Gait parameters estimation using inertial sensors: comparative analysis of 12 methods

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***Abstract* — The assessment of human walking using wearable inertial sensors plays a relevant role in clinical, sport and home-monitoring application. In particular, the identification of gait events, used to define gait temporal parameters, represent a fundamental aspect in this evaluation. In order to define gait parameters, many algorithms have been implemented. Each of them processes peculiar signals (acceleration or angular velocity) measured from sensors attached on different anatomical part of the body. The aim of this study is to compare the performances of 12 methods proposed for gait events detection and temporal parameters estimation. The number of false negative/positive in detecting gait events, the precision and accuracy in estimating temporal parameters vary according to the signal considered, the data processing applied and the sensors positioning.**

***Keywords*— gait events, temporal parameters, inertial sensors, stereophotogrammetry.**

I. Introduction

INERTIAL Measurement Units (IMUs) have been widely used to assess walking performance. Thanks to their small size, low cost and portability, in particular, they represent an ideal device for functional assessment outside the gait analysis laboratory. One of the main IMUs application is the identification of gait events (GE), which included toe off (TO) and heel strike (HS), used to quantify gait temporal parameters (GTP), such as stride time, step time, swing time and stance time. GPT definition plays a relevant role in clinical, sport and home-monitoring applications [4]. In the literature, many GE estimation algorithms have been proposed, differing in modelling approach, number and positioning of IMU [1–7]. Previous analysis compared the performance of some of these algorithms [4] considering similar IMU positioning. The aim of this study is to compare the performances of 12 methods proposed for GPT estimation, identified from a literature review, analyzing the influence of IMU positioning.

II. Methods

A. Partecipants

Thirty-five healthy subjects (17 female, 18 male; 26.0±3.8 years old; 1.72±0.08 m; 69.0±13.1 Kg) were recruited for this study. All the subjects were recruited from the students/volunteers at the University of Bologna and gave informed consent before participating.

B. Motor tasks and measurement equipment

Five tri-axial IMUs (WaveTrack, Cometa, Milano, fc285Hz) were positioned on the feet, shanks and pelvis of each subject for acceleration and angular velocity acquisition. Four retroreflective markers were applied on each foot (toe, lateral malleolus, III and V metatarsal head) for 3D trajectories acquisition using stereophotogrammetry (BTS Smart-DX, fc250Hz). Participants were asked to walk for 2 minutes at their self-selected comfortable speed.

C. Data analysis

GEs identified from stereophytogrammetric data were assumed as gold standard (GS) [8]. To identify the GEs from IMUs data 11 methods from the literature [1-7] and one newly proposed method (M1) were implemented. M1 is based on the local minima identification of the shank angular velocity. For each method, GPTs were calculated from GEs. Then, the following parameters were calculated:

1) the number of missed GEs relative to the number of true GEs (sensitivity) and of correctly detected GEs relative to the total amount of detected GEs (positive predicted values, PPV) [4];

2) the accuracy and the precision of GE estimation;

3) the accuracy and the precision of GPT estimation.

Data analysis were performed with MatLab (Math Works 2017a, NATICK, USA).

III. Results

A. Sensitivity and PPV

The highest sensitivity and PPV values were obtained for M1, [1] and [7] methods. All the three methods exploit angular velocity signals from sensors mounted on the shank. Values of sensibility and PPV for TO and HS are illustrated in Table 1.

TABLE I
SENSIBILITY AND PPV FOR TOE OFF AND HEEL STRIKE

Method	*Sensibility*		*PPV*		*Position*
	TO	*HS*	*TO*	*HS*	
M1	0.90	0.95	0.98	0.80	
[1]	0.87	0.96	0.99	0.83	Shanks
[7]	0.90	0.97	0.98	0.82	

B. Accuracy and precision of GE and GPT estimation

Bland-Altman's plots show:

- a higher accuracy and precision in GE detection for M1, [1] and [3] methods. In Figure 1 an example of Bland – Altman plot obtained for TO detection in M1 method is reported.

- a higher accuracy and precision in GPT estimation for M1 and [1] methods. In Figure 2 an example of Bland – Altman plot obtained for step estimation in [1] method is shown.

Figure1 Bland – Altman for TO (M1)

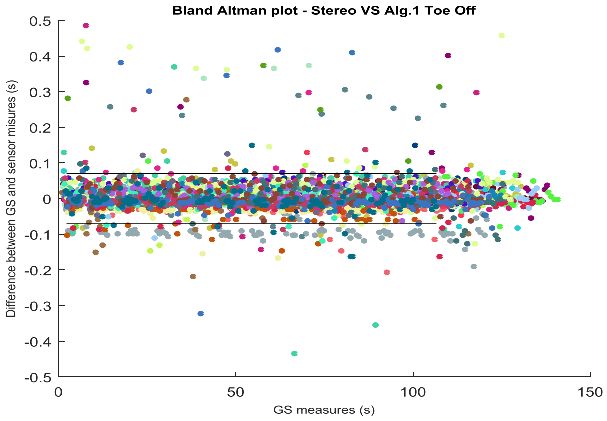
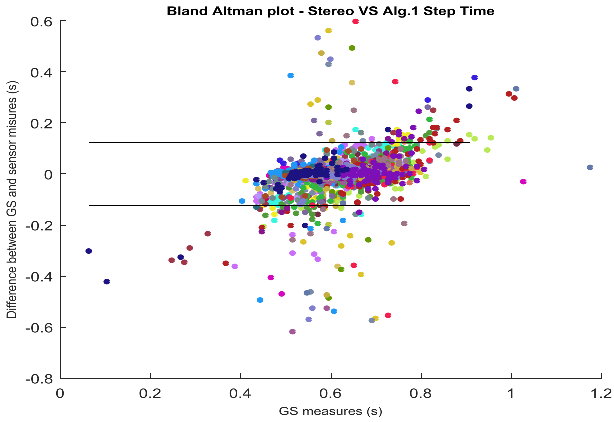


Figure 2 Bland – Altman for step time ([1])



IV. Conclusion

In this study a comparative performance estimation of 12 methods proposed for GPT estimation was defined. The assessed performance of the 12 methods suggests that the most reliable results (low number of false positives/negatives, high accuracy and precision of GE and GPT estimation) are obtained for methods exploiting angular velocity signals from sensors mounted on the shank (M1, [1]). The comparison of these results to algorithm using shank linear acceleration ([7]) shows similar values for PPV and sensibility, while lower values of accuracy and precision are obtained. The positioning of the IMU on the foot ([3]) seems to provide as good accuracy and precision in GEs and GPTs detection as using sensors mounted on the shank (M1, [1]), but with an increased number of extra and missing events. In general, the worst performance in observed for methods exploiting the linear acceleration measured on the pelvis ([2,4]), both in terms of number of false positives/negatives, accuracy and precision of GEs and GPTs. These preliminary results, based on the functional assessment of healthy subjects, should be extended to subjects with specific gait abnormalities.

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