REAL-TIME MEASUREMENT OF WALKING SPEED USING AN INTEGRATED ACCELEROMETER

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Abstract

A technique for the instantaneous measurement of walking speed using accelerometry is proposed. A two-axis accelerometer was fitted to the trunk of a healthy male subject with the sensor's x-axis horizontal to the ground. Data from the subject walking at five different walking speeds was recorded. Moving average x-axis acceleration RMS with a 0.1 s window was taken for each recording. A linear model of walking speeds and x-axis acceleration RMS was proposed and the mean error between predicted walking speed and measured walking speed was < 7.5 %.

Introduction/Background

In healthy gait, as a subject's walking speed increases, the contraction intensity of the Tibialis Anterior increases [1].

In close-loop control of hemiplegic drop foot, one parameter of gait, which may be used to input to controllers, is the subject's walking speed. Walking speed is an important measure in a variety of medical applications, from the assessment of claudication distance in vascular diseased subjects, to the assessment of the effectiveness of gait correction strategies in motor disabled subjects (refs). For some of these applications, real-time measurement of walking speed is required to enable the development of closed loop control systems.

Methods

A 52 year old healthy male subject was fitted with an biaxial ADXL202[1]-based integrated accelerometer unit (Figure1) mounted on the surface of an Infotronic Ultraflex[2] data-logger, as shown in Figure 2. The accelerometer was mounted, such that the active X-axis of the device is horizontally oriented in the forward direction and the active Y-axis of the device is vertically oriented in the upward direction. The data logger was firmly fitted to the subject's trunk using a Velcro® strap

The X-axis analogue acceleration output of the accelerometer unit was sampled at 100 Hz using the Ultraflex datalogger.

[1] Analog Devices, Inc., Norwood, Mass., USA
[2] Infotronic, Henglo, The Netherlands

The subject was asked to walk at five different walking speeds over an eleven-meter walkway using the technique of Wade [2]. A metronome was used to pace the subject at different walking speeds. Walking speed was measured over the eleven-meter walkway using a stop-watch accurate to two decimal places.

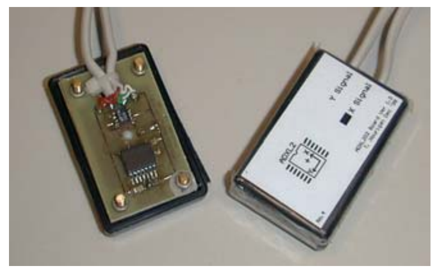

Figure 1 –UL Biomedical Electronics Laboratory, ADXL202 dual channel accelerometer unit

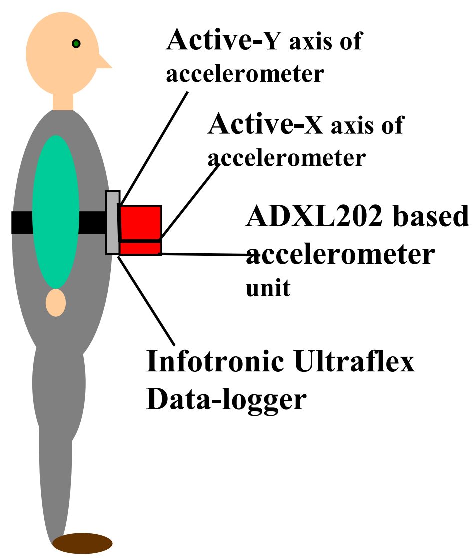

Figure 2 – Positioning of the ADXL202 accelerometer unit for real-time measurement of walking speed.

The real-time walking speed measurement technique developed uses the following signal processing sequence on the accelerometer X-axis analogue acceleration signal to determine walking speed dynamically.

- Band-pass filtering (1-4 Hz),
- Moving RMS calculation using a 0.1 second window
- Low-pass filtering (4 Hz) of the tangential trunk accelerometer signal.

To determine average walking speed over the walking interval, the mean of the processed X-axis analogue acceleration signal was determined over this interval.

Signal processing was carried out as post-processing routine using MatLAB[3].

The technique was tested on a 52-year old healthy male walking on an 11-meter walkway at five different walking speeds (0.64-1.41 m/s).

Results

The trunk forward acceleration measurements at the two extremes of walking speed (1.41 m/s and 0.64 m/s) were used to develop a linear model for the relationship between the mean of the RMS of the filtered accelerometer signal and walking speed measured using a stop-watch. The resulting linear model had a slope of 0.72 s and an intercept of –0.575 m/s. The remaining three sets of readings were used to determine whether a linear model was appropriate. These three mean of the RMS readings (1.245, 1.371 and 1.726 m/s^2) were applied to the linear equation and a predicted walking speed was calculated. A percentage error between the predicted walking speed and the actual walking speed was calculated for these three readings (0.0%, 3.65%, and 7.85 %). The average percentage walking speed error for the linear model was 3.83 %.

RMS Tangential Acceleration (m/s^2)	Measured Walking Speed (m/s)	Predicted Walking Speed (m/s)	Error (m/s)	% Error (%)
1.091	0.64	0.64	0.00	0.00
1.245	0.778	0.751	-0.027	-3.414
1.371	0.897	0.842	-0.055	-6.115
1.726	1.185	1.097	-0.088	-7.397
2.16	1.410	1.410	0.00	0.00

Table 1- RMS of tangential acceleration, measured walking speed, predicted walking speed (linear model) for 52-year old healthy subject

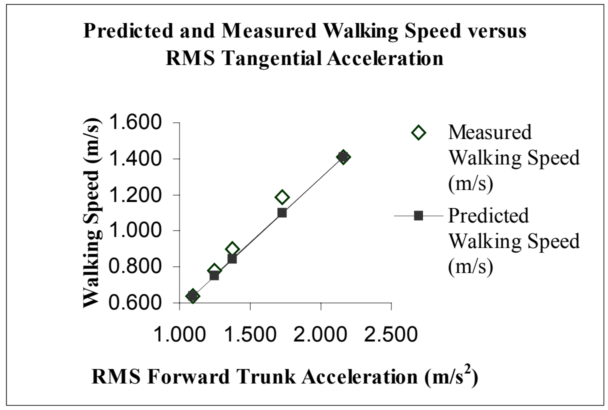

Figure 3 – Predicted and Measured Walking Speed versus RMS of tangential trunk acceleration

Discussion/Conclusions

Thus a linear model of walking speed derived from the RMS of forward trunk acceleration provided a high degree of accuracy (<7.5%) in predicting walking speed compared to direct measurements. These results are very encouraging and suggests that the technique has merit in the real-time measurement of walking speed.

References

[1] Perry, J; 'Gait Analysis Normal and Pathological Function'; Slack Inc., Thorofare, New Jersey; 1997.
[2] Wade DT, Wood VA, Heller A, Maggs J, Langton Hewer R. Walking after Stroke. Scand.J.Rehab.Med:1987:19:25-30.

Acknowledgments:

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[3] MathWorks, Cambridge, MASS., USA