Computers in Biology and Medicine 41 (2011) 559–564

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

DFAspike: A new computational proposition for efficient recognition of epileptic spike in EEG

Anup Kumar Keshri [a], Rakesh Kumar Sinha [b,*], Aishwarya Singh [a], Barda Nand Das [c]

[a] Department of Information Technology, Birla Institute of Technology, Mesra, Ranchi, Jharkhand 835215, India
[b] Department of Biomedical Instrumentation, Birla Institute of Technology, Mesra, Ranchi, Jharkhand 835215, India
[c] Department of Electronics and Instrumentation, Krishna Institute of Engineering and Technology, 13th. KM stone, Ghaziabad-Meerut Road, Ghaziabad, Uttar Pradesh 201206, India

ARTICLE INFO

Article history:
Received 14 March 2011
Accepted 4 May 2011

Keywords:
Deterministic finite automata
Electroencephalogram
Epileptic spike
Real time diagnostic machine

ABSTRACT

An automated method has been presented for the detection of epileptic spikes in the electroencephalogram (EEG) using a deterministic finite automata (DFA) and has been named as DFAspike. EEG data (sampled, 256 Hz) files are the inputs to the DFAspike. The DFAspike was tested with different data files containing epileptic spikes. The obtained recognition rate of epileptic spike was 99.13% on an average. This system does not require any kind of prior training or human intrusion. The result shows that the designed system can be very effectively used for the detection of spikes present in the recorded EEG signals.

1. Introduction

The electrical activity along the scalp occurs due to the firing of neurons. The recording of these electrical activities is known as electroencephalogram (EEG), which aids in the diagnosis of a variety of neuro-physiological disorders such as epilepsy, coma, encephalopathy, brain death and other focal brain disorders. Epilepsy is a chronic neurological disorder, which is characterized by symptoms such as abnormal synchronous activities in the brain. Such symptoms are termed as seizures. These are manifested as sharp abrupt changes in the EEG amplitude in a very small time interval (Fig. 1). Epilepsy cannot be totally cured, but it can be controlled. However, for the treatment of epilepsy, its occurrence must be efficiently identified. Because of its non-stationary and nonlinear properties, it is very hard to predict the time of occurrence of epileptic events. Thus, a smart automated system with minimum complexity is required for its diagnosis.

Various techniques are available to the researchers and clinicians for the recognition of epileptic spikes. Some of the important methods by which one can proceed for diagnosis of epilepsy are using artificial neural networks [1–5], fuzzy logic [6] and various other time-frequency approaches [7–12]. Most of the previous techniques for automated spike recognition need initial training as well as the optimization of the system. Moreover, to the best of authors' knowledge, none of these methods provide accurate information about the time of initiation, total number and the frequency of occurrences of the epileptic spikes.

To overcome the mentioned demerits in spike recognition techniques, deterministic finite automata (DFA) based spike identification algorithms have been developed with both sequential [13] as well as parallel processing [14] approaches. In these approaches the epileptic spike patterns present in the EEG data were defined with a specific combination of occurrences of a set of predefined symbols, which was having only two elements. The average recognition rate of the epileptic spike pattern achieved was 95.68%. Though, in the parallel processing based system, the average recognition rate of epileptic spike pattern was similar to the sequential approach; the use of data parallelism improved the speed of processing of enormous data. Similar DFA based approach for detection of onset of epileptic seizures in noisy domain has also been proposed recently [15]. However, the recognition accuracy achieved by these DFA based methods was not the best as reported with many of the automated system approaches, where the spike recognition rate was claimed with an accuracy of more than 99%. Therefore, to improve the spike recognition rate, in the current work the epileptic spike has been redefined with a set of predefined symbols having three elements. Based on this new definition of epileptic spike and the concept of DFA, a new system named DFASpike has been purposed.

2. Materials and methods

2.1. Data recording and pre-processing

The methodology for EEG spike generation, data recording and processing was used as described earlier [16]. The pre-recorded

* Corresponding author. Tel.: +91 9431382724.
E-mail address: rksinhares@gmail.com (R.K. Sinha).

0010-4825/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compbiomed.2011.05.007

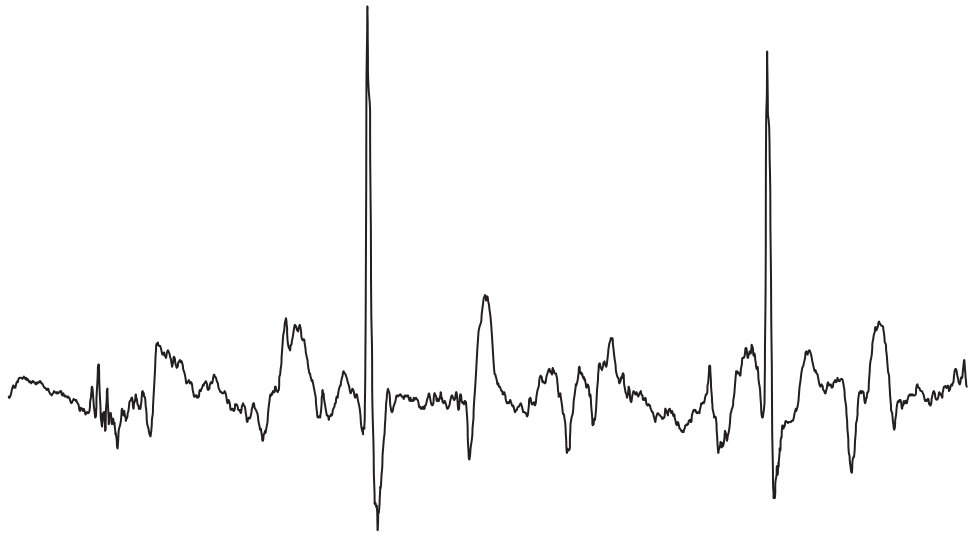

Fig. 1. Example of two consecutive epileptic spike patterns taken from the recorded data.

