Epicenter Location by Analysis of Interictal Spikes

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Abstract: *Surgical resectioning can cure some forms of epilepsy. The precise location of the area of excision is currently determined with a network of surgically implanted subdural electrodes. This means that the cure entails two surgical procedures: one to implant the electrode array that precisely locates the epicenter, and another surgery to remove the epicenter. This paper outlines an experimental Diagnostic Software System (DSS) that will use Artificial Neural Network (ANN) analysis of Magnetoencephalographic (MEG) data to eliminate the first of these surgical procedures. The MEG recording is a quick and painless process that requires no surgery. This approach has the potential to save time, reduce patient discomfort, and eliminates a painful and potentially dangerous surgical step in the treatment procedure.*

Keywords: epilepsy, MEG, interictal spikes, artificial neural networks.

1. Introduction

Epilepsy is the uncontrolled firing of neurons (neural cells) in the brain. In some cases, the uncontrolled firing starts in a single location and spreads like an electrical storm across the brain. This form of epilepsy, known as single focus epilepsy, can be cured by removing the portion of the brain that is at the epicenter of the storm. This epicenter must be located very precisely so that the source of the seizure is removed, but nothing else.

Currently, surgical resectioning in patients with single focus epilepsy proceeds in four stages [1]:

1. Collect surface Electroencephalogram (sEEG) data to locate the general area of the epicenter.

2. Surgically implant a network of subdural electrodes to record data from multiple sources during multiple seizures so the epicenter can be precisely located.

3. Remove the small amount of neural matter containing the epicenter.

4. Return the cured patient to the primary care physician.

Stage 2 requires that the implanted electrodes remain in place until the precise location of the epicenter is located. This stage can require hospitalization for a month or more, is the most frequent source of patient complaints, and sometimes introduces new problems. As with any surgery, there is always a danger of infection and other complications [2].

Our research is aimed at changing stage 2 from a surgical procedure to a procedure that involves non-invasive recordings and computer analysis of the recorded data. To understand how this is accomplished, we will take a brief look at both interictal spikes and artificial neural networks in the following two subsections of this paper.

1.1 Interictal Spikes

MEG (and EEG) recordings of patients with single focus epilepsy contain a characteristic spike (Figure 1) that occurs between seizures [3]. These interictal spikes (inter + ictal = between events) have four important characteristics:

