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Dynamic tracking of a 2.4GHz waist mounted beacon for indoor basketball player positioning

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Abstract

Wireless player tracking is being considered for use within indoor team sports for coaching assistance. Few research studies exist into wireless RF signal tracking of players in indoor team sports, in particular the game of basketball. Utilising the RF signal trilateration positioning technique with three anchor nodes per quarter court, players wearing RF beacons could be tracked and their positional data recorded in real time. This study builds on a previous study conducted under static conditions by Kirkup et al. (2013). Identifying the player with the ball is also important in recording and assessing team strategies. Accelerometer sensors located on the body have been widely used to monitor the movements of the body and can potentially be used to recognize when a player is bouncing the basketball (dribbling). This paper reports the findings of using the received signal strength positioning technique with one anchor node to estimate the position of a moving basketball player towards the node and the use of a wearable triaxial accelerometer sensor to identify the person bouncing the ball. Both slow and fast game pace conditions are tested. Player position accuracy can be achieved to within 0.5m for distances less than 9m. A study of the power law variation in signal strength over distance gives an exponent n of 2.23 under moderate paced conditions with a Pearson squared correlation coefficients of r^2 = 0.42. This means that 42% of the variation can be explained by the approximation. Under moving conditions, changes in the transmit antenna orientation will result in an increase of random variation in position prediction which is included in this result. The acceleration signature from a wrist sensor of the hand-ball contact process while dribbling distinctively shows ball dribbling possession. A single moving player scenario is discussed and measured results with and without the basketball demonstrate the accuracy and feasibility of the positioning and ball possession techniques. The techniques will provide valuable information for further study into multiple player and multiple beacon wireless indoor positioning.

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Keywords: Basketball; Indoor Propagation; Indoor Sports Science; Sensors; Indoor Tracking; Positioning; Team Sports

1. Introduction

Object tracking within typical indoor environments containing static infrastructure objects has been widely researched and published in the last decade resulting in a variety of positioning techniques. Recent surveys by Hui et al. (2007), Yanying et al. (2009) & Abdat et al. (2010) highlight this fact and today there are over a dozen wireless positioning techniques suggested for use (IPIN 2012). In this study the wireless radio frequency (RF) signal propagation (RSS technique) from a body-mounted 2.4GHz beacon and the information from body mounted accelerometer sensors were investigated to confirm the feasibility of dynamically tracking a single basketball player and ball possession on an indoor basketball court. It was reported previously by Kirkup et al.

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(2013) that for an indoor basketball court under static conditions, for distances less than 10m, there is very little interference from the ground reflection or other multipath signals. DiStasi et al. (2008) determined that 2.4GHz signal variations up to 5dB are typical for distances less than 10 m under these Ricean type conditions. The relationship between received power and distance is considered for use as a technique for determining the position of the player. Apparent frequency variations (Doppler Shift) due to a player's movement was considered and found to be negligible.

Possession of the basketball by a player is also valuable information for coaches and trainers. Previous research into the tracking of a ball in sport has been based on using video analysis or through the use of wireless sensors/beacons placed within the ball. As an alternative, the use of accelerometer sensors is being considered so that international rules of the game are not violated. Accelerometer sensors have been used to monitor the movements of the body as previously reported by Neville et al. (2011) but have not been considered for ball possession. These sensors can potentially be used to recognize when a player is bouncing the basketball (dribbling), thereby indicating one form of ball possession.

2. Method

2.1. Single player tracking

The testing environment used for this study was an indoor basketball court (play area) constructed to international standards as outlined by the Federation Internationale de Basketball (2012), with the court floor consisting of polished thin planks of hardwood. One quarter of the court was used in the study representing the other three quarters of the play area. As only the play around the basketball key (the area surrounding the basket) is of interest in this study the center of the court around the center circle was removed from consideration. The transmitting beacon as outlined by James, D. A., Leadbetter, R. I., et al. (2011), was located on the body directly under the front of the chest using a custom built elastic fabric strap. The beacon was configured to transmit a continuous carrier wave signal at approximately 2.4 GHz with 0 dBm power level. The beacon signal was received by a hand-held spectrum analyzer mounted at the bottom of a purpose built wooden test rig (Fig. 1a) and connected to a laptop. The receive antenna is a vertically polarized directional patch antenna with approximately 9 dBi gain at 2.4 GHz. The transmit antenna used by the beacon is a grounded quarter wave monopole meander antenna printed on FR4 type circuit board.

