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THE USE OF A HIGH-END GLOBAL NAVIGATION SATELLITE SYSTEM IN A 100 M SPRINT

UPORABA VISOKO-LOČLJIVEGA GLOBALNEGA NAVIGACIJSKEGA SATLITESKEGA SISTEMA V SPRINTU NA 100 M

ABSTRACT

The aims of this study were to provide a method of computation time and velocity from Global Navigation Satellite System (GNSS) measurements in sprint running for predetermined positions along a sprint track and to show that section times and velocities can provide additional significant data in order to analyse performances in 100 m sprint running in greater detail. Experiments were performed on two male athletes. Photocells were set along a 100 m sprint track. Using the proposed GNSS system, 40 times were calculated for each runner, and afterwards 39 section times were derived, each covering 2.5 m. The main findings in this study are: 1) a new method of measuring time segments in a 100 m sprint with the use of GNSS has been developed, providing relatively small differences of measured time in comparison to the photocell method; 2) a new method of measuring time enabled precise direct location comparisons between the runners; and 3) additional times and velocities in sprint running using the new method provide "hidden" data along the run which can help experts or scientists analyse performance. The method of computation time from the high-end GNSS surveyed trajectory provides reliable and accurate results for measurements in sprint running. From the usage point of view, it represents a good alternative to the established photocell measurement, especially for highly detailed or scientific analysis.

Keywords: track and field, GNSS RTK, GPS, time, velocity

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IZVLEČEK

Cilj te študije je bilo poiskati način računanja časa in hitrosti iz meritev Globalnega Navigacijskega Satelitskega Sistema (GNSS) v sprintu za vnaprej določene položaje vzdolž atletske steze in pokazati, da lahko časi odsekov in hitrosti priskrbijo dodatne pomembne podatke za analizo uspešnosti na 100 m sprintu. Poskusi so bili izvedeni na dveh moških športnikih. Fotocelice so bile nameščene ob 100 m atletski stezi za neposredno merjenje časa. S predlaganim GNSS sistemom pa je bilo izračunanih 40 časov in iz tega 39 časov odsekov od katerih vsaka zajema 2,5 m. Glavne ugotovitve v tej študiji so: 1) predstavljen je bil novi način merjenja časa odsekov na 100 metrski atletski stezi z uporabo GNSS merilnega sistema, ki zagotavlja razmeroma majhne razlike v izmerjenih časih v primerjavi s fotocelicami; 2) nova metoda merjenja časa omogoča neposredno primerjavo med tekači v krajevni odvisnosti, in 3) dodatno izmerjeni časi in hitrosti v sprintu s pomočjo nove metode merjenja priskrbijo sicer "skrite" razlike med sprinterji, ki lahko pomagajo strokovnjakom ali znanstvenikom podrobneje analizirati uspešnost. Metoda za izračun časa iz trajektorij visoko-natančnega GNSS sprejemnika zagotavlja zanesljive in točne rezultate meritev časa v sprintu. Z uporabnega stališča je nova metoda dobra alternativa za ustaljene meritve s fotocelicami, zlasti za zelo podrobne ali znanstvene analize.

Ključne besede: Atletika, GNSS RTK, GPS, čas, hitrost

INTRODUCTION

Results in sprints depend on the optimal integration of four phases: start, starting acceleration, maximum velocity and deceleration (Mero, Komi, & Gregor, 1992). Sprint running is a complex cyclical movement and is a product of stride frequency and stride length. Both parameters are mutually dependant and individually conditioned by the processes of the central regulation of movement, biomotor abilities, energy processes and morphological characteristics. Various phases influence the final result in a sprint race with different levels of importance. The study by Tellez and Doolittle (1984) revealed that the starting action contributes 6%, starting acceleration 64%, maximum velocity 18% and deceleration 12% to the final time in a 100 m sprint race.

Sprinting is, by definition, a cyclical movement with maximum possible velocity. However, the velocity changes significantly in individual segments. These changes are the result of the biomechanics of sprinting stride, the activation of various biomotor abilities, processes of neuromuscular control and functional factors (Coppenolle & Delecluse, 1989; Donatti, 1995; Muller & Hommel, 1997). The subject of this study was an examination of the control of dynamics in sprinting velocity in individual segments of a sprinting track in a 100 m race with the use of GPS technology. Previous research studies by several authors used a model of measuring time over 10 m segments, most frequently with the use of photocells. Such time-related information enabled researchers to precisely monitor the sprinting velocity. Nevertheless, the problem of such a method is its lack of precision when runners pass the beam as they can activate the photocell with different parts of their body; this factor cannot be controlled. When passing the beam with the hand first, at least a 1/100 second difference occurs than when passing the beam with the torso first. As a result, partial segment velocities over 10 m intervals provide only a partial insight into the dynamics of sprinters' velocity. One alternative is the laser method which has been used in track and field since 2001. The laser works on the principle of the Doppler effect and provides more detailed information than the system of photocells. It enables the linear monitoring of sprinters' movement in space. The key problem of the measurement precision is the reflection of beams from different sprinters' body parts, i.e., the beam can reflect differently from a head, leg, torso etc., which can lead to a relatively large inaccuracy of results.

