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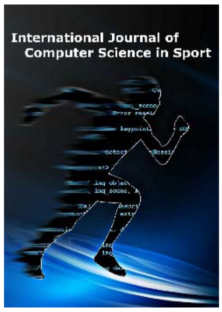

The Accuracy and Reliability of a New Optical Player Tracking System for Measuring Displacement of Soccer Players

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Abstract

Recently, a novel optical player tracking system has been developed to determine positional information of athletes in a non-invasive manner. The aim of this study was to measure the accuracy and reliability of displacement estimates derived from the system. Participants completed five soccer-specific running courses at three different speeds three times each, while being filmed using the multi-camera system. The participant's *x*,*y* field positions were determined by the optical player tracking system and displacement was estimated using Euclidean distance, and compared with real distance. On average, the difference between actual distance and estimated displacement was 0.25% (mean absolute difference = 0.79 ± 0.56m) with a slightly larger coefficient of variation during 90° turns (4.89%) when compared with straight line running (4.09%). In addition, there were strong correlations between actual distance and measured displacement (r = 0.986 – 0.988). Collectively, the typical error (0.25 – 0.36 m), typical error as a coefficient of variation (1.06 – 1.75%) and intraclass correlation coefficient (0.88 – 0.93) showed high levels of intra-operator reliability. The optical player tracking system provides accurate and reliable estimates of displacement of players on a soccer field. This system provides non-invasive position detections for players and opposition players during soccer matches.

KEYWORDS: MOTION ANALYSIS, FOOTBALL, MATCH ANALYSIS, PERFORMANCE ANALYSIS

Introduction

Monitoring the physical performance of players in training and matches has become commonplace in elite soccer to assist with optimal physical preparation. Vision-based tracking technology, as well as global (GPS) and local (LPM) positioning systems, are routinely used to quantify the movement demands of both matches and training. Vision tracking systems involve the installation of multiple cameras around the playing stadium in such a way that when all camera views are combined they provide coverage of the entire playing field (Di Salvo, Collins, McNeill, and Cardinale, 2006). Automated tracking of player coordinates and trajectories are derived using proprietary software, followed by a quality control process by an experienced operator. STATS SportVU^{TM} (STATS, Chicago, USA), is an optical tracking system that is currently used by a number of professional soccer teams. The system has reported deviations from the criterion measure of -0.57% for total distance, -11.35% for high-speed running (20 to 25km/h) and -14.31% for very high-speed running (>25km/h) (Linke and Lames, 2017).

Global position systems are an alternate method for quantifying the physical performance of soccer players, utilising a network of earth-orbiting satellites that transmit signals to a receiver worn by a player. An estimate of the ground location can be calculated using the differential of multiple satellite transmissions (MacLeod, Morris, Nevill, and Sunderland, 2009). Global positioning devices sampling at 10Hz are a valid measure of instantaneous and constant velocity, however the level of accuracy tends to decline with an increase in running velocity (CV = 1.9 – 6.0 %) (Varley, Fairweather, and Aughey, 2012). Similar to GPS, local positioning systems require players to wear a device, however electromagnetic waves travel from the device to local static base stations. The position of the player is determined by calculating the time-of-flight (TOF) and time difference of arrival (TDOA) of the electromagnetic waves travelling from the transmitting device to the base stations (Stelzer, Pourvoyeur and Fischer, 2004). On average, the absolute error for an LPM system (Ogris, Leser, Horsak, Kornfeind, Heller and Baca, 2012) to detect player positions was shown to be 23.4 ± 20.7 cm, resulting in an estimated error for aggregate distance measurements of 5%. In addition, the Inmotio LPM system (Inmotio Object Tracking BV, Amsterdam, The Netherlands) has been shown to underestimate distance measurements by less than 1.6% on average (Frencken, Lemmink and Delleman, 2010). A similar wave-based LPM system (Ubisense, Cambridge, UK) was reported to underestimate distance by 3.45% on average, when assessed using a basketball specific running protocol (Leser, Schleindlhuber, Lyons and Baca, 2014).

