



Short Communication

Foot side detection from lower lumbar spine acceleration



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ARTICLE INFO

Article history:

Received 11 March 2015

Received in revised form 28 May 2015

Accepted 29 May 2015

Keywords:

Accelerometer

Gait

Side detection

Lumbar spine

ABSTRACT

The purpose of this paper is to present a reliable algorithm to discriminate between left/right foot contact using an accelerometer located over the lower lumbar spine. With the given accelerometer frame orientation, the side detection algorithm, based on the sign of the derivative of the sinusoidal shape obtained from the filtered mediolateral (ML) acceleration, showed 100% correct side detection for all subjects at all walking velocities. From the obtained results, it is concluded that in healthy subjects, the side of subsequent foot contact can be reliably obtained from the ML acceleration pattern of the lower lumbar spine.

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1. Introduction

Accelerometers have been found reliable for the assessment of gait parameters from different body locations [1,2]. To minimize the number of sensors, lower lumbar spine placement is often recommended for gait assessment [3–6]. Unlike accelerometers located at thighs, shanks and feet, parameters assessed from lumbar accelerometer cannot be directly attributed to the left/right side.

During walking, differences between left/right lower extremities have been mentioned frequently. In the case of asymmetrical gait, the determination of the affected side is often an advocated goal for physical therapy. Only a few studies attempted to discriminate left/right foot contacts despite the importance of this identification [3–6]. In some projects, gyroscopes were introduced as a tool of side detection [3]. However, the gathered information are not sufficient to quantify gait parameters. To cover these shortages, new tendencies propose the fusion between gyroscope and accelerometer for gait assessment [3]. While the results were encouraging, some other studies suggest the use of a single accelerometer. Zijlstra and Hof [4] developed a method based on the analysis of the sign of foot contact for the phase of the first harmonic from lumbar accelerometer. Their results showed that six out of fifteen subjects presented 12% of 756 foot contacts labeled falsely. Köse et al. [5] presented a wavelet-based approach

to detect the gait events and identify the foot side contact simultaneously from right pelvic acceleration. However, some studies found that it can generate extra initial contacts (IC) [7]. Capela et al. [6] described a method based on the filtered ML acceleration gathered from smartphone located at the lower lumbar spine. Then, the tangent at one arbitrarily chosen point ($a = 0.25$ of step duration) was computed. A right step was identified if the y -coordinate of two points on the tangent with x -coordinates equal to $(a + \text{locking period})$ and $(a - \text{locking period})$ were above the filtered ML acceleration. The appropriate locking period was defined by a dedicated algorithm. The exposed condition depends on the orientation of the ML axis of the accelerometer and the authors did not account for it. Furthermore, the authors reported that some foot steps were not identified without giving further information about the issue.

In this framework, the aim of this study is to present a simple yet robust algorithm to discriminate between left/right foot contact using a single accelerometer located over the lower lumbar spine.

2. Methods

2.1. Subjects

Ten able bodied subjects (29 (6) years, 1.79 (0.08) m and 79 (9) kg), with no clinical history of injury that could interfere with their walking pattern, participated in the study. Each participant provided written informed consent before starting. The experiment was approved by the local ethics committee.

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2.2. Equipment and data acquisition

Acceleration and ground reaction forces (GRF) were measured by a triaxial capacitive accelerometer (MMA8453Q, Free scale Semiconductor, Austin, Texas USA, 200 Hz, range: ± 4 g, resolution: 7.8 mg) and a treadmill with dual integrated force-plates (ADAL3D-F TECHMACHINE, Andrezieux, France, 200 Hz), respectively. For this study, the accelerometer was fixed firmly over the lower lumbar spine (L3–L4) by a waist belt and double-sided tape.

2.3. Procedures

The capacity of the accelerometer located at the lower lumbar spine to discriminate between left/right step was evaluated during treadmill walking. After a 30 s warm up, measurements were recorded for a period of 30 s at the following treadmill walking speeds (2.7 km h^{-1} , 3.6 km h^{-1} , 4.5 km h^{-1} , 5.4 km h^{-1} and 6.3 km h^{-1}).

Gait is a succession of foot contact with the floor during a set of subsequent left/right steps. Each IC marks the beginning of the stance phase with different subphases. The first one corresponds to the double limb support which starts with an IC and extends until the transfer of the body weight from the back to the front leg. This transfer is characterized by a ML acceleration of the body center of mass toward the front leg [8].

