ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

TEMPORAL GAIT PARAMETERS DETERMINATION FROM SHANK-WORN MIMU SIGNALS RECORDED DURING HEALTHY AND PATHOLOGICAL GAIT

[1]Diana Trojaniello, [1]Andrea Cereatti, [1]Gabriele Paolini, [2]Andrea Ravaschio and [1]Ugo Della Croce
[1]Information Engineering Unit, POLCOMING Department, University of Sassari, Sassari, Italy; email: dtrojaniello@uniss.it
[2]Department of Neurosciences, University of Genoa, Italy

SUMMARY

In this preliminary study, a novel method for estimating initial and final foot contacts (IC and FC) during gait for both healthy and pathological subjects using two inertial sensors attached just above the ankles is proposed and validated against the measurements obtained from an instrumented walkway. Data from five healthy and five pathological subjects walking in different conditions were acquired. The proposed method consists of a preliminary identification of trusted swing and stance phases, so that the search intervals for IC and FC could be narrowed. In the two resulting time intervals, IC and FC timings were identified from characteristics of the gyroscope and accelerometer signals. Stance and swing time were then determined. Differences with respect to the stance and swing timings obtained with the instrumented walkway are limited to an average of less than 0.01s for all walking conditions and all subjects. Additional validation work is required on gait of other pathological populations in order to safely adopt the proposed method in clinical settings.

INTRODUCTION

In recent years, wearable inertial sensors (MIMUs) have been extensively proposed as effective tools for measuring gait temporal characteristics [1-5]. In most studies the proposed techniques were applied to the gait of healthy subjects, with a few exceptions [6-8]. Discrepancies with gold standard were in the range of 0.03s - 0.04s in determining temporal events in Parkinson patients gait [6]. In this preliminary work we evaluate a novel technique for the determination of the timing of initial foot contact (IC) and final foot contact (FC) and the determination of consequent temporal gait parameters, by comparing its results to those obtained from an instrumented walkway during one-minute walking trials of both healthy and pathological subjects. The hypothesis of the study was that, by using a method able to restrict the search intervals in the MIMU signals in which gait events can be found, an adequate reliability of their estimate can be obtained for both healthy and pathological gait.

METHODS

Gait data from five Parkinson patients (three females, 75 ± 3 y.o.) and five healthy subjects (one female, 36 ± 7 y.o.) were acquired simultaneously using body worn MIMUs (Opal, APDM) and an instrumented walkway (GAITRite, CIR System Inc). Two MIMUs were attached laterally to the shank (2cm above the lateral malleolus), using velcro straps, on both sides (x-axis pointing downward, y-axis pointing forward and z-axis pointing laterally). The MIMUs and the instrumented walkway were synchronized using a dedicated trigger output from the instrumented walkway and sampled at 128Hz and 120Hz, respectively.

Subjects were asked to walk back and forth for about one minute along a 12-meter walkway in three different walking conditions: a) self-selected, comfortable speed, b) higher speed and c) comfortable speed while performing a cognitive task (subtracting repetitively the number three from a pre-assigned number).

For every gait cycle, time intervals of trusted swing (T_{SW}) and of trusted stance (T_{ST}) were first identified and the remaining time intervals were used as IC and FC search intervals (T_{IC} and T_{FC}). T_{SW} was identified by isolating the time interval during which the gyroscope signal along the z direction (ω_z) exceeded the 20% of its maximum value. T_{ST} was obtained by isolating, at the center of the portion of the gait cycle outside the T_{SW} interval ($^\wedge T_{SW}$), the time interval in which ω_z showed a standard deviation 60% lower than that in $^\wedge T_{SW}$. Therefore, T_{IC} and T_{FC} were defined as the time intervals between T_{SW} and T_{ST} and T_{ST} and T_{SW}, respectively. For each gait cycle, IC (t_{IC}) and FC (t_{FC}) instances were identified inside T_{IC} and T_{FC}, respectively (Figure 1).