Global and local positioning devices are commonly worn during training sessions of elite level soccer teams, however they were not permitted in official Fédération Internationale de Football Association (FIFA) matches until recently and cannot be used to investigate indoor training sessions. Therefore, data obtained from GPS devices have often been limited to friendly matches. Despite providing valuable physiological information to teams and researchers, vision-based systems have traditionally only been available to professional male teams (and only a small proportion of elite female teams). Accordingly, the physical characteristics of elite female soccer matches have yet to be thoroughly examined, with previous research using laborious manual tracking methods (Andersson, Randers, Heiner-Moller, Krustrup, & Mohr, 2010; Gabbett & Mulvey, 2008; Mohr, Krustrup, Andersson, Kirkendal, & Bangsbo, 2008). These tracking methods have typically required an observer to manually record the time that individual players spend in different movement activities (e.g. walking, jogging, running) and distance covered was estimated as the product of time and a pre-determined speed for each activity.

Recently, a vision-based tracking system has been developed (VisionKit, Australian Institute of Sport, Canberra, Australia) to track the movements of individual and team sport athletes. This development has provided the opportunity for previously underreported information to be acquired during competitive matches. The optical player tracking system samples noisy detections at 25 frames per second. Individual detections are aggregated into temporal sequences using the low and medium level hierarchical association methods described by Liu, Carr, Collins, and Liu (2013). This method generated short-term tracklets (the path of individual players over consecutive one-second epochs). A piece-wise cubic polynomial was fitted to the continuous player tracking using the midpoint for each one-second epoch. Coordinates (x,y) for players can then be estimated by solving the cubic polynomial at any time point. This method provides a compact representation of the large-scale tracking data, and also offers a smoothing function for noisy data. This system has been used previously to discover adversarial group behaviour in field hockey (Lucey, Bialkowski, Carr, Morgan, Matthews, and Sheikh, 2013), as well as to quantify the physical demands of elite female soccer players (Mara, Thompson, Pumpa, and Morgan, 2017a; Mara, Thompson, Pumpa, and Morgan, 2017b). However, this is the first study to assess the accuracy of this system for tracking players on a soccer field.

The aim of this study was to measure the accuracy of displacement estimates derived from the Optical Player Tracking System for players on a soccer field. A secondary aim of the study was to assess the reliability of the manual quality control process of the optical player tracking system.

Methods

Participants

One male (age: 23y; mass: 80kg; height: 180cm) and two females (mean age: 25y, mean mass: 65kg; mean height: 164cm) volunteered to participate in this study. The number of participants used is in line with previous studies that have validated GPS (Varley, Fairweather and Aughey, 2012) and LPM (Frencken, Lemmink and Delleman, 2010) systems. Participants were regularly involved in competitive sport and free of injury. Institutional ethical committee approval was granted and all participants were informed of the procedures by verbal and written communication before informed consent forms were signed.

Soccer-specific running protocol

The running protocol (figure 1) was designed based on common directional changes (Bloomfield, Polman, and O'Donoghue, 2007) and sprint lengths (Vescovi, 2012) in soccer and was similar to that which has been used previously to validate LPM (Frencken, Lemmink, and Delleman, 2010) and vision-based tracking (Di Salvo, Collins, McNeill, and Cardinale, 2006; Redwood-Brown, Cranton and Sunderland, 2012) systems. The distance of each running course was determined using a measuring tape. Running times were acquired by timing gates (Smartspeed, Fusion Sport, Cardiff, UK). The timing gates for each course were positioned at different locations on the soccer field (figure 2). Participants completed three trials of each running course at three varying self-paced speeds (jog, stride, sprint), providing 27 data points for each of the five running courses and resulting in 135 data points in total.

