Determining over ground running speed using inertial sensors

Jonathon Neville*, David Rowlands, Andrew Wixted, Daniel James

*Centre for Wireless Monitoring and Applications, Griffith University, 170 Kessels Road, Queensland 4111, Australia
Centre of Excellence for Applied Sports Science Research, Queensland Academy of Sport, Nathan, Queensland, Australia

Abstract

Accurate activity monitoring techniques provide coaches and athletes with the tools to better analyze the effect of training sessions in the lead up to competition. The most common approach for monitoring elite level athletes comes in the form of using Global Position Systems (GPS) in an effort to obtain the time spent running in different speed levels as well as recording the total distance travelled. Accelerometers, on the other hand, are steadily growing in popularity as activity monitoring tools and offer researchers, coaches and players an alternative way to track athlete performance. Accelerometers have previously been used to approximate running speeds and energy expenditure in athletes running on a treadmill. It is often argued both by athletes and researchers that the biomechanical processes involved in treadmill running differ significantly when compared to over ground running. This paper extends previous research by exploring the use of accelerometers to accurately approximate over ground running speeds. Performance monitoring units were placed in a specially designed vest, that when worn by the player, positioned the tracking unit around the middle to upper thoracic vertebrae. An experiment was conducted in which the accelerometry data for experienced runners over a range of speeds was recorded alongside an external speed measurement. Participants were asked to run a series of 50 m stretches of track at what they perceived to be constant speeds. Players were asked to steadily increase their speed for each trial, beginning roughly at 8km/h and finishing at around 30km/h. The accelerometer data was exported to MATLAB where a series of post processing steps were used to extract the stride frequency. The stride frequency derived from the accelerometer data was compared to an externally measured speed and found to produce a linear relationship as expected from the literature. This research has provided the groundwork for the use of accelerometers in measuring the speed of over-ground running.

© 2011 Published by Elsevier Ltd. Open access under CC BY-NC-ND license. Selection and peer-review under responsibility of RMIT University

Keywords: Accelerometer; over ground; running; athlete monitoring; stride frequency

* Corresponding author. Tel.: +61-7-37375-5036; fax: +61-7-37375-5384.
E-mail address: jononeville@gmail.com.
1. Introduction

The physical demand on elite level athletes continues to play an important role in the sporting community. Accurate activity monitoring provides coaches and athletes with the tools to better analyze the effect of training sessions and competitions. With respect to over ground running, the most common approach for monitoring athletes comes in the form of Global Position Systems (GPS). These systems often attempt to classify the time an athlete spends running in different speed zones, as well as recording the total distance travelled [1-3]. GPS systems in their very nature, however, require active satellite connections and are therefore dependent on an external source. Accelerometers on the other hand are often referred to as ‘sourceless’ as they are self-contained systems in which the data can be measured and manipulated without reference to external devices [4]. The research conducted in this paper has therefore been designed to provide an alternative method to analyze the running characteristics of athletes by exploring the use of accelerometers as a tool to analyze over ground running speeds.

Accelerometers have previously been used to approximate running speeds and energy expenditure in athletes running on a treadmill [5]. In this previous study it was identified that the stride frequency could be extracted from accelerometer data for athletes both walking and running. It also identified that a linear relationship between stride frequency and speed existed, however the linear relationship differs between walking and running. It has often been argued both by athletes and researchers that the biomechanical processes between treadmill and over ground running differ significantly [6]. This paper is therefore targeted at approximating the speed of athletes using accelerometers from over ground running data.

2. Methodology

The aim of this research is to investigate the relationship between the stride frequency and speed of a professional athlete in relation to over ground running. This study also attempts to confirm a previously developed post processing method [6] used to extract player stride frequency from accelerometer data.

Data was collected using a GPSport’s Wi SPI (1 Hz) GPS tracking unit. This unit includes a GPS sensor, which was used to log coordinates at 5Hz coupled with three axes of acceleration, which measured up to +/- 8g, and logged data at 100Hz. The GPSport’s Wi SPI unit weighed approximately 100g and continuously recorded data for approximately four hours. The data was stored locally on the device and downloaded to a computer after each training or game session through the use of a USB cable.