The latest technology is the Global Navigation Satellite System (GNSS) which enables the registration of a sprinter's velocity in various time and position points on a 100 m race track. Examining instantaneous velocity at precisely defined moments of a race provides important information about the running biomechanics, motor control processes, the energy processes of runners and their degree of preparation. Further, monitoring the points of velocity along the track allows an indirect comparison of velocity parameters between sprinters of various levels.

The Global Navigation Satellite System is a term referring to different satellite navigation systems that provide autonomous global geo-spatial positioning; among these, the United States Global Positioning System (GPS) has recently been used in many different human locomotion and sport measurements (Ai & He, 1999; Skaloud & Limpach, 2003; Karboviak, 2005; Edgecomb & Norton, 2006; Tropedet al., 2008). GPS has been proven to be reliable when measuring distance and velocity in several outdoor activities (Ai & He, 1999; Schutz & Herren, 2000; Terrieret al., 2000; Larsson, 2003; Witte & Wilson, 2004; Rodriguezet al., 2005; Witte & Wilson, 2005; Townshendet al., 2008). However, GNSS has never been used to accurately measure performance or intermediate time, even though the system's internal computation of positions relies on very accurate atomic clock time measurements (Parkinson & Spilker, 1996).

The aims of this study were: 1) to provide a method of computation time and velocity from GNSS measurements in sprint running for predetermined positions along the sprint track; and 2) to show that section times and velocities can provide additional important data in order to analyse performances in 100 m sprint running in greater detail.

METHODS

Subjects

Experiments were performed on two male athletes (age: 28.0 and 23.0 years, body height: 183.0 and 186.0 cm, body weight: 78.2 and 74.0 kg), who provided written informed consent. All procedures were approved by the Ethical Committee of the Faculty of Sport in Ljubljana, Slovenia and the study was conducted according to the Declaration of Helsinki.

Overall Design of the Study

The study started with a mathematical overview of a procedure for computation time and velocity from real-time kinematics (RTK) GNSS-surveyed trajectories on predetermined positions along a sprint track. Thereafter, a 100 m sprinting experiment was performed to show the functionality and advantages of the RTK GNSS system and methodology in sprint running.

Time and velocity computation

All GNSS systems comprise three-dimensional movement trajectory in relation to time. In this study, the RTK GNSS system measured the trajectory sprinters' movement. As the research intended to examine times and velocities for particular segments of the race track, first the marks of these segments had to be set along the track; in this study, every 2.5 m from the start to the finish. Mathematically speaking, these points were used to define referential planes which needed to be placed vertically and at a right angle to the direction of a race track (see Figure 1). Thus the calculated trajectory of a sprinter in the 100 m race crossed these referential planes. When the intersections of trajectory with each of the referential planes were calculated, running times from the start of the trajectory to the calculated intersections were derived. The calculated differences between individual segments represented the times of the segments. The desired precision of the time measurement is higher than the sampling rate of the GNSS device. Therefore, a "cubic spline" interpolation and an adequate "2-way" Kalman filter providing the time and place of the intersections more precisely were used.

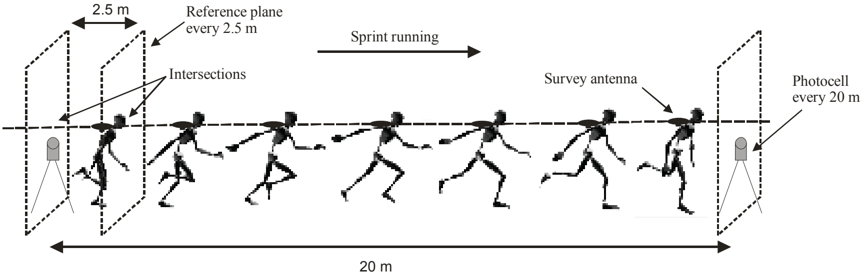

Figure 1: Diagram of a sprint runner passing the reference planes and photocell beams. Note that reference planes as used in combination with the GNSS were constructed every 2.5 m for timing purposes and were 10 times denser for velocity purposes.