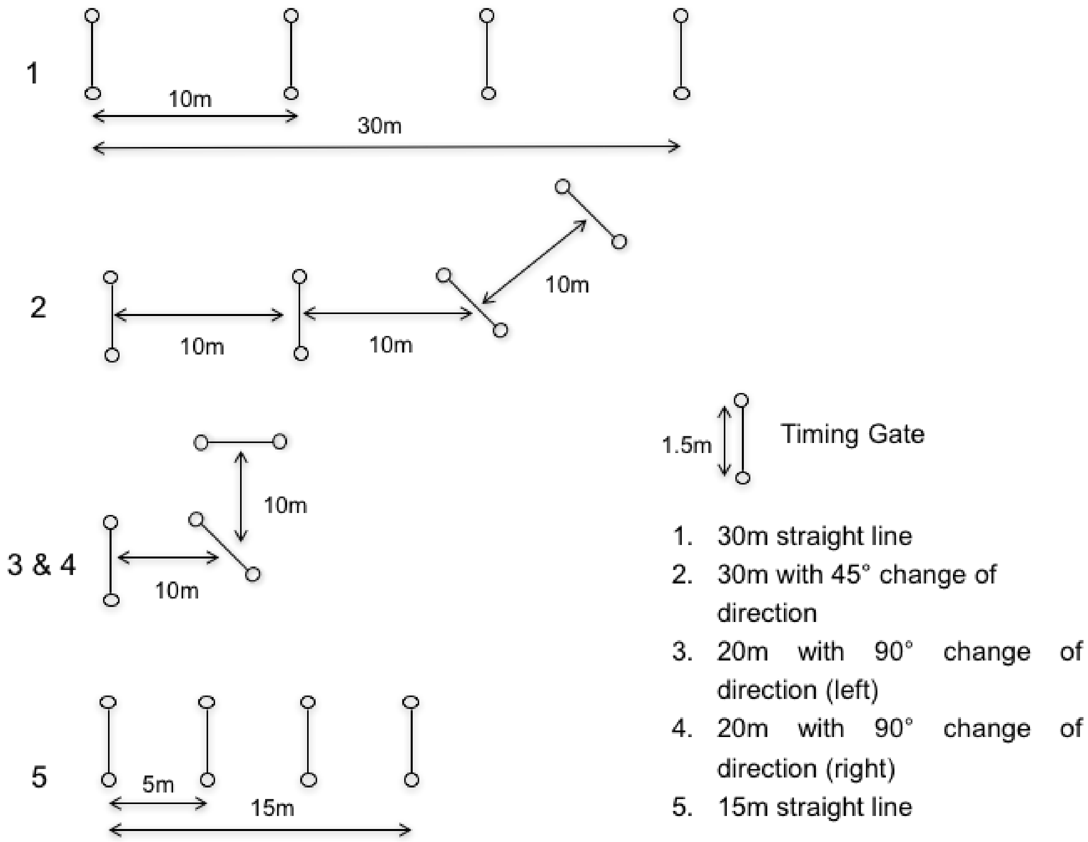

Figure 1. Schematic diagram of the soccer-specific running protocol

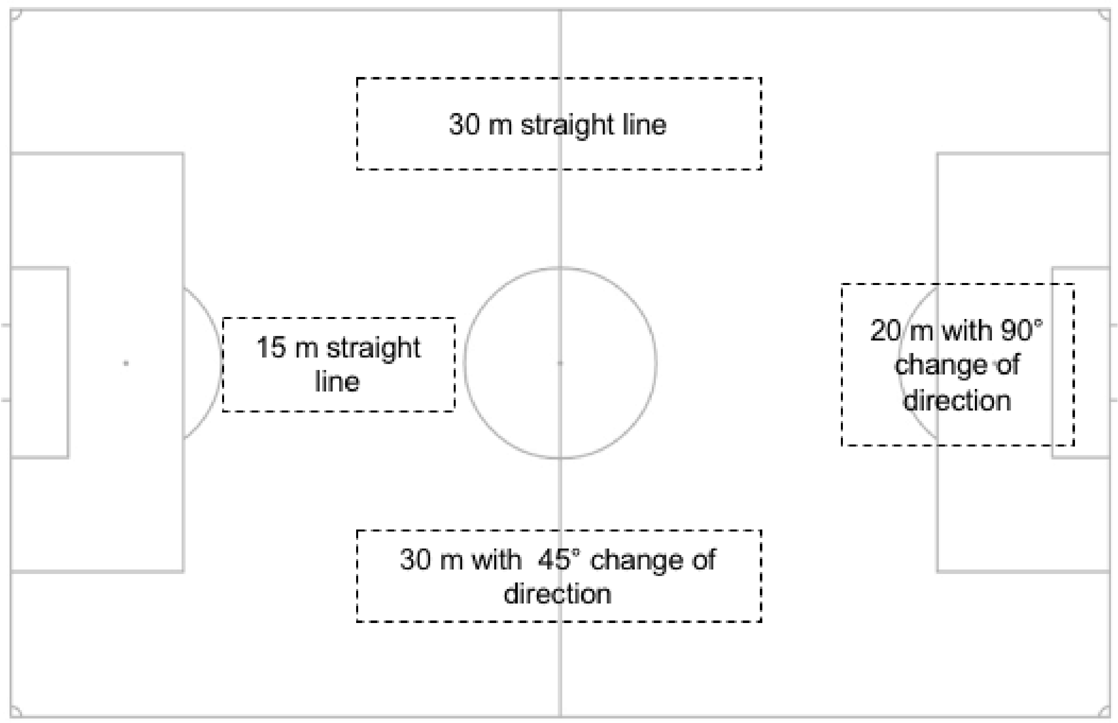

Figure 2. The placement of each running course on the soccer field.

Optical Player Tracking System

Participants were recorded using eight stationary high-definition video cameras (Legria HF R38, Canon, Tokyo, Japan) at vantage points that collectively covered the entire 105m x 68m playing area. Two video cameras were positioned 10m behind each corner of the soccer field at a height of 20m, which allowed for uninterrupted and unobscured vision of the area for the duration of the running protocol. Following the running protocol, the video footage was imported onto a desktop computer (Apple iMac, California, USA) and split into separate video files for each individual trial. The start and end point of the video files were chosen as the frame at which the timing gate light was observed to have extinguished, indicating that the participant had crossed the gate. The video files were imported into the tracking software (VisionKit, Australian Institute of Sport, Canberra, Australia) and each camera's video image was calibrated to the markings of the soccer field so that a pixel represented a known unit of measurement. A state-of-the-art optical player detector (Carr, Sheikh, and Matthews, 2012) generated a set of player detection observations where each observation consisted of an x, y ground location and a timestamp t. Following the automatic tracking process, an operator manually verified that the trajectories identified for each participant remained constant to that participant to ensure quality control. This process involved the operator observing the video and confirming the tracklets remained positioned at the feet of the moving player. To determine operator reliability, each video underwent the manual quality control process twice.