To discriminate between left/right step, an algorithm based on the study of the sign of the derivative of the filtered ML

acceleration was proposed. The following steps for the side detection algorithm (SDA) were realized:

1. Apply the mathematical algorithm proposed by Moe-Nilssen to transform the dynamic acceleration into a vertical-horizontal coordinate system [9].
2. Detect the moment of IC from the anteroposterior acceleration [4] which were verified against treadmill data.
3. Filter the ML acceleration component with fourth-order zero-lag Butterworth filter at 1 Hz (Low-pass filter). A sinusoidal shape (SinS) was obtained.
4. Study the sign of the derivative of the SinS at the moment of IC.

As presented in the SDA at the second step, IC were detected from anteroposterior acceleration and left-right normalized vertical GRF (Fig. 2, top-panel) measured by the instrumented treadmill. Square and circles represent the instants of left/right contact, respectively. These IC were transcribed on the filtered ML lumbar acceleration signal.

With the given accelerometer frame orientation following the ISB standard, foot contact on the right side (circles) coincides with a descending part of the SinS. Thereby, the derivative of SinS at each right IC is negative. Likewise, the IC of left foot (squares) were located on the ascending part of the SinS and its derivative is positive.

To validate the detection of the side of IC, the instrumented treadmill was set as the gold standard. Based on the vertical component of the GRF, the IC was detected as the first value greater than 20 N [10] (Fig. 1).

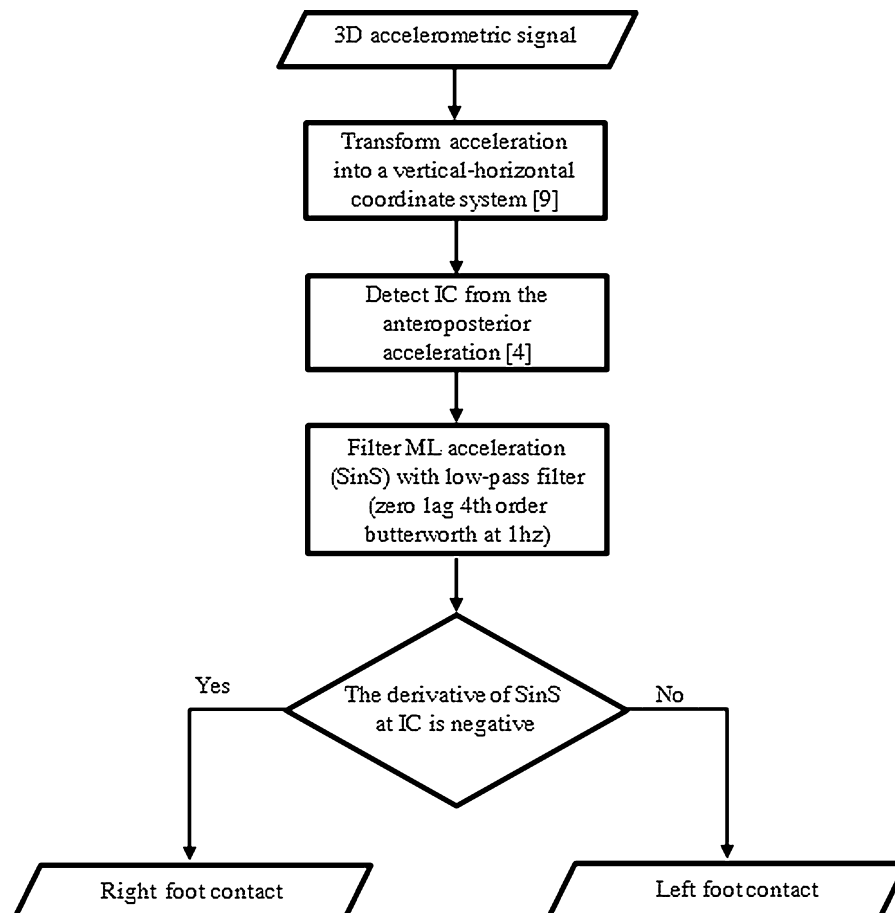


Fig. 1. Flowchart for step side detection.

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