In the first experiment, the transmit and receive antenna heights were set to 1.45 m above the court surface, representing the height under the chest of an elite basketball player. A series of straight paths traversing a quarter of the court floor (Fig. 1b) was chosen for moderately paced dynamic tests. The test paths were divided up into 1m distance makings from the starting point using tape on the floor which were clearly visible by a single video camera. Wearing the beacon under the chest, the test subject was asked to move towards the receiving antenna at a moderate pace along the length of each path, sounding out as each distance marker was reached. Slower movements were chosen in this experiment to obtain a more accurate confirmation of the subject's position. Due to the short distance from the video camera to the markers parallax errors were minimized. From the video playback these markers were used to determine the time taken to pass each marker by the subject's feet. The hand-held spectrum analyzer (sampling rate of approximately 100Hz) has the capability to record and log the received power with associated time stamps. Approximate velocities (Table 1) and plots of signal strength vs distance were obtained by correlating the spectrum analyzer time stamps with the video timing and distance markers. Beacon position accuracies recorded through the video camera to within 0.1m are achievable. The accuracy and precision of the player and therefore the beacon was determined by these markings as viewed through the high definition video camera.

2.2. Ball possession

Three wireless sensors (identical to the beacons used in the player tracking experiment) were configured to utilize their in-built triaxial accelerometer sensors to record/log data on a nearby laptop. The three sensors were mounted behind the right wrist, behind the right elbow and directly under the players' chest centered using specially fabricated straps. Before starting the test all sensors were synchronized. The experiment consisted of three tests: a) bouncing the ball while stationary; b) bouncing the ball while moving slowly along the 5 m path; and c) bouncing the ball vigorously along the 5m path.

2.3. Single player tracking and ball possession at fast pace

A third experiment was conducted with a new subject undertaking a predetermined offensive drill (Fig. 2). The equipment used previously was employed. The subject was asked to run to a marker on the court floor then, while moving, catch a basketball thrown to him near that marker and dribble at a fast pace in a straight line path. The path was approximately 9m long with 1m equidistant tape markers on the court floor. This experiment included both arbitrary and fast movements typical in a basketball game. Both signal field strength and acceleration measurements were recorded as in the previous two experiments.

All volunteers in this study were amateur basketball players and were informed of the reasons for the study and signed consent forms to participate in the study. The study was approved by the institution's Ethics Committee (ENG/16/12/HREC).

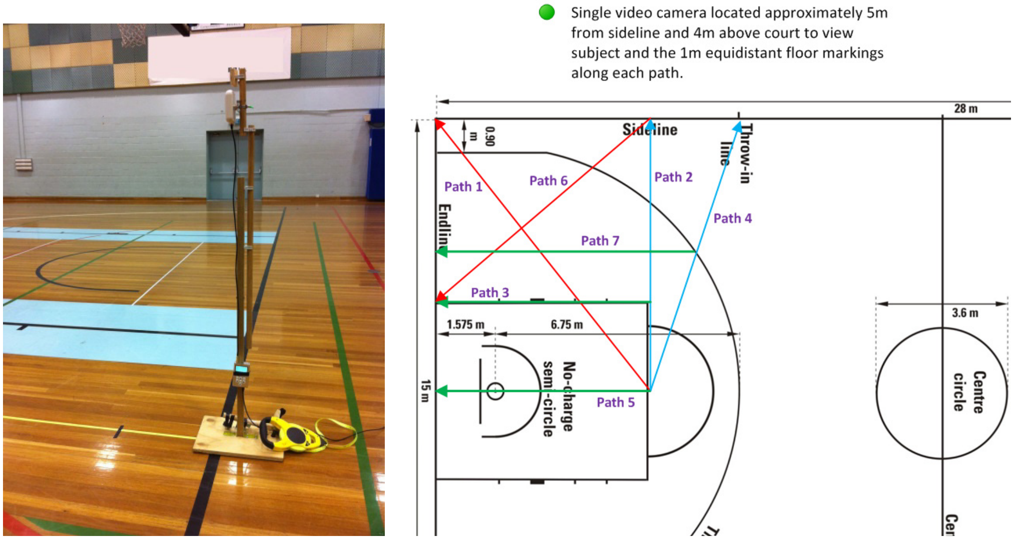

Fig. 1. (a) Receive antenna test rig; (b) Seven measured paths over quarter court (blue, green and red). Each arrow head indicates the position of the receive antenna and direction of travel.

