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Wavelet-based characterization of gait signal for neurological abnormalities

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ABSTRACT

Studies conducted by the World Health Organization (WHO) indicate that over one billion suffer from neurological disorders worldwide, and lack of efficient diagnosis procedures affects their therapeutic interventions. Characterizing certain pathologies of motor control for facilitating their diagnosis can be useful in quantitatively monitoring disease progression and efficient treatment planning. As a suitable directive, we introduce a wavelet-based scheme for effective characterization of gait associated with certain neurological disorders. In addition, since the data were recorded from a dynamic process, this work also investigates the need for gait signal re-sampling prior to identification of signal markers in the presence of pathologies. To benefit automated discrimination of gait data, certain characteristic features are extracted from the wavelet-transformed signals. The performance of the proposed approach was evaluated using a database consisting of 15 Parkinson's disease (PD), 20 Huntington's disease (HD), 13 Amyotrophic lateral sclerosis (ALS) and 16 healthy control subjects, and an average classification accuracy of 85% is achieved using an unbiased cross-validation strategy. The obtained results demonstrate the potential of the proposed methodology for computer-aided diagnosis and automatic characterization of certain neurological disorders.

1. Introduction

People suffering from motor disorders account for more than 500,000 in North America alone and the propensity is constantly increasing with age [1]. Parkinson's (PD), Huntington's (HD) and Amyotrophic lateral sclerosis (ALS) diseases are three neurodegenerative diseases where severe disturbances in gait and gait initiations are frequently reported. Hence, from a diagnostic perspective, research shows a growing trend toward gait study for characterization of these conditions.

Clinical measures to diagnose these neurological disorders (ALS, HD and PD) include blood tests, EMG analysis, genetic testing and spinal tap (lumbar puncture) and these are carried out to rule out other medical conditions. Although such diagnosis is important, the task of early detection based on these procedures remain a complex time-consuming problem. This is because, during the initial stage, the symptoms can be misconstrued for any of the three neurodegenerative conditions [2]. Hence, to facilitate effective treatment planning, there exists a need for pre-screening of these conditions to benefit a large population.

The most noticeable symptom in all these conditions is abnormal involuntary trembling movements (corresponding to (a) Chorea – ALS & HD and (b) Dyskinesia – PD). These abnormal movements alter the gait, and causes difficulties during lateral coordination of legs, and other associated movements. Besides these abnormality-introduced changes, the stride-to-stride fluctuations also vary among subjects for patient and control groups. Hence, a scheme that suitably characterizes the underlying differences (inherent + those introduced by abnormalities) in gait is crucial. In this study, the embedded long-term correlation information in normal and abnormal gait is exploited using a multiresolution wavelet-based analysis for efficient discrimination of neurological disorders.

1.1. Computer-aided characterization of gait pattern

Existing studies [3,4] to distinguish gait from PD, HD and ALS were carried out by characterizing the stride variability. One such investigation, proposed by Hausdorff et al. [3], estimates the variations in gait cycle using the detrended fluctuation analysis.

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This study primarily focused on quantification of the abnormal alterations in the fractal properties of the gait dynamics using the degree of correlation information. Their findings indicate a reduced correlation in the gait pattern for HD subjects. Following this study, their research group [4] demonstrated the increase in stride variability for certain abnormal subjects.

Research by Costa et al. [5] characterized the regularity of the gait signal by introducing a SampEn ratio. Their metric is computed for each of the coarse-grained time series to facilitate understanding of the dynamic properties of the time-varying gait. However, limited investigation has been carried out for characterization of different gait disorders. Certain other works [6] explored the usefulness of multiresolution and multiscale techniques to characterize the time-varying gait pattern. A novel estimation technique to compute the relative risk of falls between subjects with disorders using a wavelet-based scheme was proposed by Khandoker et al. [7]. Later, Liao et al. [8] extended the usability of multiresolution analysis for characterization of gait symmetry and detection of neurological disorders. Similarly, Myklebust et al. [9] presented the importance of coherence measures to identify the distinguishable features between normal gait and gait of an HD subject. Some of the other available works in this direction [5,7,8], also used wavelets to facilitate identification of the asymmetry of gait pattern with degenerative disease conditions. Owing to the non-stationarity of the gait variability, certain recent works [10–13] investigated the use of statistical and time–frequency (TF) methods for classification of gait from subjects with neurological disorders.