Data Treatment for Determining Displacement

The x,y coordinates of the participants for each frame of video were exported as text files before being imported into Excel spreadsheet software (Microsoft, Redmond, USA) for data treatment. The displacement covered by each participant per frame $\delta(n)$ was calculated using Euclidean distance:

$$\delta(n) = \sqrt{[x(n) - x(n-1)]^2 + [y(n) - y(n-1)]^2} \quad (1)$$

where:

$x(n) – x(n – 1)$ = change in x position between frame n and frame n – 1

$y(n) – y(n – 1)$ = change in y position between frame n and frame n – 1

The displacement covered per frame was then summed to determine total distance.

Statistical Analysis

Statistical analysis was conducted using SPSS version 21.0 (SPSS Inc, Chicago, IL) and Microsoft Excel spreadsheet software (Microsoft, Redmond, USA). Descriptive statistics of the difference between actual distance and displacement measured by the Optical Player Tracking System (mean ± SD, range, % difference and 95% confidence intervals) were calculated. Further, regression analysis determined the relationship between actual distance and measured displacement. Data were checked for heteroscedasticity by plotting the absolute difference against the mean and computing a correlation (Atkinson and Nevill, 1998). To determine the reliability of the manual quality control process, absolute and relative (%) differences in displacement between the two measurements taken by the operator were determined. Typical error, total error, intraclass correlation coefficient (ICC) and typical error expressed as a coefficient of variation were calculated (Hopkins, 2000; Hopkins, Marshall, Batterham, and Hanin, 2009). A confidence interval of 95% was used for all statistical analyses.

Results

Table 1. The difference between the distance measured by the optical player tracking system and actual distance.

