Gait segmentation using continuous wavelet transform for extracting validated gait events from accelerometer signals

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In our aging society, gait disturbance becomes a major concern as it inevitably leads to limitations in mobility and to an increased risk of falls. Spontaneous walking speed normally decreases by about 1% per year from age 60 onward [1]. A population-based study has shown a 35% prevalence of gait disorders among persons over age 70 [2], and some abnormal gait features can be predictive of a progression to dementia of Alzheimer type, e.g., [3], [4]. Problems of balance and gait are associated with immobility and falls, which markedly impair the quality of life, e.g., [5]. Thus, it is important to develop quantitative methods aimed at monitoring gait disturbances in natural environments, and at the critical analysis and development of new therapeutic strategies. Accelerometer-based methods have become popular to deal with such applications using accelerometers with small size and low power consumption, as well as algorithms that accurately extract relevant gait events and gait phases, e.g., [6], [7].

In this context, our project deals with the three-dimensional (3D) accelerometer-based analysis of normal gait and pathological gait [6], [8], [9]. In [6], we developed a signal processing algorithm to automatically extract validated gait events in healthy walking, i.e., heel strike (HS), toe strike (TS), heel-off (HO), and toe-off (TO), from three-axis accelerometer signals measured at the level of the heel and toe of the right and left feet. This algorithm uses a segmentation method that roughly detects relevant signal sub-regions. Gait events are further extracted with high accuracy and precision in these signal sub-regions. However, this segmentation is limited to the gait of young and healthy subjects.

In this paper, we extend and modify this segmentation method to analyze the gait of elderly patients with Parkinson's disease, which is characterized by a shuffling gait involving slow steps with reduced length (Fig. 1). Here, we use a new segmentation method based on the continuous wavelet transform (CWT) to isolate (1) time intervals where the heel and toe acceleration signals are close to zero, from (2) time intervals in which the accelerometers are moving. This segmentation method allows to identify parkinsonian gait patterns, thereby allowing for a robust extraction of the subsequent gait events/parameters using the validated gait event algorithm proposed in [6] (Fig. 2). These gait events/parameters include HS, TS, HO, TO, and durations of stance phase, swing phase, loading response, foot-flat, and push-off. In addition, the experimental results show the potential of the segmentation combined with the validated gait event algorithm when used in neurology (e.g., for the characterization of parkinsonian gait: slowness, shuffling, short steps, freezing of gait, and asymmetries in gait), rehabilitation, geriatrics (e.g., for the monitoring of activity parameters in the elderly), orthopedics, and sports.

Keywords: Accelerometers, gait segmentation, gait analysis, validated gait events.
References


Fig. 1. Block diagram of the gait analysis by our signal processing algorithm. This algorithm uses a new segmentation method based on the continuous wavelet transform (CWT) and can isolate time epochs in which the accelerometers are at rest from time epochs in which the accelerometers are moving.
Fig. 2. Example of the application of the developed segmentation method to acceleration signals measured at the level of the heel of the right foot in the vertical direction. The experimental results demonstrate that this segmentation method can successfully extract patterns of interest from healthy and parkinsonian gait data, thereby allowing for a robust extraction of the subsequent gait events/parameters (e.g., heel strike (HS), toe strike (TS), heel-off (HO), toe-off (TO), and durations of stance phase, swing phase, loading response, foot-flat, and push-off). Data was obtained from (a)-(b) an elderly patient with Parkinson’s disease and (c)-(d) a healthy young subject; both of them wore their own shoes and walked at their self-selected speed.