Comparison of Step Length Estimators from Wearable Accelerometer Devices

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INTRODUCTION

Video-based gait analysis, and other measurement devices such as force-plates, electrogoniometers, or electrodes to measure EMG signals are adequate for laboratory studies but are not designed for usability in ambulatory applications.

Conversely, accelerometers provide easily portable systems that supply real-time data, which is why they are widely used in ambulatory diagnostic devices. However, such systems do not provide direct measure of several spatio-temporal parameters of interest such as step length, walking distance, or walking velocity. Instead, they have to be estimated with a mathematical model from indirect sensor measurements. Specifically, in this chapter we are concerned with the accelerometry-based estimation of the step length in straight-line human walking.

BACKGROUND

Gait analysis is frequently made by means of video-based recording of markers placed at end-points in a subset of some body segments. However, such equipment is not easily portable and requires off-line digitizing that can be time-consuming and automated real-time acquisition systems, which can be costly. Because of that, nonspecialist users cannot use these systems in ambulatory applications. Other measurement devices such as force-plates, electrogoniometers, or electrodes to measure EMG signals (Grasso, Zago & Lacquaniti, 2000) are also not designed for usability.

Conversely, accelerometers provide easily portable systems that supply real-time data. In addition, these systems come at a decreased cost when compared to video motion analysis systems, making them easily available to a wide range of clinics. Precision and repeatability characteristics of accelerometry make it adequate for gait analysis (Henriksen, Lund, Moe-Nilssen, Bliddal & Danneskiod-Samsoe, 2004), and it has been widely used recently, mainly in ambulatory diagnostic (Auvinet et al., 2002; Kavanagh, Barrett & Morrison, 2004; Moe-Nilssen, 1998a, 1998b; Najafi, Aminian, Paraschiv-Ionescu, Loew, Bula & Robert, 2003).

For instance, there exist empirical relations between the step length and the maximum and minimum vertical acceleration of the body's center of mass (COM) (Analog-Devices, 2000). More frequently, it is accepted as a linear relation of the step length with the step frequency (Ladetto, Gabaglio & Seeters, 2003). Finally, clinical studies show that an inverted pendulum model can describe the displacement of the body's COM while walking, and the model can be applied to estimate the step length from this displacement (Brandes, Zijlstra, Heikens, van Lummel & Rosenbaum, 2006; Zijlstra & Hof, 1997). All these estimators had in common that they require a previous parametric adjustment or calibration from experimental walking data for every individual. After that, they all provide comparable estimation results, as will be shown in this chapter.

In the following, we compare these common step length estimators reported in the literature. Also, modifications to these estimators are proposed, based on biomechanical considerations. Results show that

these modifications lead to improvements of interest over previous methods.

EXPERIMENTAL COMPARISON OF STEP LENGTH ESTIMATORS

Participants

Measurements were taken from a group of four adult men, ages 32 to 38. Height of subjects varied from 168cm to 186 cm. None of them presented vestibular or neurological disorders that could affect the experiments, and all of them gave their signed consent.

The step length was estimated from a three-axial accelerometer placed close to the L3 vertebral position, accepted as a fine approximation of the COM position during normal walking (Moe-Nilssen, 1998b). The device is fixed to the lower lumbar spine with an adjustable corset to avoid movement artifacts.

Apparatus

The device prototype (see Figure 1) is built over two biaxial accelerometers AXL202AE from Analog Devices (Analog-Devices, 2000) mounted to form a three-axes frame with a measuring range of $\pm 2g$ being g the gravity acceleration. A calibration procedure takes into account offset and scale factors and the orthogonality of the axes (Krohn, Beigl, Decker, Kochendorfer, Robinson & Zimmer, 2005). A PIC16F877 Microchip micro-controller has been used as interface and data logger. Signals are sampled at 50Hz using a 10-bit A/D conversion. Data gathered during the experiments are stored in an internal memory and transferred to an external computer through a serial communication link for further processing. A total of 64K samples can be stored in memory, so we were able to extend the experiments over 20 minutes.

Procedure

During test procedures, subjects were asked to walk along a 100-meter-long corridor following a straight path, back and forth (see Figure 1). The first 10m of walking were discarded for the analysis, as gait is not stable during initial phases of displacement. Each individual completed four independent excursions, and they were asked to maintain a constant velocity for each walk: "preferred" (first excursion), "fast" (second excursion), "low" (third excursion), and "medium" (a velocity between preferred and fast velocities, last

Figure 1. Experimental setup: (Up) Accelerometer device and data acquisition system. The triaxial accelerometer (A) is sampled at 50Hz with the data logger (B) and is fixed to the lower lumbar spine (C) with an adjustable corset (not shown in figure) to avoid movement artifacts. (Down) Procedure: individuals walk a 100m distance at different paces, back and forth.
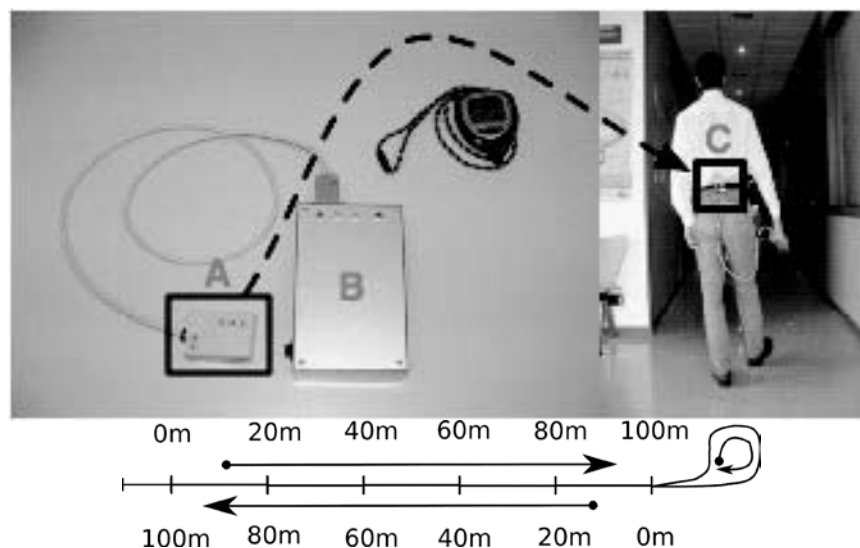
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