The Analysis of Basketball Free Throw Trajectory using PSO Algorithm

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Abstract: The following paper described the method for automatic measurement of selected parameters of a basketball free throw trajectory. The research material was based on 10 sequences recorded by a monocular camera. For tracking the ball the particle swarm optimization (PSO) algorithm was used. Additionally the method of ball detection was developed. The study was conducted on a group of 10 basketball players who participated in the Polish Second Division during the 2014/2015 season. The 10 parameters (four distances, three velocities, and three angle parameters) were taken into account. The experimental results showed that the value of the initial angle was equal to 47.27 ± 4.42 degrees, and the height of ball trajectory was at the level of 3.84 ± 0.34 m. The correlation between body height and parameter of a free throw was also determined. The analysis conducted showed a significant correlation between the height and shape of a free throw trajectory. The suggested method can be used in the training process as a tool to improve performance of the free throw.

1 INTRODUCTION

A free throw is the special component of technical preparation of every player, which is based on automation of movement. It is always performed in the same way (correct rhythm and speed). If anyone thinks about winning, effectiveness of free throws should be at a high level. There are a lot of technical aspects of a free throw, but it is generally said that the most important thing is the effectiveness, which equals 90% for the best players.

Free throws could have an important meaning for the final score. Therefore, nobody can disregard this element and its impact for the game. Research conducted in this case concerns many of aspects, but the main purpose is the correction of effectiveness of a free throw. Hamilton and Reinschmidt (Hamilton and Reinschmidt, 1997) analyzed the throw angle, speed of the ball and impact of those components on accuracy. Whereas, Button et al. (Button et al., 2003) have evaluated the posture of the player during a free throw. In other studies (Englert et al., 2015) scientists rated the level of concentration of the player, who is throwing free throws. Gablonsky and Lang (Gablonsky and Lang, 2005) presented a different approach. They elaborated mathematical model of a free throw, which contains an ejection angle and velocity of the ball. These studies have been extended by Murphy (Murphy, 2012). The author focused on finding the best parameters of a free throw. The player's body height, speed and angle of the ball's throw were considered. The conclusion of this research is that the taller players have smaller ejection angle and speed of the ball. A similar problem was presented by Tran and Silverberg (Tran and Silverberg, 2008), who analyzed an ejection angle, speed, rotation and height of the ball's flight. The performed studies show that the effectiveness of the throw is equal to 70%, when the ball leaves the player's hands at an angle of 52°.

The quality of technical elements is based on accuracy and precision of the move. It is really hard to rate because it is only a visual observation. That is why every year we have a lot of new studies containing automatic and half-automatic analyzing players move at sport (Liu et al., 2010; Xu et al., 2001).

Technological progress facilitates observation and evaluation of technical elements. In recent years scientists using multimedia equipment, showed several methods of game analysis in team sports. Noteworthy is the research by Perše et al. (Perše et al., 2009), which provided a system to detect basic technical elements during a basketball game. This system showed trajectory move of the players in defense and offense. Video analysis was also used by Hua-Tsung Chean et al. (Chen et al., 2012), who presented a method based on observation typical moves of individual players.

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The system automatically detects if team play rather defensively of offensively .

The main objective of this study was to develop a method for automatic measurement of selected parameters of a basketball free throw trajectory. The system was based on particle swarm optimization algorithm and utilized video data captured by a monocular camera. The main contribution of this work was to develop the methods of ball tracking and detection. The PSO algorithm has been used to track the ball. For automatic ball detect the circularity factor and the size of segmented objects were taken into account.

Table 1: Description of parameters used in analysis.

Parameter	Description
h_1 [m]	height between ball and basket
h_2 [m]	height of ball parabola
l_1 [m]	distance between 1st and 2nd phase
l_2 [m]	distance between 2nd and 3rd phase
v_1 [m/s]	velocity of ball in 1st phase
v_2 [m/s]	velocity of ball in 2nd phase
v_3 [m/s]	velocity of ball in 3rd phase
α_1 [°]	angle of ball in 1st phase
α_2 [°]	angle of ball in 2nd phase
α_3 [°]	angle of ball in 3rd phase

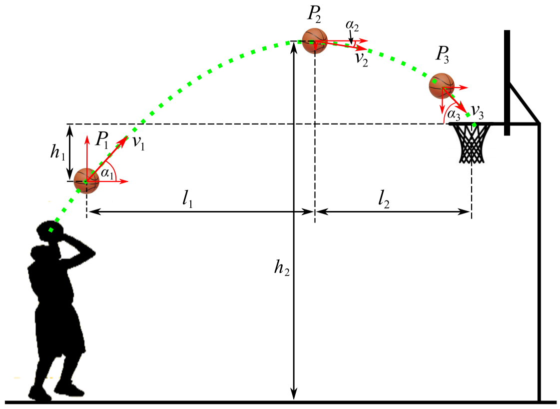

Figure 1: Analyzed parameters of a basket throw.