Course	Difference (optical player tracking system minus actual distance)				SD as CV%
	Mean ± SD (m)	Range (min-max) (m)	% of actual distance	95% CI (m)	
30m Straight					
Overall	-0.31 ± 1.02	-1.84 – 1.82	-1.03	-0.69 – 0.07	3.43
Jogging	-0.59 ± 1.25	-2.16 – 1.82	-1.97	-1.41 – 0.23	4.27
Striding	-0.48 ± 0.61	-1.18 – 0.45	-1.61	-0.08 – -0.88	2.05
Sprinting	0.03 ± 1.24	-1.72 – 1.70	0.09	-0.78 – 0.84	4.11
30m 45° Turn					
Overall	-0.46 ± 0.89	-1.85 – 1.19	-1.53	-0.79 – -0.12	3.01
Jogging	-0.79 ± 0.74	-1.62 – 0.61	-2.62	-1.27 – -0.30	2.54
Striding	0.12 ± 0.65	-0.92 – 0.92	-0.40	-0.54 – 0.30	2.17
Sprinting	-0.47 ± 1.16	-1.85 – 1.19	-1.57	-1.23 – 0.29	3.94
20m 90° Right Turn					
Overall	0.16 ± 0.99	-1.57 – 2.41	0.82	-0.21 – 0.54	4.93
Jogging	0.52 ± 1.04	-1.21 – 2.04	2.58	-0.17 – 1.19	5.09
Striding	-0.11 ± 1.21	-1.57 – 2.41	-0.56	-0.90 – 0.68	6.08
Sprinting	0.09 ± 0.65	-1.01 – 1.14	0.43	-0.34 – 0.51	3.23
20m 90° Left Turn					
Overall	0.48 ± 0.99	-1.52 - 2.24	2.37	0.09 – 0.85	4.86
Jogging	0.01 ± 0.87	-1.52- 1.06	0.02	-0.56 – 0.57	4.34
Striding	1.04 ± 0.81	0.07 - 2.24	5.22	0.52 – 1.57	3.84
Sprinting	0.37 ± 1.09	-1.06 - 1.92	1.86	-0.34 – 1.08	5.34
15m Straight Line					
Overall	0.09 ± 0.71	-0.90 – 1.84	0.60	-0.18 – 0.36	4.73
Jogging	0.02 ± 0.71	-0.68 – 1.22	0.11	-0.45 – 0.48	4.75
Striding	0.25 ± 0.74	-0.61 – 1.80	1.64	-0.24 – 0.73	4.88
Sprinting	0.01 ± 0.74	-0.90 – 1.21	0.06	-0.48 – 0.49	4.94

On average, the Optical Player Tracking System overestimated displacement by 0.25% (Table 1). The absolute mean difference for the estimates derived from the Optical Player Tracking system when compared with actual distance for all running courses was 3.59% (0.79 ± 0.56m). The standard deviation of displacement measurements was greatest during sprinting trials (CV% = 4.31) when compared with striding (CV% = 3.80) and jogging trials (CV% = 4.19). A larger standard deviation was also observed with a greater turning angle (90° CV% = 4.89) when compared with straight line running (CV% = 4.08). Linear regression showed a strong correlation between displacement estimated from the Optical Player Tracking System and actual distance for jogging (n = 45, r = 0.987, p < 0.001), striding (n = 45, r = 0.988, p < 0.001) and sprinting (n = 45, r = 0.986, p < 0.001) trials. The data did not exhibit heteroscedasticity. Further analysis revealed high levels of reliability for the manual quality control process for all running courses (Table 2). Typical error was greatest during courses with a larger turning angle (90° TEM% = 1.74) when compared with straight line running trials (TEM% = 1.44).

Table 2. Reliability measures of the manual quality control process for each running course.

Course	Typical Error (m)	Total Error (m)	ICC	Typical Error as CV%
30m Straight	0.36	0.76	0.91	1.21
30m 45° Turn	0.31	0.67	0.93	1.06
20m 90° Right Turn	0.35	0.75	0.88	1.75
20m 90° Left Turn	0.35	0.75	0.89	1.73
15m Straight	0.25	0.53	0.89	1.67

Discussion

The aim of this study was to measure the accuracy and reliability of displacement estimates derived from an Optical Player Tracking system while participants completed a soccer specific movement protocol. The key findings were 1) the mean difference between estimated displacement and actual distance was -0.25% 2) the coefficient of variation was larger with a greater running speed and turning angle; 3) the manual quality control process showed high levels of reliability.