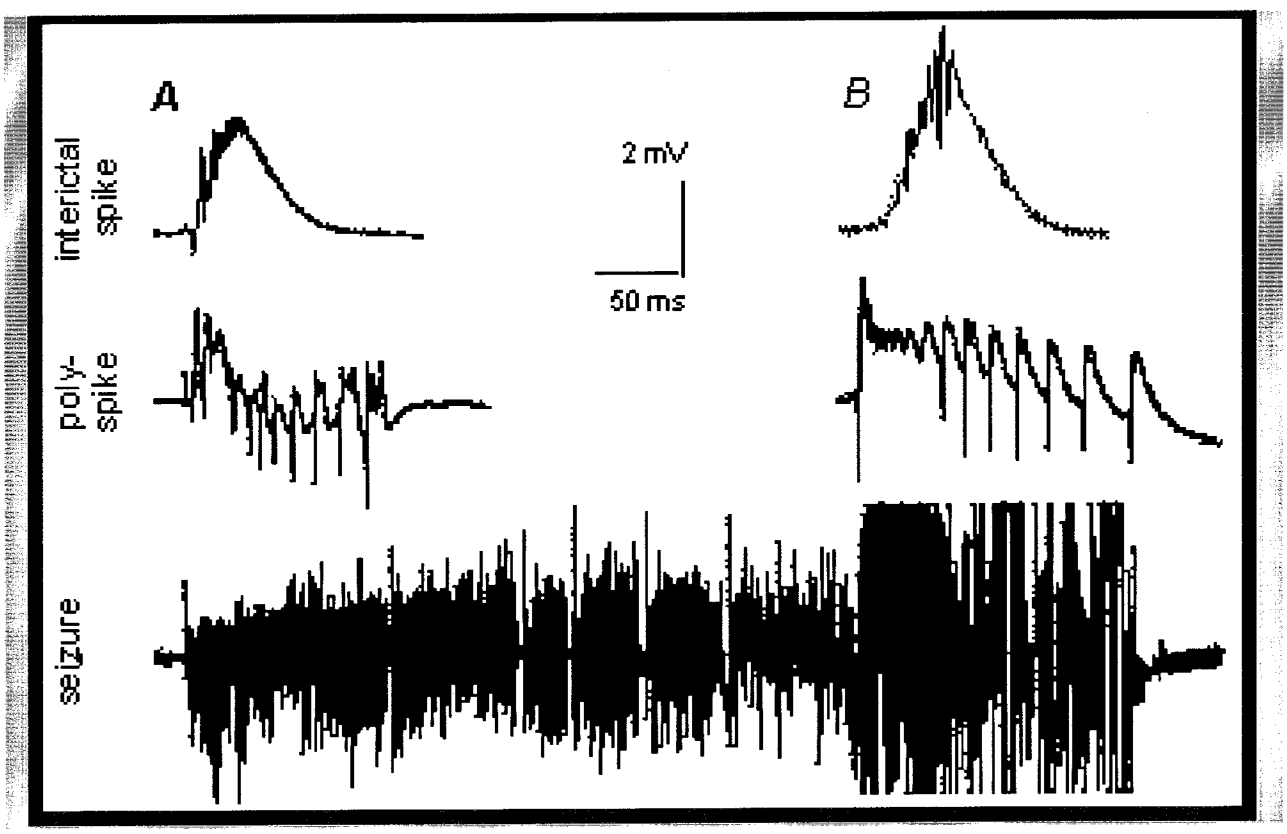
1. They occur between seizures and therefore against a relatively calm background.

2. They originate from the same epicenter from whence the seizures began.

3. They propagate across the brain in a predictable fashion.

4. They show a predictable shape.

Interictal spikes are large, slow pulses with steep sides (see Figure 1). The spikes are often reminiscent of half moons (Figure 1, A) or Gaussian normal distribution curves (Figure 1, B). Sometimes the spikes come in a rapid succession called a "poly-spike." Poly-spikes of type A and B spikes are shown directly below the corresponding spike form. At the bottom of Figure 1 (for comparison) a seizure is shown. All of these signals are plots of voltage potential changing over time and all are to the scale given. Interictal spikes are detectable with MEG, and to a lesser extent, with EEG in most patients with epilepsy.



1.2 Artificial Neural Networks

Artificial Neural Networks (ANN) are a powerful information processing technology based on biological models. Much of the information processing in the biological world is done with collections of interconnected neural cells. ANN are collections of simple computational units that are connected in networks whose architectures are similar to the network architectures employed by biological systems. Consequently, ANN behave more like biological systems than like computer systems. For example, ANN are trained (like animals) rather than programmed (like computers).

Working ANN are developed in three separate steps: design, training, and evaluation. In the design step, the network of interconnections is determined.

During the training step, databases of characteristic stimulus-response pairs are presented to the neural net. At each such presentation, the weights are adjusted to cause the ANN to give a response that is closer to the target response. Training terminates when the responses are within pre-selected tolerance limits.

In the evaluation step of the ANN development process, the ANN is installed in the real (or simulated) environment in which it is intended to function. Acceptable performance in this environment validates the design process and the training process, and unacceptable performance indicates that the design and training stages should be repeated [4].