The velocity of movement versus time was down-sampled to every 0.25 m from the measured trajectory with an intention of acquiring data about changes in velocity versus distance in order to enable a direct comparison on the race track between the measured subjects. To achieve this, first the velocities for the entire sprint race in relation to time were calculated with the use of a linear approximation; afterwards, its absolute values were calculated. A method identical to the calculation of the time segments was used to acquire the times of the race trajectory crossings with referential planes for every 0.25 m of the track. The times were then entered into the absolute velocity, related to time; thus calculating absolutevelocities for every 0.25 m of the race. As previously stated, a "cubic spline" interpolation was used to identify precise values. It must be noted that these values represent absolute velocities at precisely defined points of the race track and are not mere average velocities of the interval, which would be an equivalent parameter of time segments. In practice, the velocity-versus-time according to velocity-versus-distance was slightly down-sampled.

Instruments

A high-end RTK GNSS system with 99.99% reliability (according to the manufacturer; http://www.leica-geosystems.com/uk/en/lgs_18994.htm) was used to measure the athletes' trajectories. A rover and a reference station were built from the same hardware components: a dual frequency L1/L2, geodetic, Leica GX1230GG GNSS RTK receiver, a Leica GLONASS/GPS AX1202 GGsurvey antenna and Leica Satelline 3AS radio modems (Leica Geosystems AG, Heerbrugg, Switzerland) for real-time corrections. The system works in RTK mode at a maximum 20 Hz sampling rate $s = 10$ mm + 0.5 ppm and $s = 20$ mm + 0.5 ppm horizontal and vertical accuracy, respectively.

For all measurements, the reference station stood on a fixed tripod and was less than 100 m away from all surveyed points to transmit real-time corrections. To capture the athletes' trajectories, the rover's receiver, modem and antenna were placed in a small backpack worn by the athlete, with the antenna at the level of the upper thoracic spine (T2-T4). For the survey start and finish positions of the sprint track as well as to set the photocell positions, the antenna was attached to a 2 m high carbon geodetic pole and the rover was set to a static measurement mode with $s = 5$ mm + 0.5 ppm and $s = 10$ mm + 0.5 ppm horizontal and vertical accuracy, respectively. A local geodetic co-ordinate system was used for all measurements in order to achieve maximum accuracy (Parkinson & Spilker, 1996). At least eight satellites were visible during the measurements with an elevation cut-off angle set to 15°. For validation purposes, six sets of Microgate Polyfemo photocells and Racetime 2 chronometers (Microgate S.r.l., Bolzan, Italy) were used, with a resolution of $3.47 \cdot 10^{-5}$ and $1.25 \cdot 10^{-4}$ s, respectively.

Experiment: 100 m sprint running

In the sprint running experiment, six photocells were set along a 100 m sprint track at 2.5, 20, 40, 60, 80 and 100 m. Using surveyed start and finishpositions, each 2.5 m point was interpolated using a linear approximation. The first calculated time was at 2.5 m. The two athletes performed one 100 m run each. Using the proposed GNSS system, 40 times were calculated for each runner, and afterwards 39 section times were derived, each covering 2.5 m. In addition, five times were measured with the photocells and, from these, five section times were calculated. For validation purposes, the differences in time measured with GNSS and photocells were evaluated for the last four sections. To continue, using GNSS data absolute velocities were defined every 0.25 m with an emphasis on 2.5 m and compared to average velocities that were derived from 20-m section times measured from photocells.

Statistics

Where appropriate, the data were presented as the mean and standard deviation (s). Scatter and line plots were used to present section times and absolute velocities. All calculations and plots were programmed in Matlab R2007a.

RESULTS

The mean differences in time between the GNSS and the photocell measurements over the last four 20-m sections were 0.0021 s ($s = 0.0051$) at a mean sprint velocity of 7.46 m · s^{-1} ($s = 0.32$), derived from 20-m sections. The mean time calculated for the last four 20-m sections for the two runners was 2.69 s ($s = 0.12$).

