AMBULATORY GAIT ANALYSIS USING GYROSCOPES

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INTRODUCTION

Recently, technical progress has made possible to realize miniature kinematic sensors such as accelerometers and angular rate sensors (Sparks et al. 1998). These sensors can be battery powered and are promising tools for ambulatory gait monitoring and analysis. The possibility to detect simple parameters such as steps and cycle time from trunk or heel acceleration has already been demonstrated (Aminian et al, 1995). Gait analysis using gyroscope has proved to be an other alternative technique for gait analysis (Tong and Granat, 1999). Unlike the accelerometer, the gyroscope can be attached anywhere to a body segment since the angular rotation is still the same along the segment. However no clear correspondence has been established between gait events and the patterns of angular velocity. In this study we describe an ambulatory system for temporal parameters estimation using gyroscopes. The accuracy of the measurement was assessed using as criterion standard the information provided by footswitches. To show the effectiveness of the method in a wide range of walking performance, gait parameters were obtained from young and old subjects.

METHODS

Measurement were taken from a group of 9 young (21±2 years) and 11 elderly (79±8 years) subjects. Informed consent was obtained from all subjects. Each young subject performed four trials including at least 20 gait cycles. Three trials corresponded to walking on a treadmill at the preferred speed, under and over the preferred speed. The fourth trial was performed over ground at preferred speed. The elderly performed only two trials over ground at their preferred speed. A miniature gyroscope was attached on each shank. These sensors measure the velocity of angular rotation parallel to the mediolateral axis. Footswitches placed under the right foot (beneath the heel and beneath the big toe), have been used as criterion standard to validate the temporal parameters estimated by the gyroscopes. All signals were digitized at a sampling rate of 200 Hz by a portable data logger and stored on a memory card.

Gait phases were determined for each leg from the precise moments of heelstrike and toe-off. These events give rise to distinctive features on shank angular velocity signals in form of rather sharp negative peaks. A multi-resolution wavelet decomposition (Mallat, 1989) was used to enhance the toe-off and heel-strike event during walking. Temporal parameters of a gait cycle were computed from heelstrikes and toe-offs as percentage of gait cycle. In order to reach a good precision for the temporal parameters, at least 20 gait cycles have been considered for analysis. For each trial the value of temporal parameters was averaged over all cycles.

RESULTS AND DISCUSSION

Fig. 1 shows a good correspondence between gait events detected by footswitch and gyroscopes. An excellent agreement (r=0.99) is found. The difference between estimated stance (gyroscope) and actual value (footswitch) is not significant (N=58, p>0.80) with an RMS error of 0.023s (2.8%). No significant change is neither observed between estimated gait cycle and actual (N=58, p>0.97). The RMS error is 0.008s (0.5%). The 95% confidence interval for the difference between heelstrike detection by footswitch and gyroscope is [0.007s, 0.013s]. Gyroscope detects heelstrike 0.01 s (in average) later than footswitch. The 95% confidence interval for the difference between toe-off detection by footswitch and gyroscope is [-0.005s, 0.004s]. Therefore there is no significant difference in toe-off detection. As expected, the gyroscopes provide the same time for both left and right gait cycles, with RMS error less than 0.015s (r>0.99, 1.3%). In addition, results did not suggest any differences in validity of the system across age group. The proposed method reveals a promising monitoring tool for functional evaluation of gait improvement. It allows measuring gait temporal features (stance, swing, single and double support) during a long period of walking and supplying in this way the stride-to-stride variability of gait. It has many potential clinical applications such as outcome measure after total knee or hip replacement, prosthesis adjustment for amputees, gait disturbances analysis in neurological diseases, and fall risk estimation in elderly. The system is light (300 gr), portable, and low cost and involves no discomfort for the patient who can carry it for a long period of time.

SUMMARY

A new method using wavelet transform to detect toe-off and heelstrike from shank angular velocity is proposed. A high correlation with actual gait events detected with footswitch was found. No significant error is observed for toe-off detection, while a slight systematic delay (10ms in average) exists between heelstrike obtained from gyroscopes and footswitch. By considering a sampling period of 5ms (200Hz) this error is acceptable.

REFERENCES

D.R. Sparks, X. Huang, W. Higdon, J.D. Johnson, (1998). Microsystem Technologies 4, 139-142, Springer-Verlag

Aminian K, Robert P, Jequier E, Schutz Y (1995). *Med Sci Sports Exerc.*, 27:226-34.

K. Tong, MH. Granat, Med. Eng. Phys., 21, 1999, 87-94

S.G. Mallat, (1989). IEEE Trans., Pattern Anal.& Machine Intelligence, 11, 674-693

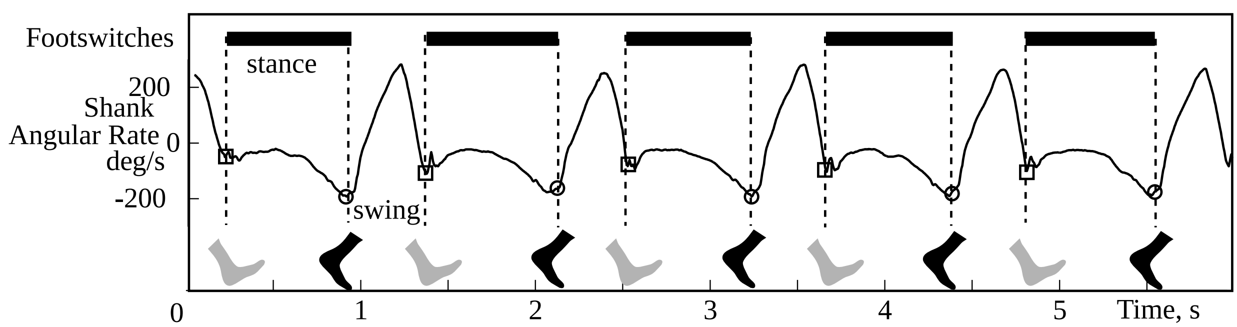

Figure 1- Correspondence between gait events detected by footswitches and gyroscopes. Negative peaks of angular rate corresponding to heelstrikes(□) and toe-off (○) are detected after wavelet transform.