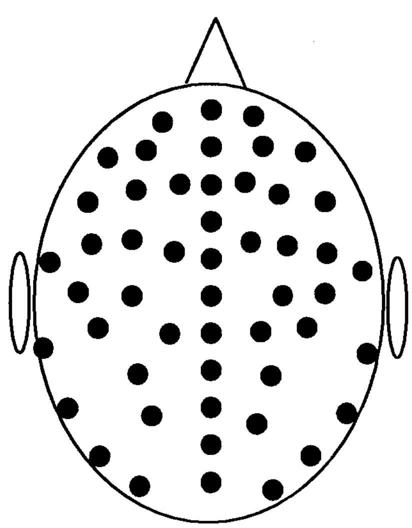


Figure 2: A Typical Pattern of Electrode Placements (viewed from above)

2. Research Approach

MEG (and EEG) recordings show the variation in magnetic (electrical) potential over time. These are multi-channel recordings because the potentials are sampled from multiple locations (see Figure 2). Typically a few dozen electrodes are used for EEG; and a few hundred electrodes are used for MEG [1,2].

Our current research is focused on the development of a Diagnostic Software System (DSS) that uses information gained from MEG and EEG recordings to detect the source of interictal spike propagation. The DSS consists of a family of artificial neural networks, each one of which responds to one and only one of the key attributes of Interictal Spikes (IIS). This architecture of cooperative networks, where each network responds to one and only one attribute of the target, is patterned [5] on the mammalian vision cortex in which one area responds only to color, one area responds only to edges, another only to movement, etc. Similarly, in the DSS there is a network that responds only to IIS shape, another that responds only to frequency of IIS movement, and a third that detects the outward direction vector of IIS movement. There also are ANN that respond only to epicenter attributes such as size and depth, and therefore help to locate the exact spot on the cranial surface that is superior to the epicenter. Each aspect of IIS behavior gives rise to a different ANN component of the DSS system. Synaptic networks [6,7] are used to fuse the diverse information from the constituent ANN into a clear picture [8] of the exact location of the location of the source of the interictal spikes (and hence the exact location of the epicenter of the seizures).

2.1 ANN components of the DSS

Here are some of the major components of the DSS with potential ANN architectures for each component:

Frequency Network: The IIS frequency (number of IIS per second) is different for different MEG electrodes. Electrodes far from the epicenter may never see an IIS. Generally the closer to the epicenter an electrode is the higher the observed IIS frequency. ICA networks have been shown [9] to be effective with this kind of "blind source separation" problem.

Shape Network: The closer the electrodes are to the epicenter, the sharper the spikes are. As IIS propagate across the brain they become blurred which makes them lose their crisp shape and they start to look wider and noisier. Eventually IIS merge into the background noise of the brain. There are a wide variety of ANN [4] that successfully recognize and categorize decaying signal patterns.

Direction Network: Spikes that originate in certain locations tend to move in characteristic directions. By observing the direction of spike movement, we can get some indication of the spike's origin and therefore the location of the epicenter. These kinds of pattern movements can be accurately tracked with cellular neural networks [10].

Scarring Network: If the IIS pattern does not change when the patient is asleep or awake, the area containing the epicenter is "scarred" i.e., disconnected from the rest of the brain because of the epilepsy. This fact is useful to know when planning the surgical resectioning.

The majority of IIS research has focused on the first of these four aspects with some work on aspect number two -- mostly using singular value decomposition to separate IIS from the background noise [1,2]. The DSS project will use all four aspects plus two other aspects of IIS that are currently a topic of research: the shape and size of the clearest instances of the IIS. It has not been verified but it is reasonable to expect that the depth of the epicenter can be determined by analyzing the way an IIS presents itself to the electrode nearest the epicenter. This is especially true if the origin of the IIS is subcortical e.g., if the epicenter is in the hippocampus rather than in the cortex. We are currently examining MEG data from multiple patients to develop better techniques for combining the information from constituent networks.

3. Acknowledgement

The preliminary research ideas described in this paper were developed at the Jet Propulsion Laboratory, California Institute of Technology and this work was sponsored by the National Aeronautics and Space Administration.

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