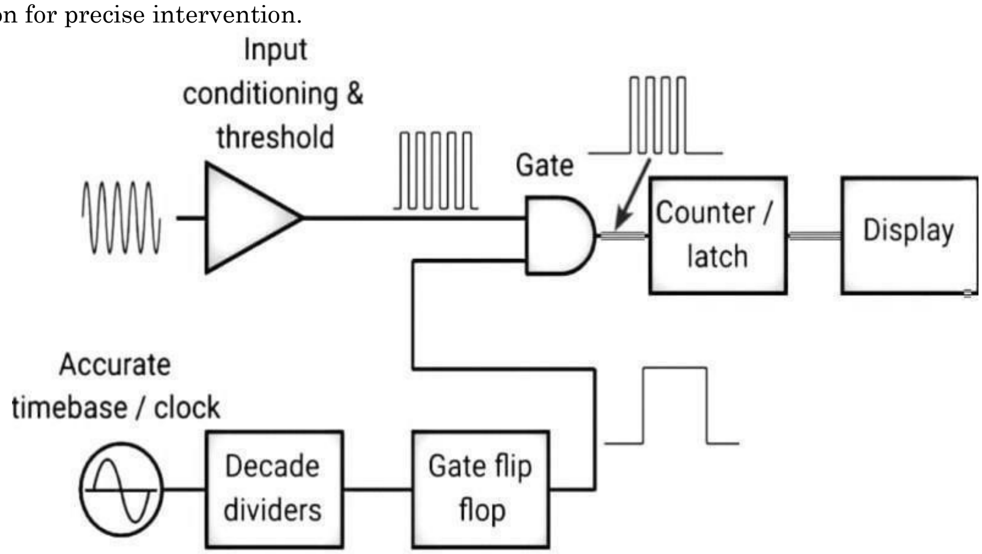

Fig 8. *System block diagram*

The deep brain stimulation works wirelessly in two ways: little stimulation at all times using a small current of 100mA, a voltage difference of 3V, tissue resistance of 1000 ohms, and a frequency of 0.00006 Hz. Secondly, High stimulation at the moment when the situation occurs. Here, the stimulation will help to stop the epilepsy condition using a current of 200A, a voltage difference of 1mV, and a frequency of 2Hz [5]. By adjusting the intensity and frequency of stimulation, the system can safely modulate neuronal activity to prevent or terminate seizures without invasive surgery.

5.Results and Discussion

Through the readings and results, we have shown that it is possible to design an electronic system that alerts when epilepsy occurs and treats the disease by using wireless electrical stimulation of the brain in a modern, innovative, and accurate way. The system demonstrates the feasibility of integrating multiple physiological sensors with AI-based predictive algorithms for real-time seizure management. This device is also useful for the treating physician because it enables him to follow up on his patients remotely via phone application. The smartwatch provides continuous data logging, which can assist clinicians in adjusting treatment plans and evaluating patient response over time.

This Review explores recent advancements in wearable digital health technology specially designed to manage epilepsy. Epilepsy presents unique challenges in monitoring and management due to the unpredictable nature of seizures. Wearable devices offer continuous monitoring and real-time data collection. Additionally, these devices can help reduce emergency hospital visits by providing early alerts to caregivers, potentially lowering healthcare costs. Wearable technology is important in epilepsy management because it enables early detection, prediction, and personalized intervention.

6. Advantages and Disadvantages

Advantages

- Providing effective monitoring of epilepsy patients before, during, and after seizures through providing timely alerts and care.
- It utilizes wireless electrical stimulation to inhibit epilepsy by reducing the sodium concentration inside the cell through brain stimulation, offering a non-invasive treatment option for patients.
- The watch can send notifications to both the patient's caretaker and physicians in emergencies through a smartphone application integrated with GIS technology, ensuring swift responses in critical moments.
- Integration of AI algorithms allows the system to adapt to individual patient patterns, improving predictive accuracy over time.
- By incorporating sensor technology to track changes in blood pressure and heart rate, the watch can provide accurate data for the diagnosis and management of epilepsy, enhancing the precision and effectiveness of treatment.
- The use of real-time sensing technology in the watch promotes continuous monitoring of the patient's condition, enabling early detection of seizures and timely intervention to improve the overall quality of care for individuals with epilepsy.

Disadvantage

- The reliance on wearable sensor-based systems and remote monitoring technology may introduce issues related to data privacy and security, which were not thoroughly addressed in the paper.
- Battery life and device maintenance could affect long-term usability, requiring frequent charging or sensor recalibration.

7. Conclusion

The pivotal role of wearable digital health technology in managing epilepsy, addressing the challenges inherent in traditional approaches, while presenting new opportunities for personalized care. These devices integrate monitoring, prediction, and therapeutic intervention in a single wearable platform, offering a holistic solution for epilepsy management. By harnessing continuous monitoring and real-time data collection, these devices offer invaluable insights into seizure patterns and trends, empowering patients and healthcare providers to make informed decisions and take proactive measures. The AI-driven analysis of physiological signals further enhances the ability to predict seizures before they occur, potentially reducing emergency interventions and improving patient safety. The implications for clinical practice are profound as wearable technology enables more comprehensive and timely interventions, potentially leading to improved outcomes and quality of life for individuals with epilepsy. We can advance wearable digital health technology by integrating the diagnosis of various diseases and treatment methods. The security of the data from the watch and mobile app can be safeguarded for the patient's privacy. Furthermore, the device can be inserted below the skin of the wrist to prevent external damage and loss of the device.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

Declaration of generative AI and AI-assisted technologies in the writing process: The authors declare that no generative AI or AI-assisted technologies were used in the writing process of this manuscript.

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