Few works [14,15] focused on the influence of age and gender in abnormality detection. Although young-elderly classification of gait signal is of significance to identify the at-risk population among the elderly, an automated scheme that targets efficient separation of certain neurological disorders is a more complex problem [16]. This is because, the former deals only with selective characterization (control and one disorder) while the latter requires the performance to be consistent to cater multiple neurological disorders. From literature [5,7,8,14,15], it is evident that, there is a non-availability of a generalized scheme that would help to discriminate between gait patterns from normal and subjects with neurological disorders. As a suitable directive, we propose an automated gait identification scheme for pre-screening of certain neurological disorders among the entire population.

1.2. Rationale for multiresolution analysis

Literature [13] reports suggest that the readability of non-stationary gait signals could be improved by mapping the data on a suitable representation space where the inherent time–frequency (TF) connection is well-preserved. One such representation is obtained using the widely used discrete wavelet transforms (DWTs). The significance of wavelet-based techniques is due to the inherent localization properties of wavelets in both time and frequency planes and their ability to provide good dimensionality reduction.

In this study, the biorthogonal mother wavelet is employed owing to the following properties [17]:

(1) *Have linear phase:* this is critical to minimize distortion in the transformed signal and
(2) *Possess optimal vanishing moments:* presence of vanishing (or zero) moments facilitates dimensionality reduction (and sparse representations).

The standard DWT defined by the scaling ϕ and wavelet ψ functions is represented as follows,

$$\phi_{j,k}(t) = 2^{j/2}.\phi(2^j t - k), \quad j,k \in \mathbb{Z} \tag{1}$$

$$\psi_{j,k}(t) = 2^{j/2}.\psi(2^j t - k), \quad j,k \in \mathbb{Z} \tag{2}$$

where j is the dilation parameter and k is the translation parameter. Here, the scalar component $2^{j/2}$ is included to ensure orthonormality [18] and the scaling function, ϕ defined by the low frequency function is used to obtain the signal approximation.

Additional details about the theory and implementation of wavelets can be obtained from [19]. To facilitate automated detection of neurological disorders, the concepts of re-sampling and wavelet-based pattern recognition is suitably exploited in this work. In the next section, details regarding the research direction followed in this work are elaborated.

2. Materials and methods

2.1. Data description

The gait data used in this study was recorded by Hausdorff et al. [3,20] and is obtained from Physionet [21]. A group of patients devoid of any known neurological conditions, comorbidities and who were not under medications (which might have an effect on the gait pattern) contribute to the control (CO) dataset in Physionet. The control group consists of 16 healthy subjects (consisting of 2 men and 14 women) aged between 20 and 74 years (mean age – 39.3). In addition to the healthy subjects (i) a group of 15 PD patients: 10 men and 5 women aged between 44 and 79 years old (mean age – 66.8), (ii) 20 HD patients: 6 men and 14 women aged between 29 and 71 years (mean age – 46.6) and (iii) 13 ALS patients: 10 men and 3 women aged between 36 and 70 years (mean age – 55.6) contributed to this database.

2.2. Proposed approach

A general block diagram of the proposed neurological disorder classification scheme is shown in Fig. 1.

2.2.1. Pre-processing

The gait signals obtained from Physionet were sampled from a dynamic process, i.e., with non-uniform sampling instants exhibiting time-varying changes. In analyzing these non-stationary signals, time–frequency (TF) techniques (such as DWT) are often preferred since they provide high-resolution representation in both time and frequency axes. However, the use of these techniques require the extraction of *apriori* signal values with uniform sampling and hence, data obtained from dynamic sources may not be suitable candidates for TF analysis. This necessitates

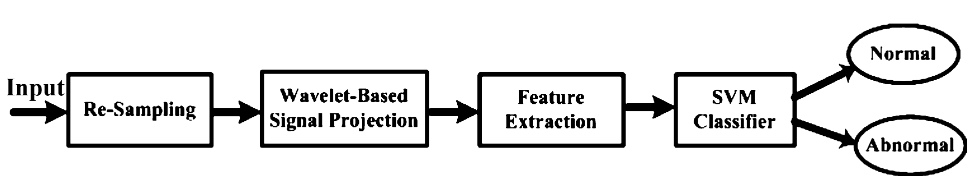

Fig. 1. Block diagram of the proposed approach.