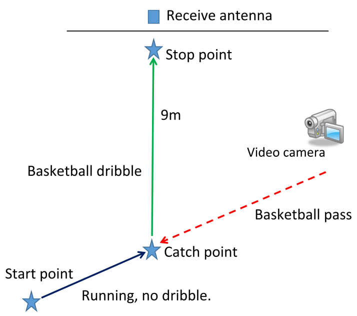

Fig 2. The path of an offensive drill at fast pace.

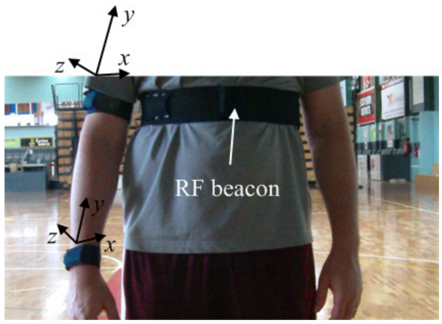

Fig. 3. Accelerometer sensor positions on the player.

3. Experimental Results

3.1. Single player tracking

Recorded signal strength measurements were analyzed using MATLAB® R2013a. Fig. 4 shows comparisons between the various paths of received field strength versus absolute distance over each dynamic path as the player moved towards the receiver. The data was fitted to the power law relation:

$$P(d) = \frac{P_0}{d^n} \qquad (1)$$

where d is the separation distance (m), P_0 the power at 1 m from the transmitter and n the power factor (for free space $n = 2$).

3.2. Ball possession

A straight line linear regression fit using the method of least square errors was applied to all paths separately for the measured values. In this study n = 2.3 (Pearson squared correlation coefficient r^2 = 0.42) which is comparable with a previous study conducted under static conditions. Table 1 shows the variation n and speed of movement for all paths.

Distinctive pattern signatures from the dominant accelerometer Y plane of dribbling a basketball were recorded for a sensor positioned on the wrist for a right-handed subject bouncing the ball with the right hand (Fig. 5). Stationary, slow moving and moderately fast ball dribbling were recorded. The x axis shows a sample of time taken from the path recording at a 100Hz sampling rate. Each major spike shown represents a portion of the ball bounce process. The y axis shows acceleration, selected for the ± 4g m/s^2 range.

Pattern signatures from the dominant accelerometer Y plane were also recorded on a second right-handed subject for three sensors positioned on the wrist, the arm (above the elbow) and immediately below the chest centre respectively (Fig. 6). The chest mounted sensor recording shown in Fig. 6(c) highlights that a noticeable pattern signature is not always distinguishable for the chest sensor position.

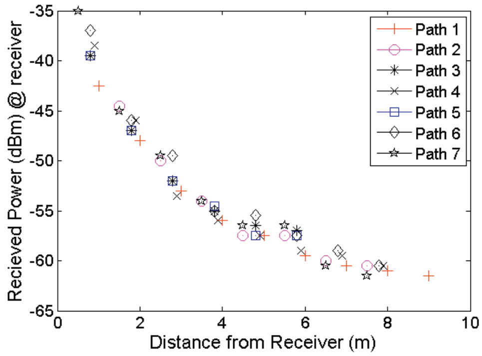

Fig. 4. Field strength vs. absolute distance at a moderate pace.

Table 1. Path loss slope exponents and velocities under dynamic movement.

Path No.	Distance travelled (m)	*n*	Average Velocity (m/S)
1	9-1	-2.09	0.66
2	7.5-1.5	-2.40	0.61
3	5.8-0.8	-2.02	0.49
4	7.9-0.9	-2.44	0.62
5	5.8-0.8	-2.21	0.57
6	7.8-0.8	-2.43	0.59
7	7.5-0.5	-2.41	0.62
All Paths	9-0.5	-2.3	0.60

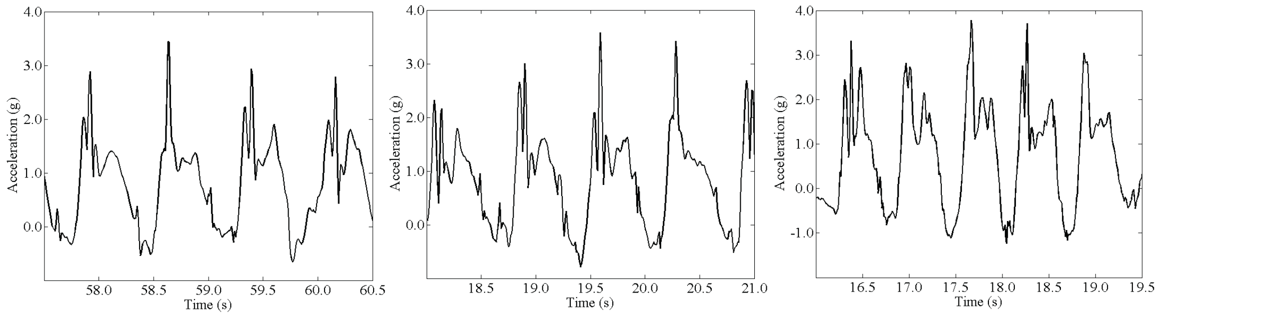

Fig. 5. Right wrist accelerometer patterns of first right-handed subject. (a) stationary ball bouncing; (b) slow moving dribble; (c) moderately fast dribble.

