An automated heel strike and toe-off detection method for doctors office inertial sensor gait measurement.

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I. Introduction

THE gold standard to evaluate the severity of pathologies such as osteoarthritis in the doctors office remain clinical scores [1], [2]. However, clinical scores are inherently subjective and they depend from the patients impression and from the clinicians interpretation. Gait analysis in modern gait laboratories with force plates and photogrammetry brings a lot of crucial information is a good tool to have an objective, quantified and precise insight in osteoarthritis [3]. Compared to matched controls, knee osteoarthritis patients have reductions in walking speed [3] and cadence [4] [5], longer double support time [4] [6], a smaller stride length [7]. But for clinical measurements in consultation, simpler methods are needed. For practical reasons, skin mounted inertial sensors are well suited for investigating gait kinematics [8]. Signal processing is an important step in the development of measuring gait in the doctors office. One crucial step is the detection of gait moments. Human gait cycle is composed of four moments: Heel Strike (HS), Foot Flat (FF), Heel Off (HO) and Toe Off (TO). It is essential to be able to compute parameters from the raw data in an automatized way to be able to treat a big amount of data in the case of an all-day measurement or to be able to give real time results of the measure to the clinician in the everyday consultation. Reliable automatic step detection is a complex problem that is still not solved today [9][16]. This study propose automatic methods of detection of the HS and the TO.

II. Methods

A. Subjects

12 subjects with no gait impairment were included in the study (40 to 87 years, mean 60.8). They gave their written consent to participate in this study.

B. Instrumentation

Feet linear acceleration and angular velocity were collected using two triaxial accelerometers, gyroscopes and magnetometers (XSens MTw Measurement Units 100 Hz). The sensors were fixed on both feet using manufacturer designed adhesive Velcro tape.

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C. Experimental design and data acquisition

The participants were instructed to execute following steps: stand quiet 6 s, walk 10 m at preferred walking speed on a level surface, make a U turn, walk back at preferred walking speed on a level surface, stand quiet 2 s. Participants could keep their wares and their shoes on.

D. Heel strike and Toe off detection

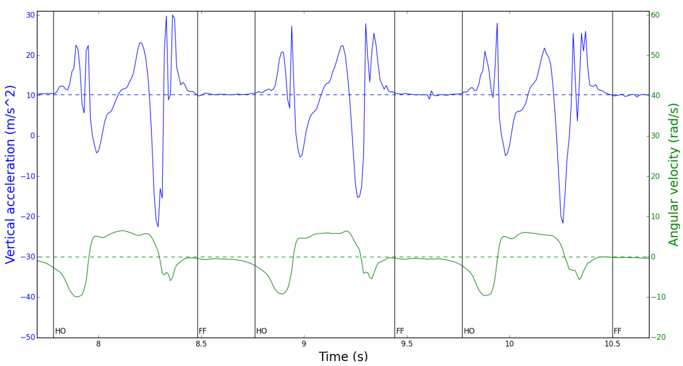


Fig. 1. Vertical acceleration and the antero-posterior angular velocity

Figure 1 shows typical data for the vertical acceleration and the antero-posterior angular velocity. Interesting gait cycle moments are depicted. HO and FF are given by an algorithm previously developed. No information can be given on this algorithm for commercial reasons. The studied signals are comprised between HO and FF. TO and HS are part of these signals.

Automatic detection criteria for HS were:

- Identify the first maximum in the HS zone.
- Identify the maximum of the HS zone with preceded by the highest jerk.
- Identify the highest maximum in the HS zone.
- Identify the change of sign of the antero-posterior angular velocity in the HS zone.

Automatic detection criteria for TO were:

- Identify the last maximum preceding the swing phase.
- Identify the global minimum of the signal in the first half of the studied interval.
- Identify the zero value of the antero-posterior angular velocity in the TO zone.
- Identify the local maximum preceded by the smallest jerk in the first half of the signal.