data taken from Sinha et al. [5] was used in this study. These EEG data files were recorded from male Charles Foster rats weighing between 200 and 250 g. EEG recording electrodes were implanted on the rat's head under urethane (Sigma, USA) anesthesia (1.5 g/kg i.p). Three stainless steel screw electrodes of 1 mm diameter soldered with flexible radio wires were implanted extradurally. Two electrodes for EEG recordings were placed on the frontal and occipital parts of the skull and one reference electrode was placed on the anterior most part of the skull. To induce epileptic seizures, 50 units of benzyl penicillin in a volume of 10 ml were injected 2 mm below the cortical surface of the parietal region of the brain. The intracerebral injection of the above mentioned dose of benzyl penicillin induces spontaneous seizure initiation just after 3–5 min of injection and observed its continuous presence as spike patterns in EEG up to an average of 30 min.

The single-channel bipolar EEG signals were recorded with standard amplifier setting as suggested by Sarbadhikari [17], just before and continuously for 45 min through an electroencephalograph (EEG-8, Madicare, India) from the time of injection of penicillin to the end of seizure patterns. The EEG signals were recorded for two minutes in separate data files to the computer hard disk after digitization of the traces at 256 Hz. The data were collected using the Visual Lab-M software (ADLink Technology Inc., Taiwan). Following the recording, whole data were pre-processed for removal of baseline shift and band pass filtered using an infinite impulse response (IIR) 4th order Butterworth filter with a lower cutoff of 0.25 Hz and a higher cutoff of 35 Hz [16,18]. Whole experimental procedures in this study had been conducted in compliance with 'committee for purpose of control and supervision of experiments on animals (CPCSEA)', India as well as with internal institutional policies and guidelines.

2.2. Description of DFA

In the current work, a system (DFAspike) has been designed using the concept of deterministic finite automata to recognize the epileptic spike present in EEG signal data. Deterministic finite automata can be defined with five tuples Q, $\sum$, δ, $q_{0,}$ F [19–21], where

Q: finite non empty set of states.
$\sum$: finite non empty set of input symbols.
δ: transition function and is defined as $Q\times\Sigma\rightarrow Q$.

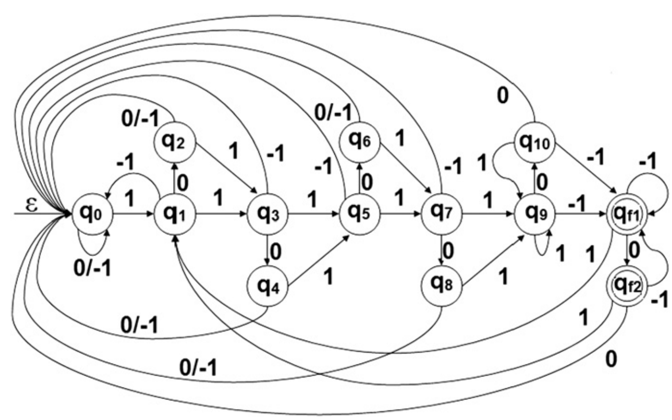

Fig. 2. Pictorial representation of the transition function used for modeling the optimized system DFAspike to recognize the epileptic spike patterns.

q_0: initial state and it is a member of Q, i.e. $q_0\in Q$.
F: finite non empty set of final states and $F\subseteq Q$.

For designing a DFA based system, we will have to define the five tuples for that system. For DFAspike, these five tuples have been defined as follow:

1. The DFAspike is consists of 13 states: $Q=\{q_0, q_1, q_2, q_3, q_4, q_5, q_6, q_7, q_8, q_9, q_{10}, q_{f1}, q_{f2}\}$
2. q_0 is the starting or initial state of the DFAspike,
3. The set of final state F for the DFAspike is having two elements: $F=\{q_{f1}, q_{f2}\}$
4. The DFAspike starts its transition from its initial state and moves to other states depending upon the transition function δ: $Q\times\Sigma\rightarrow Q$ defined in Fig. 2 and Table 1. The epileptic spikes can be defined as the sudden and sharp change in amplitude. When a spike occurs, it has been observed that the slope between two data points, which lies in spike, is very high (generally greater than 85°).
5. The values of EEG amplitude and time are scanned from the input EEG data file one by one. These values are then use to produce the string of input symbols for DFAspike. The conversion is done as follows:
   a. 'x' stands for time and 'y' stands for EEG amplitude in the EEG data.