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Nonlinear Analysis

Nonlinear Analysis 64 (2006) 1666–1678

www.elsevier.com/locate/na

Nonlinear similarity analysis for epileptic seizures prediction

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Received 29 March 2005; accepted 11 July 2005

Abstract

The prediction of epileptic seizures can promise a new diagnostic application and a novel approach for seizure control. This paper proposes an improved dynamical similarity measure to predict epileptic seizures in electroencephalographic (EEG). First, mutual information and Cao's method are employed to reconstruct a phase space of preprocessed EEG recordings by using the positive zero crossing method. Second, a Gaussian function replaces the Heavyside function within correlation integral at calculating a similarity index. The crisp boundary of the Heavyside function is eliminated because of the Gaussian function's smooth boundary. Third, an adaptive detection method based on the similarity index is proposed to predict the epileptic seizures. In light of test results of EEG recordings of rats, it is found that the new dynamical similarity index is insensitive to the selection of the radius value of Gaussian function and the size of segmented EEG recordings. Comparing with the dynamical similarity index proposed by Le Van Quyen et al. [Anticipating epileptic seizures in real time by a non-linear analysis of similarity between EEG recordings, NeuroReport 10 (1999) 2149–2155], the tests of twelve rats show the new dynamical similarity index is better to predict the epileptic seizures.

Keywords: Epileptic seizure; EEG; Similarity; Phase space; Gaussian function; Prediction

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0362-546X/$ - see front matter
doi:10.1016/j.na.2005.07.014

1. Introduction

Epilepsy affects more than 50 million individuals worldwide—about 1% of the world's population. Of these individuals, the patients of 25% do not respond to available therapies [14]. An interesting issue in epileptology is whether the epileptic seizures can be anticipated prior to their occurrence or not? The ability to predict the epileptic seizures well before clinical onset promises a new diagnostic application and a novel approach for seizure control. The first work on predicting the epileptic seizures began in 1970s [28]. Since 1990s, the prediction of epileptic seizures has been paid more attention by researchers and clinical doctors in neuroscience, which was derived form the discovery of a pre-seizure state in temporal-lobe seizures [6,17]. So far, many methods to predict the epileptic seizures have been proposed (e.g. [4,7,11–13,15,17–19]), mainly including nonlinear dynamics and chaos (e.g. [7,11,13,17]), similarity [12,19], phase coherence (e.g. [18]), time domain analysis (e.g. [14,15]), and so on.

Maiwald et al. [16] compared three nonlinear seizure prediction methods and illustrated the dynamical similarity index proposed by Baulac et al. (see [12,19]) is the best. Unfortunately, the dynamical similarity index is so far not sufficient for clinical applications [16]. This method is composed of the phase space reconstruction of electroencephalographic (EEG) dynamics using time intervals between two positive zero-crossings and the measurement of dynamical similarity between a reference window and a test window (a segment of EEG recordings). The key issues of this method, but the reconstruction of phase space, are to determine a radius value, which is applied for the normalized cross-correlation integral to calculate the dynamical similarity index [9,25], and the length of the windowed EEG recordings. It is found the dynamical similarity index dramatically rises or falls when the radius of hypersphere or the length of the EEG windowed is slightly changed. This is due to the fact that the data just outside the hypersphere (greater than the radius value) are not accounted and one in the hypersphere (less than the radius values) are equally treated because of the hard or binary boundary of Heavyside function.

To overcome the above problems, a new dynamical similarity index is proposed in this paper. A Gaussian function is employed to replace the Heavyside function in the dynamical similarity; as a result, the hard boundary of Heavyside function becomes soft, so the closer the data points, the more similar they. The effect of size of radius and window length of segmented EEG on the similarity first is discussed. Rat EEG recording tests show the fuzzy similarity index does not change abruptly during the normal state of brain when the width of Gaussian function or the length of EEG windowed is changed slightly. Then, a prediction method based on the new similarity index is proposed. The real rat tests demonstrate that the new similarity index can be successfully employed to predict epileptic seizures; the results of prediction are better than ones with the dynamical similarity index.

2. Methods

2.1. Phase space reconstruction

EEG recordings are nonstationary time series. The first step in nonlinear time-series analysis is devoted to the phase space reconstruction for the underlying dynamical system [2].