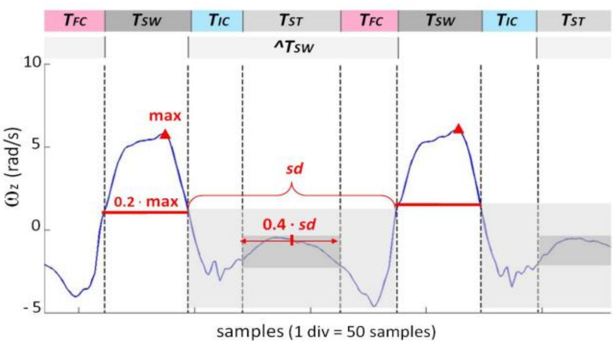

Figure 1: The gyroscope signal ω_z during approximately two gait cycles. Trusted swing (T_{SW}) and trusted stance (T_{ST}) are identified first, so that IC and FC search windows (T_{IC} and T_{FC}) result as their complement within the gait cycle.

The t_{IC} was identified as the instant of minimum ω_z [7] in the time interval between the beginning of T_{IC} and the instant of maximum anterior acceleration a_y in T_{IC}. The instant t_{FC} was defined as the occurrence of the minimum of

a_y preceding the instant of the last maximum value in T_{FC} (Figure 2). Stance time (ST_{Time}) and swing time (SW_{Time}) were obtained from t_{IC} and t_{FC} and compared against those obtained from the instrumented walkway. Therefore, only the data acquired while the subjects walked over the instrumented walkway were used for the analysis.

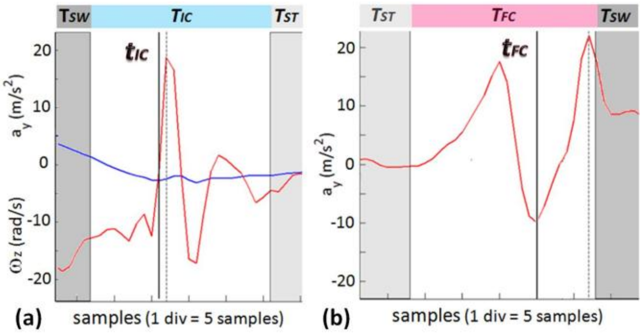

Figure 2: IC (t_{IC}) and FC timing (t_{FC}) identification. (a) The gyroscope signal ω_z (blue) and acceleration signal a_y (red) in the T_{IC} search window are shown. The vertical dashed line represents the instant of maximum a_y in T_{IC}, while the solid vertical line identifies the IC detected. (b) The acceleration a_y (red) in the T_{FC} search window is shown. The dashed vertical line represents the instant of the last a_y maximum in T_{FC}, while the solid line identifies the FC detected.

RESULTS AND DISCUSSION

In Table 1, ST_{Time} and SW_{Time} as determined by the MIMU and their difference (Δ) with respect to the values obtained with the instrumented walkway are reported for all subjects walking in the three conditions, for a total of more than 1500 measurements. Results showed extremely low values for Δ across the three walking conditions: the average absolute value of Δ was always lower than 0.01s (*sd* =0.02s) in both healthy and pathological subjects. This result is particularly promising considering that the gait characteristics in the same gait condition showed a remarkable variability across subjects (ST_{Time} varied from 0.62s to 0.82s at comfortable speed). Moreover, the proposed method was able to properly estimate ST_{Time} and SW_{Time} both in very regular gait (*sd* = 0.01s in S1 comfortable walk) and in less regular gait (*sd* = 0.08s in P2 comfortable walk).

CONCLUSIONS

The validation of the proposed method for determining temporal gait events and consequent parameters provided robust results across gait conditions and subjects. However, a wider range of pathologies should be tested in order to have a stronger validation of the method. Moreover, gait conditions could be extended to variations of gait such as obstacle negotiation and turning.