The scatter and the overlaid line plot in Figure 2 show the section times for 100 m runs measured with the GNSS and the photocell measurement systems. The resulting diagram is divided into three different phases: 1) an acceleration phase, with rapidly decreasing section times; 2) a middle phase with relatively constant section times; and 3) a deceleration phase with increasing section times. The results show that Runner B was faster over all sections and that the differences in the runners' section times increased from the start to the end of the 100 m run. The larger number of section times derived from the GNSS compared to the photocell set-up (39 vs. 5) provided more detailed and different information. For example, the shortest section times measured with the GNSS system were in the sections between 37.5 and 40 m, and 82.5 and 85 m for runners A and B, respectively. However, when the section times from the photocell measurements were analysed, the shortest time was between 40 and 60 m for Runner A and between 60 and 80 m for Runner B. Further, the photocell times show that Runner B was accelerating up to the region between 40 and 60 m with no possibility of providing a more detailed point. In contrast, the more detailed GNSS demonstrates that Runner B only accelerated up to 40 m, after which the runner's speed was relatively constant for ~10 m (4 sections) and thereafter started to decrease. At the end of the run, the section times taken from the photocells for Runner B only show a small increase, whereas the section times measured by the GNSS system increased considerably.

Similar to the times of the segments, the absolute velocities of the race were presented with the "line and overlaid scatter plot" and with three identical segments (see Figure 3). Changing the velocity from time- to space-related enabled a direct comparison of the runners according to their positions. Velocities acquired with the use of GNSS measurements represent instantaneous velocity at every part of the track. The curve of absolute velocities in relation to space showed the acceleration of both athletes in the first phase ("acceleration phase"), with clearly visible areas of first-foot take-off, changing of legs and the second-foot take-off. In the first strides, up to the 7.5 m mark, no significant differences in velocities were noticed between the athletes. From that point onwards, the difference in the absolute velocity of the runners increased and remained unchanged between the 17.5 and 47.5 m marks (0.2–0.3 m/s). Further, the velocity curves for both runners have oscillations corresponding to inter-stride velocity changes. With Runner B, the oscillation of velocity during strides in the "middle phase" was higher than with Runner A. This difference was particularly noticeable in the "deceleration phase" as the oscillation in the velocity

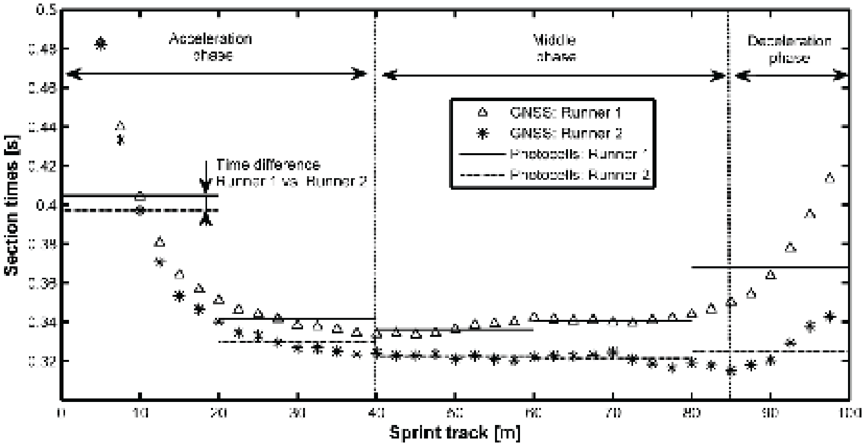

Figure 2: Section times (y axis) measured every 2.5 m on the sprint track (x axis) with the GNSS RTK system and every 20 m with photocells on a 100 m track for two different runners. Note that the times measured by the photocells were divided by the ratio of the photocells and the GNSS RTK interval length to allow an easier comparison and now show the average times as they would be for 2.5 m intervals.

of Runner B increased in comparison to the previous phase, whereas with Runner A it decreased. In addition to velocities for every 0.25 m, Figure 3 also clearly shows instantaneous velocities for every 2.5 m; the velocities varied between maximum and minimum values. Similarly to the time values (Fig. 2), also in this parameter (Fig. 3) the higher density of data (GNSS) in relation to the lower density (photocell) provides different results for the areas of acceleration, deceleration, maximums, minimums etc.