On average, the optical player tracking system overestimated displacement by only 0.25% for all courses and running speeds, which is comparable to STATS SportVU^{TM} (-0.57%) and the Inmotio LPM system (< -1.6%) (Frencken, Lemmink and Delleman, 2010), and is less than the reported difference of a 10Hz GPS device (SPI-10, GPSports) (4.5% on average) (Coutts and Duffield, 2010; Edgecomb and Norton, 2006). The absolute mean difference was found to be 3.59%, which corresponded to a mean absolute difference of 0.79 ± 0.56m from the criterion. In addition, very high correlations (r = 0.986 – 0.988) were observed between displacement estimates and actual distance for jogging, striding and sprinting trials. The standard deviation expressed as a coefficient of variation increased with a greater running speed (sprinting compared to jogging), and turning angle (90° turn compared to straight line running). This finding is similar to observations made for LPM-systems (Frencken, Lemmink, and Delleman, 2010) and it can be suggested that this may be partly attributed to the running course design. Participants were instructed to follow the running course as closely as possible, however at higher running speeds and turning angles the corner may be cut or over-run because of an abrupt change of direction. The soccer-specific running protocol was based on courses used in studies that have previously validated vision-based tracking (Di Salvo, Collins, McNeill, Cardinale, 2006) and LPM systems (Frencken, Lemmink, and Delleman, 2010) however future research may need to consider running courses that ensure participants do not deviate from the marked track for maximal accuracy of the criterion measure. Regardless, the coefficient of variation was well below 5% on average and collectively these results show that the optical player tracking system accurately estimates displacement on a soccer field.

The intraclass correlation coefficient values were similar for all running courses (ICC = 0.88 – 0.93) and showed high agreement between measures. The typical error expressed as a coefficient of variation was slightly greater for the 90° turns when compared with straight line running, however on average the typical error was only 1.48%. In addition, this value is smaller than the reported coefficient of variation for intra-model reliability of GPS (5.5% on average) (Coutts and Duffield, 2010; Edgecomb and Norton, 2006). Collectively, data showed high levels of intra-operator reliability and therefore the human error associated with the manual quality control process is minimal.

The optical player tracking system described in this study has been used previously to discover adversarial group behaviour in field hockey (Lucey, Bialkowski, Carr, Morgan, Matthews, and Sheikh, 2013). This previous research described the ability of the system to track all twenty hockey players on the field simultanesouly, with manual input of an operator particularly during moments of occlusion. The present study only assessed the system's ability to measure the distance covered in single runs for one player at a time. Future research should aim to address the validity and reliability of displacement measurements in soccer match-specific scenarios with multiple players (e.g. small sided games and corner kicks) to enhance the ecological validity of the study design (Leser and Roemer, 2014). It should also be noted that each of the running courses were positioned in different locations on the soccer field. This was to ensure the study design encompassed as much of the field as possible. However, this study did not measure the accuracy of position detections in the centre of the field compared to the peripheral and should be considered for future research designs.

The current study used the total distance of individual running courses as the criterion measurement to compare against the aggregated distance as measured by the system. Therefore, actual position data (x,y coordinates) of the participants were not collected. Future validation methods should consider using a gold-standard tracking system (e.g. 3D infrared systems such as VICON) to collect actual x,y coordinates as the criterion measurement to compare against the x,y coordinates of the optical player tracking system (Leser and Roemer, 2014). The present study determined the accuracy and reliability of displacement estimates derived from the optical player tracking system. Velocity and acceleration measures were not assessed, as an accurate estimation of displacement subsequently results in an accurate estimation of velocity and acceleration using the algorithms described by Osgnach, Poser, Bernardini, Rinaldo, and di Prampero (2010).

Conclusions

The results of this study show that the optical player tracking system offers an accurate and reliable method for determining displacement of players on a soccer field. Information related to activity profiles of soccer matches (particularly female soccer) are scarce due to tracking devices not being permitted in competitive matches until recently. The non-invasive nature of this player tracking system offers an advantage over tracking devices as physical and tactical information of opposition teams can also be collected. In addition, this system allows data to be collected in indoor environments, offering an advantage over global positioning systems.

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