ACKNOWLEDGEMENTS

This study was carried out as part of the V-TIME project partially funded by the European Commission under the 7th Framework Program, grant #278169

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Table 1: Trial average (gray background) and *sd* (no background) values for ST_{Time} and SW_{Time} as determined from the MIMU signals and the difference (Δ) with respect to the relevant values obtained from the instrumented walkway for three different gait conditions. Numbers are reported in seconds.

	COMFORTABLE WALK				FAST WALK				COGNITIVE TASK WALK			
	ST_{TIME}	Δ	SW_{TIME}	Δ	ST_{TIME}	Δ	SW_{TIME}	Δ	ST_{TIME}	Δ	SW_{TIME}	Δ
S1	0.77	**0.01**	0.46	**- 0.01**	0.58	**0**	0.40	**0**	0.66	**0.01**	0.42	**- 0.01**
	0.01	***0.01***	*0.01*	***0.01***	*0.02*	***0.01***	*0.01*	***0.01***	*0.03*	***0.02***	*0.02*	***0.02***
S2	0.69	**0**	0.43	**0**	0.59	**0**	0.39	**0**	0.69	**0.01**	0.41	**- 0.01**
	0.02	***0.01***	*0.02*	***0.01***	*0.03*	***0.01***	*0.02*	***0.01***	*0.03*	***0.01***	*0.02*	***0.01***
S3	0.65	**0.02**	0.38	**- 0.02**	0.53	**0**	0.36	**0**	0.71	**0.01**	0.42	**- 0.01**
	0.01	***0.01***	*0.01*	***0.01***	*0.03*	***0.03***	*0.03*	***0.03***	*0.03*	***0.01***	*0.02*	***0.01***
S4	0.62	**0**	0.40	**0**	0.46	**0**	0.33	**0**	0.68	**0**	0.42	**0**
	0.02	***0.02***	*0.02*	***0.02***	*0.02*	***0.01***	*0.01*	***0.01***	*0.03*	***0.01***	*0.02*	***0.01***
S5	0.67	**- 0.01**	0.42	**0.01**	0.51	**0**	0.34	**0**	0.72	**0**	0.43	**0**
	0.03	***0.03***	*0.03*	***0.03***	*0.02*	***0.02***	*0.02*	***0.02***	*0.04*	***0.02***	*0.04*	***0.02***
P1	0.65	**0**	0.38	**0**	0.57	**0**	0.36	**0**	0.64	**0**	0.38	**0**
	0.02	***0.02***	*0.01*	***0.02***	*0.04*	***0.02***	*0.02*	***0.02***	*0.03*	***0.02***	*0.02*	***0.02***
P2	0.83	**0.01**	0.36	**- 0.01**	0.70	**- 0.01**	0.32	**0.01**	0.83	**- 0.01**	0.29	**0.01**
	0.08	***0.03***	*0.04*	***0.03***	*0.07*	***0.03***	*0.03*	***0.02***	*0.05*	***0.03***	*0.03*	***0.03***
P3	0.82	**0.02**	0.40	**- 0.02**	0.74	**0**	0.38	**0**	0.81	**0.02**	0.40	**- 0.02**
	0.04	***0.02***	*0.03*	***0.02***	*0.04*	***0.02***	*0.02*	***0.02***	*0.05*	***0.06***	*0.03*	***0.04***
P4	0.79	**- 0.01**	0.44	**0.01**	0.67	**- 0.01**	0.40	**0.01**	1.10	**0**	0.48	**0**
	0.06	***0.01***	*0.04*	***0.01***	*0.02*	***0.01***	*0.02*	***0.01***	*0.12*	***0.02***	*0.06*	***0.02***
P5	0.70	**- 0.02**	0.41	**0.02**	0.67	**- 0.02**	0.41	**0.01**	0.79	**- 0.01**	0.45	**0.01**
	0.02	***0.01***	*0.01*	***0.02***	*0.03*	***0.01***	*0.01*	***0.02***	*0.04*	***0.01***	*0.02*	***0.01***