The tracking units were placed in a specially designed vest that when worn positioned the tracking unit around the middle to upper thoracic vertebrae. Figure 1 shows the three axis of the accelerometer with respect to the player. The three axes of the accelerometer align with the player’s body in such a way that acceleration in the x channel correspond to movement in the mediolateral axis, accelerations in the y channel correspond to movement in the superior-inferior axis and accelerations in the z channel correspond to movement in the anteroposterior axis.
The study was conducted as two separate series of trials:

- Explored the relationship of stride frequency to speed measured using a stopwatch.
- Explored the relationship of stride frequency to speed measured using a GPS unit.

In each experiment a single elite level long distance runner was asked to participate in a series of trials. In each trial, the athlete was fitted with the GPSports sensor and was asked to jump several times, in an effort to ensure synchronisation between the accelerometer and external video reference. The athlete was then asked to run a 100 meter section of track, while attempting to maintain a constant speed. From each 100 meter run associated with the first experiment, the time across the middle 50 meters of track was also recorded using a stopwatch to allow for an approximation of speed.

The accelerometry data recorded from both experiment was imported into MATLAB. Figure 2 shows x, y and z accelerations from the raw data for the first experiment.

Fig. 1. Left: A visual representation of the location and orientation of the GPS, accelerometer tracking unit. (The outline depicted in the figure is facing away – through the page). Right: An image of the GPSports Vest and the location of the sensor during the trials.

Fig. 2. Raw three axis accelerometer data for the first experiment consisting of 20 individual running trials.
From Figure 2 it can be seen that the spikes in the accelerometry data, particularly in the y axis, are clearly visible. This allows for a specific 100m running section of data to be extracted and analysed. An example of an individual running trial can be seen in Figure 3. In this data, the three jumps used to synchronise the video and GPSports sensor data can be clearly identified as well as the section of data where the run is being conducted.

![Accelerometer Data for the running trials](image)

Fig. 3. Raw three axis accelerometer data for an individual trial, clearly demonstrating the jumps used for synchronisation.

Once each trial has been identified there are several post processing steps can be implemented to extract the stride frequency. Figure 4 provides a graphical view of the post processing conducted on the accelerometer data in order to extract the stride frequency.

The process of extracting the step frequency begins with the removal of the baseline of the signal. The accelerometer data is then passed through a low pass Hamming window filter of 0.9 Hz. This filter is designed to identify the effects of sensor orientation. As 0.9 Hz is significantly slower than the minimum stride frequency the accelerometer data relating to the impacts with the ground will not be filtered out. The orientation signal was then subtracted from the original signal to remove any effects due to the athlete’s angle.

A second Hamming window low pass filter (9 Hz) was applied to the signal to remove any sharp movements or artefacts. As the maximum typical stride frequency for running is around 4 – 5 Hz a low pass filter of 9 Hz will not remove the underlying shape caused by the athlete’s impacts with the ground.

Figure 4 (right), shows the sinusoidal waveforms that are the result of the previously mentioned filtering process. A MATLAB program was written to count the number of impacts with the ground by counting the zero crossings of the filtered signal in the y axis. The number of strides in the filtered signal was then divided by the time between the first and last stride to obtain the stride frequency in Hz.
3. Results and Discussion

The results of this study have been focused on approximating the speed of an athlete based on identifying stride frequency during over ground running. There were two experiments conducted as part of this research. The first study compared the accelerometer derived stride frequency to a stopwatch recorded time. This study was designed to provide a brief investigation into deriving stride frequency from over-ground running. As seen in figure 5 (left), the athlete’s running speed across the $n = 17$ trials ranged from 15-30km/h corresponding to a variation in stride frequency of 2.9-3.9Hz. As expected from the literature [6], a linear trend was observed in the data with a regression value of $r^2 = 0.896$. The second experiment ($n=15$) made use of a GPS calculated speed as seen in figure 5 (right). This study ranged in speeds from 17-28km/h corresponding to a stride frequency range of 3-4Hz. Again a linear relationship was observed and a regression value of $r^2 = 0.901$ was identified.
4. Conclusion

This paper explores the issues associated with identifying stride frequency from accelerometer data for over ground running. It has been identified in the literature [6] that accelerometers can provide accurate information on athlete stride frequency when in a controlled environment such as a treadmill. The results from this study have confirmed a methodology for analyzing the stride frequency in over ground running data and have shown that there is a linear relationship between speed (either recorded using a stopwatch or calculated from GPS measurements) and stride frequency for elite level athletes. In a general context, this research provides a basic exploration into the use of accelerometers as an alternative athlete monitoring device for over ground running.

References


