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Comparative Analysis of Temporal Dynamics of EEG and Phase Synchronization of EEG to Localize Epileptic Sites from High Density Scalp EEG Interictal Recordings

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Abstract— Our objective was to examine if the high-density, 256 channel, scalp interictal EEG data can be used for localizing the epilepsy areas in patients. This was done by examining the long-range temporal correlations (LRTC) of EEGs and also that of the phase synchronization index (SI) of EEGs. It was found that the LRTC of scalp SI plots were better in localizing the seizure areas as compared with the LRTC of EEGs alone. The EEG data of one minute duration was filtered in the low Gamma band of 30-50 Hz. A detrended fluctuation analysis (DFA) was used to find LRTC of the scalp EEG data. Contour plots were constructed using a montage of the layout of 256 electrode positions. The SI was computed after taking Hilbert transform of the EEG data. The SI between a pair of channel was inferred from a statistical tendency to maintain a nearly constant phase difference over a given period of time even though the analytic phase of each channel may change markedly during that time frame. The SI for each electrode was averaged over with the nearby six electrodes. LRTC of the SI was computed and spatial plots were made. It was found that the LRTC of SI was highest at the location of the epileptic sites. A similar pattern was not found in the LRTC of EEGs. This provides a noninvasive way to localize seizure areas from scalp EEG data.

I. INTRODUCTION

Current methods for localizing epileptic seizure onset areas within the brain are highly invasive and involve the placement of intracranial electrodes followed by waiting for one or more seizures to take place while recording a cortical electroencephalogram (ECoG). Clinicians can then use the recorded information to determine the location of interest.

Recently, Monto et al. (2007) [1] used detrended fluctuation analysis (DFA) to uncover a correlation between long-term

temporal correlations in intracranial EEGs taken during interictal sleep and the locations determined to be the onset sites of epileptic patients using traditional methods. This implies that it may be possible to determine the location of probable seizure onset without the requirement that a patient endure a seizure.

This project attempts to replicate the results of Monto et al. using high-density scalp EEG recordings, which are entirely noninvasive. Replicating the results would mean that clinicians could localize epileptic areas of interest within a patient's brain *noninvasively* and without the patient enduring a seizure, an advance that would greatly benefit the diagnosis of epileptic patients. In addition, in this report, we have further advanced this technology to better localize the epileptic sites by use of the phase synchronization of the scalp EEG data.

II. METHODS

A. Data Collection and Filtering

Epileptic seizure areas in patients were localized with intracranial EEG recordings. Prior to this, high-density 256-channel scalp EEG data was collected with an EEG system developed by Electrical Geodesics, Inc. (Eugene, OR). We used data of five patients. One representative minute of seizure-free data from each patient during sleep was selected and imported into MATLAB for further analysis. The selected data sets were not in close proximity to seizures. Raw EEG data was filtered using a FIR bandpass filter for the low Gamma band of 30-50 Hz. Excessively noisy channels were eliminated by replacing them with the averages of their neighbors. In general, there were 3-5 noisy channels in each data set.

B. Detrended Fluctuation Analysis

The cumulative sum of each channel was calculated. This sum was divided into windows of 1 through 10 seconds, as well 12, 15, 20, 25, 30, and 60 seconds. Within each window, a linear fit was found and the cumulative sum was detrended. Next, the root-mean-squared (RMS) fluctuation of this detrended sum was calculated. The median fluctuation at each window size was taken. The log of this median fluctuation was plotted against the log of the window size, and a linear fit was found. The slope of this linear fit, denoted alpha, is the result of the detrended fluctuation analysis for each channel. This is what is called long-range temporal correlations (LRTC). As shown by Linkenkaer et Al (2005) [2] and Peng et Al (1995) [3]

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that detrended fluctuation analysis exposes long range temporal correlations that are characteristic of epileptogenic neocortical networks, the areas where epilepsy begins.

C. Phase Synchronization

The synchronization between a pair of channel was inferred from a statistical tendency to maintain a nearly constant phase difference over a given period of time even though the analytic phase of each channel may change markedly during that time frame [4]. The Hilbert transform was applied on the pairs of EEG traces with a sliding window which is long enough to encompass at least two cycles of the lowest frequency of 30 Hz in the low Gamma band. The analysis was repeated by stepping the window at 8 ms intervals. The synchronization index (SI) was computed for each pair of EEG traces. A global synchronization index was also computed for each electrode by pairing it with the nearby six electrodes. There were 21 combinations of electrode pairs for each electrode. The SI was averaged over these electrode pairs for each given electrode. After that the LRTC was computed for the SI as explained above.

The alphas for the EEGs and the SI were normalized to their common average reference. Color intensity plots were constructed using a montage of the layout of 256 electrode positions. The horizontal and vertical axes for plots are in normalized length units. The color bar in each plot is for the normalized alpha values.

III. RESULTS

Figure 1. Contour plot of the LRTC of 256 channel EEG data of patient A. Nose is on the top. Positive peak does not correspond to the location of the seizure area.

Analysis of the data of two patients is given here. For the patient A, Fig. 1 shows the contour plot of LRTC for the EEG data and Fig. 2 shows the LRTC of SI. In the Fig. 2 the location of the seizure activity is also marked with an ellipse as determined from the invasive recordings. The seizure activity was located in the right posterior temporal area.

There is a peak also in the central midline area in Fig. 2 at the location (0.45, 0.38). One could interpret this also as a possible location of the seizure area. However, the larger area enclosed by the ellipse is the actual seizure area which was determined by the intracranial recordings.

Figure 2. Contour plot of the LRTC of SI of patient A. Ellipse marks the location of the seizure area.

For the patient B, the LRTC of EEG activity is plotted in Fig. 3 and the LRTC of SI is plotted in Fig 4.

Figure 3. Contour plot of the LRTC of 256 channel EEG data of patient B. It is difficult to localize the seizure area because the positive peaks are distributed in a wide area.

For this patient also the LRTC of SI plotted in Fig. 4 gives the correct location of the seizure area. The seizure activity as measured with intracranial recordings was in the frontal midline area and it is marked with an ellipse in Fig. 4. However, the LRTC of scalp EEG shown in Fig. 3 does not give a precise location. The maximum positive peak value is located at (0.55, 0.4) which is not the correct location of the seizure area.

These figures show that the LRTC of SI was excellent in localizing the epileptic sites in both patients while the LRTC of scalp EEG alone had inconclusive results. Similar patterns were found in the data of other three patients and we were able

to localize the seizure areas correctly with the contour plots of the LRTC of SI. For the other three patients, the seizure activity was located in the left frontal area, left parietal area and the right frontal area.

Figure 4. Contour plot of the LRTC of SI of patient B. Ellipse marks the location of the seizure area

IV. DISCUSSIONS

Earlier work [1] has shown that one can localize seizure areas with LRTC analysis performed on invasive cortical (ECoG) recordings. Similar analysis on scalp EEG data does not succeed in localizing the seizure areas. However, the similar analysis when applied to the phase synchronization index of high density interictal scalp EEG recordings was successful in localizing the seizure areas. This was found to be reliable in five patients. A possible hypothesis could be that in the seizure areas the electrical activity of the neurons has stronger phase synchronization as compared to the nearby seizure-free areas.

These preliminary results show that it is feasible to localize the seizure areas with a one minute long interictal scalp EEG data. This opens a new way to localize seizure areas noninvasively.

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