Fig. 2. Automatic detection criteria for HS

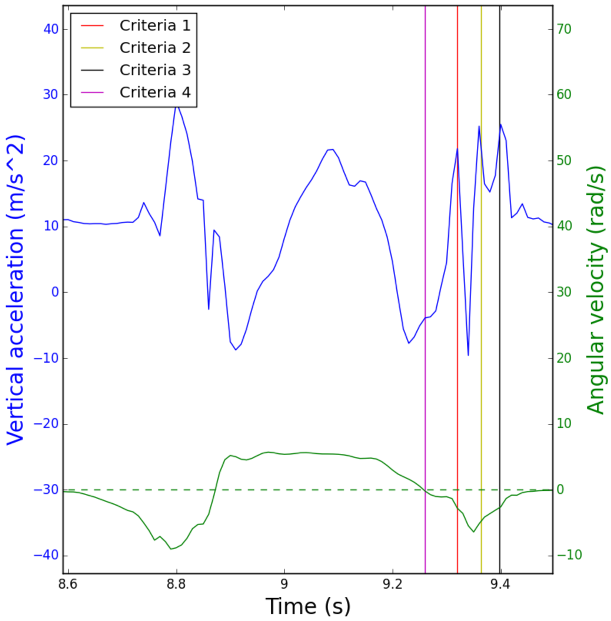
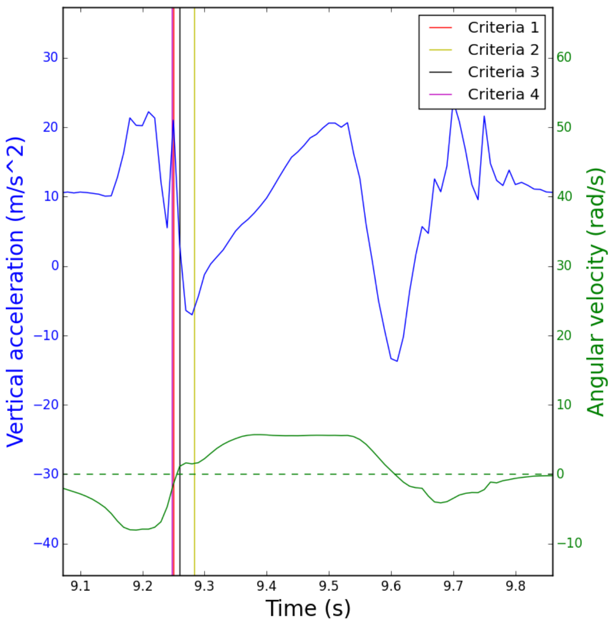


Fig. 3. Automatic detection criteria for TO



III. Results and discussion

Results for the different methods are shown on Figure 2. Figure 2 allows us to compare the different methods. Concerning HS, we have high frequency components around HS. This is typical for the shockwave propagation along the foot. Criteria 1 seem the more adapted because it reflects the first contact from the foot with the ground. Criteria 2 is justified by the fact that a shock with the flour is characterized by an important jerk. Criteria 3 is robust and simple to implement. It traduces also the contact of the foot with the ground. Criteria 4 correspond to a change of sense in the foot rotation. Basic gait observation shows that this angular velocity inversion happen before HS. Concerning TO, criteria 1 is based on the fact that the loss of contact with the ground produces a high frequency shock wave that we are able to detect with the acceleration signal. Criteria 2 is simple to implement and detects a moment of the TO zone. Criteria 3 correspond to a change of sense in the foot rotation. Basic gait observation shows that this angular velocity inversion happen right before TO. The results for these four criteria show that they always are very near from each other and that they appear in the same order. In order to evaluate the reliability of the proposed methods, we evaluated the automatic detection on 100 steps from different patients. The success rate of each criteria is reported on Table 1.

Criteria	HS	TO
1	99 %	97 %
2	99%	100 %
3	100%	92%
4	84%	92%

TABLE I
ALGORITHM RELIABILITY COMPUTED FOR 100 STEPS FROM DIFFERENT SUBJECTS.

The fact that our methods do not give the same results is precious. In fact, it reflects the uncertainty inherent to the definition of these gait instants and it allows to compute new gait parameters using the time delay between the detected points. If we had to chose on criteria to evaluate HS we would chose criteria one because it reflects the beginning of HS. For TO, we would chose criteria one because comparing with video recording, this criteria is convincing. Moreover, this criteria is very often confirmed by criteria 3.

IV. Conclusion

This inertial sensor based method show good ability to detect automatically HS and TO. The multiple way developed to evaluate HS and TO allow both to evaluate the uncertainties of the detection of these moments and to compute gait parameters (time delays between the detection methods) that are promising for further studies on gait.

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