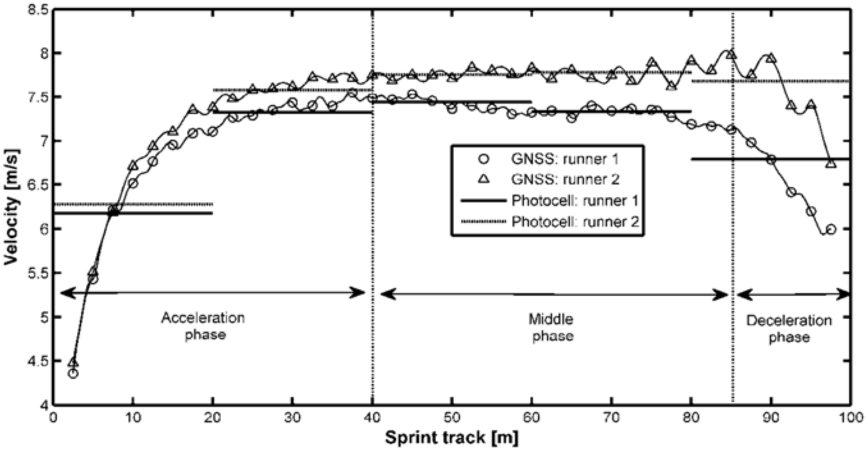

Figure 3: Velocities (y axis) derived every 0.25 m on the sprint track (x axis) with the GNSS RTK system and every 20 m with photocells on a 100 m track for two different runners. Note: triangles and circles for GNSS-measured velocities are drawn every 2.5 m in order to emphasise the instantaneous velocity in the GNSS time segments.

DISCUSSION

The main findings in this study are: 1) a new method of measuring time segments in a 100 m sprint with the use of Global Navigation Satellite System measurements has been developed, providing relatively small differences in measured time in comparison to the photocell method 0.0021 s (s = 0.0051); 2) the new method of measuring time enabled a precise direct location comparison between the runners; and 3) the additional times and velocities in sprint running using the new method provide "hidden" data along the run, which can help experts or scientists analyse performances.

The time computation method provided times from GNSS RTK surveyed trajectories in all required sections (reference planes) in the study. Further, the time differences between the photocells and GNSS derived times were small. These confirm the method's robustness to small position errors of GNSS measurements as present in the current study. Thirty-nine sections from the GNSS show comparable and reliable results, even though the sections are only 2.5 m long and shorter in the constant velocity phase than one-third of a second. In addition to the five section times and five average section velocities from the photocells, these results reveal many hidden details in performance and inter-stride velocity changes. Although the photocells allowed the setting of several split times, they did not provide measurements of instantaneous velocity the way GNSS could, but mere average velocities of intervals. Moreover, it could be argued that the athletes' posture when breaking the beam of the photocells plays an important role (Fig. 1). Different parts of the body can break the beam at different times, which is a disadvantage of photocells and the reason more sophisticated and more expensive double photocells are often used, which start/stop the time only when beams from both of them are broken. Regardless of the fact that in most competitions the time is measured with photocells, an athlete's performance is more accurately estimated by their centre of mass. Therefore, it might be speculated that the GNSS system with an antenna attached to the upper thoracic spine (T2-T4) representing the athlete's trajectory of movement passing reference planes more accurately reflects the performance than the coincidence of a body part breaking the photocell beam.

Can time computation based on RTK GNSS also be used in other sports?It provides reliable and accurate data; therefore, it can be used for scientific purposes and training at a high performance level in sports with strong technical demands, which has the benefit of providing detailed information in order to improve performance. It enables as many section times as needed with no additional costs; they can be even shifted or added after the measurements. Bearing our results from sprinting in mind, all these sections or combinations of sections may enable new important correlations between performance and physical abilities, as often studied in 100 m sprints (Cronin & Hansen, 2005; Young, 1995; Bret, Rahmani, Dofour, Mesonnier, & Lacour, 2002). However, three major shortcomings have been identified: 1) the high price compared to the photocell method when only split times are required; 2) it is relatively bulky and heavy to wear even though the athletes did not complain about this; and 3) consequently it is impossible to use it during competitions. It still represents a very good alternative to conventional photocell timing, especially for larger amounts of intermediate times. It can be expected that future progress will minimise these shortcomings.

The same computation method as presented in the current study may also be used in combination with other measuring technology, such as a local positioning system, laser guns, three-dimensional kinematics or other sensor-based systems that capture full body motion movement. What is important is that they provide adequate accuracy of the representative trajectory in comparison to the desired time resolution. However, in the case of larger measuring errors, filter methods can be used to avoid computation problems of passing the same reference plane more than once, but this does not necessarily mean that the time accuracy will be improved. Further, using a low cost GPS that only has good relative accuracy, which is appropriate for velocity measurements, the whole trajectory or some points may only be shifted according to reference positions; this could lead to large systematic errors in time measurements.

CONCLUSION

The method of computation time using a high-end GNSS RTK surveyed trajectory provides reliable and accurate results for measurements in sprint running. From the usage point of view, it represents a good alternative to the established photocell measurement, especially for a highly detailed or scientific analysis. In addition, due to changes in the body posture during performance it might be even more accurate than standard and established photocells.

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