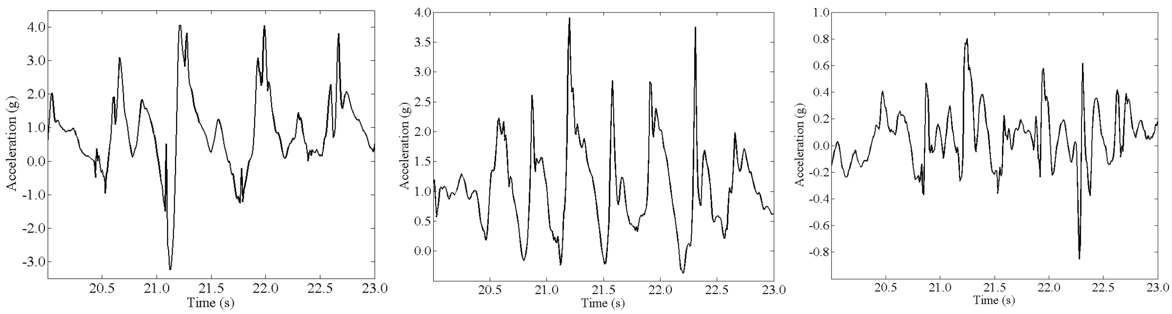

Fig. 6. Moderately fast accelerometer patterns of a second right-handed subject. (a) right wrist; (b) above right elbow; (c) directly under the chest centre. The ball bounce events are evident as large positive spikes from the right wrist and right elbow, but are not clear in the chest located accelerometer.

Measurements were taken using two different player participants in this study who each had a unique bouncing technique. It is expected that a player who has been playing basketball for many years will develop a 'soft touch' approach to bouncing the ball. In this case the ball will leave from the tip of the fingers in most cases as the final extension to the arm, hand and fingers are reached. A player with less experience or a player performing an odd bounce may have more of a 'jerking' or abrupt type bounce, where the full extension may not have been realized. Fig. 5(c) and Fig. 6(a) show that there is some difference between bounce acceleration profiles for the two players. However, further work is needed using a large number of players with various levels of experience and skill so that more definitive ball-carrier identification can be made using the accelerometer records.

3.3. Single player tracking and ball possession at a fast pace

A plot of field strength versus absolute distance under fast pace conditions is shown in Fig. 7. It is clear from this plot that there is sufficient field strength variation to use a RSS based estimation technique for position under dynamic conditions. The plot is similar to the slower movement data obtained (as shown in Fig. 4).

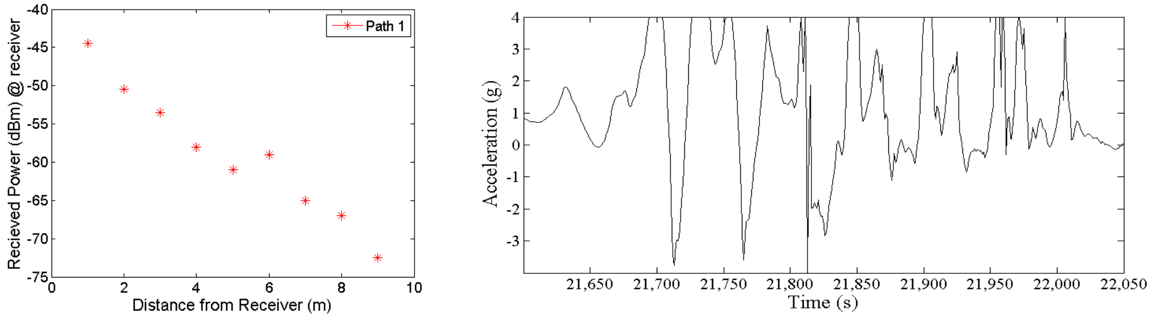

Fig. 7. Analysis of fast paced ball dribble. (a) Field strength vs. absolute distance; (b) Accelerometer pattern of third subject right wrist sensor. The accelerometer sensor was over-range for almost all ball impacts with the hand, but the identification of the bounce is still clearly evident.

Measurements of the accelerometer sensor connected to the wrist from the dominant Y plane under fast paced conditions is shown in Fig. 7b. The results show three dribble durations each consisting of a major spike immediately followed by a much lesser spike. In each signature case the first spike is greater than the second spike and the dip between spikes rarely drops below 0g acceleration. The graph also shows the movement of arms upon commencement of the drill leading up to the catch. An analysis of the pattern is as follows: (a) 21600 (start); (b) 21755 – 21825 (catch point); (c) 21825 – 21875 (1^{st} bounce); (d) 21875 – 21930 (2^{nd} bounce); (e) 21930 – 21980 (3^{rd} bounce); and (f) 22000 (ball hand slap).

4. Discussion and Conclusion

For a single player under dynamic conditions the results for received power versus court distances less than 10m (Fig. 4) highlighted a power distance relationship of a Ricean type environment. There is one dominant direct ray and the effect of multipath signals reflected from the court floor, walls and other persons in the vicinity is relatively small. For distances less than 9 meters, nulls of up to 2.5dB signal variation were observed with the majority of nulls less than 2dB. Although only a small number of distance markers could be used to locate intervals along each path, the large number of power level measurements (> 800) recorded provided results favorable for a received power versus distance position estimation technique. As expected, the distance estimation accuracy significantly improved as the beacon was moved closer to the receiver where the slope in Fig. 4 is greater. For example, at distances up to 2.5m from the receiver it is possible to achieve accuracies of within 0.3 meters. Under fast movement conditions, that would be expected in a game, similar results support the received power versus distance position estimation technique. Compared to a previous study under static conditions by Kirkup et al. (2013) movement and direction of travel will result in some change in transmit antenna orientation. This can lead to an increase in random variation in received field strength and consequently position prediction.

The main set up area for offensive players is either on or outside the basketball key. The distance between the key edge and the sideline is approximately 5m. By employing a combination of quarter-court identification and power/distance estimation methods, it is feasible to produce a player tracking system under single player conditions using three or more anchor nodes.

In any mobile environment consideration is usually given to the Doppler shift effect on the received signal frequency, due to the movement of the transmitter or receiver. However, the maximum velocity likely to be obtained by a player in indoor team sports such as basketball is much less than 10 m/s. These low velocities will have a negligible effect on the received frequency.

The validity of an indoor wireless player positioning system in a dynamic team environment using only one anchor node with a player in line-of-sight has been addressed in this study using one player under moderate and fast paced conditions. Indoor sports that could employ a single player position estimation system include indoor tennis, badminton or volleyball. Future work will assess the effect of multiple players and multiple beacons with multiple anchor nodes. To achieve quarter court coverage using triangulation a minimum of three anchor nodes/receivers will be required per quarter court.

The use of 3-axis accelerometers to indicate a type of ball possession has proven to be feasible when mounting the sensor on the wrist or above the elbow, with the wrist mounting the most predominant results as expected. The results have shown a clear response signature for both subjects including a unique spike level and signal response in the bounce process that can be used to flag when the basketball is being bounced. These acceleration spikes were clearly observed above those created by foot fall (the contact of heel and the ball of the foot on the floor) and other player movements. They were also clearly absent under conditions where the player was not bouncing the ball (Fig. 7b). Unique spikes could not always be easily distinguished in the accelerometer sensor located under the front of the chest and therefore would not be a reliable signature for detection use. This is mainly due to body attenuation of the hand-ball contact signal. Recordings of all the chest responses were therefore not reported.

The comparison of ball dribbling by three different players, Fig. 5 versus Fig. 6(a) versus Fig. 7(b), could not confirm a significant difference in signatures from the accelerometer sensors located on the wrist. However, they did show a variation in acceleration or dribble force exerted by each player. Typically players with more confidence in dribbling can exert a higher down force as shown in Fig. 7b where the acceleration is greater than 4g.

Through post data processing this study has shown that it is possible to identify a unique signature from a triaxial (3 axis) accelerometer sensor mounted on the wrist for use as a ball dribbling possession indicator.

The potential benefits from this study are a low cost and simpler alternative technique for positioning and tracking basketball players and the basketball dribble in their offensive plays around the basketball key within an indoor environment.

There may be scope to investigate body network communications as a solution to include a wrist sensor in the overall player positioning system and further work in accelerometer sensor post data analysis and signature detection are required to implement this solution for ball possession.

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