2 MATERIAL AND METHODS

2.1 Data Collection

The study was conducted on a group of basketball players who participated in the Polish Second Division during the 2014/2015 season. The analysis included 10 males aged 19.4 ± 2.8. Players were described by the parameters: body height 190.9 ± 4.9 cm, body mass 77 ± 8.7 kg, and BMI 21.2 ± 1.9. Throughout the research, the sequence of a free throw in the regulation conditions was captured. In the analysis one of correct shots for each player was used. The sequences were captured by a monocular 100 Hz Basler Ace acA645-100gc camera. The camera was placed 4.6 m from the predicted trajectory of the ball and perpendicularly to it. It should be noted that the ideal perpendicular positioning is very difficult to implement under the experimental conditions. Camera calibration was done on the basis of the distances between the characteristic objects on the scene (the basketball court), such as lines, intersection of lines, basket, etc.

The analysis included 10 parameters in three phases of throw (Figure 1). The measured parameters were: velocities in three phases (v_1, v_2, v_3), angles of the moving ball (α_1, α_2, α_3), height parameters (h_1, h_2) and distance parameters (l_1, l_2). The description of the specified parameters is shown in Table 1.

2.2 Basketball Detection

An important aspect of the proposed method for obtaining a trajectory of basketball free throw is detection of the ball. Ball detection method enables automatic initialization of tracking and it can be used to re-detection in case of a tracking failure. For the extraction of moving objects the background subtraction algorithm (Zivkovic and van der Heijden, 2006) was used. After extraction, for each object, two conditions are checked; if both are true, the object is classified as a ball. The first condition concerns the size of the object and is determined by comparing the radius of enclosing circle of the object with a ball radius. The first condition has the form:

$$|r_o - r_b| < m, \tag{1}$$

where r_o is radius of enclosing circle of the considered object, r_b is radius of the ball and m is margin factor, whose value was set at 22% of r_b. The second condition uses the circularity factor $f_c = \frac{4\pi A}{P^2}$ (Ritter and Cooper, 2009), where A is the area of the object and P is the perimeter of the object. Value of f_c for a perfectly round object is equal to 1. The second condition has the form:

$$T_c < f_c, \tag{2}$$

where T_c is circle threshold equals to 0.78. Values of m and T_c have been determined experimentally. If both conditions are true it means that the object under consideration is a ball and tracking process can be started. Additionally, in order to minimize the risk of false alarms, all the objects before the free-throw line and also below the height of 1.5 meter are removed.

2.3 Ball Tracking

In the ball tracking process, the particle swarm optimization algorithm (PSO) (Kennedy and Eberhart, 1995), was used. Its usefulness in solving problems related to object tracking has been repeatedly confirmed (Kwolek, 2009; Kwolek et al., 2012). In PSO algorithm, particle swarm is used in order to find the best solution; each of the particles represents a hypothetical solution of the problem. During the estimation, particles explore the search space and exchange information. Each i-th particle contains the current position $\mathbf{x}_i$, velocity $\mathbf{v}_i$, and its best position $\mathbf{pbest}_i$. Moreover, the particles have access to the best global position **gbest**, which has been found by any particle in the swarm. The d-th components of velocity and position of each particle are updated based on the following equations:

$$v_{i,d}^{k+1} = \omega[v_{i,d}^{k} + c_1 r_{1,d}(pbest_{i,d} - x_{i,d}^{k}) + c_2 r_{2,d}(gbest_d - x_{i,d}^{k})], \quad (3)$$

$$x_{i,d}^{k+1} = x_{i,d}^{k} + v_{i,d}^{k+1}, \quad (4)$$

where ω is a constriction factor, c_1, c_2 are positive constants and $r_{1,d}$, $r_{2,d}$ are uniformly distributed random numbers. Selection of the best position for i-th particle ($\mathbf{pbest}_i$) and best global position ($\mathbf{gbest}$) are based on the fitness function value, which determines whether a considered part of the image contains the tracked object or not. In our application the position of i-th particle represents the hypothetical position of a ball.

3 RESULTS

The monocular ball tracking method was evaluated on 10 video sequences with a basketball free throw. The quality of tracking was made by analyses carried out through qualitative visual evaluations. In Figure 2 and Figure 3 the ball tracking results for selected players were presented. As can be observed the proposed method tracking of the ball has very good accuracy.

The analysis of the data in Table 2 indicates that the maximum altitude of the ball (h_2) is 4.03 m while the minimum is equal to 3.67 m. In the case of the parameter h_1, measured from the beginning of a altitude of the ball to the basket height, it can be observed that most players reach the height of about 1 m. Only in case of one player this parameter did not exceed 0.3 m.

The distance analysis of the first part of the ball trajectory l_1 (measured from P_1 to P_2 - see Figure 1), showed that the majority of throwing players could achieve the length of approximately 2.4 m. Considering the length l_2 (measured from P_2 to P_3), it can be seen that half of the examined participants could score the distance within the range from 1.7 m to 1.79 m.

The value of an initial angle (α_1) for most players reaches a size smaller than 50°. According to earlier works (Hudson, 1982; Chen et al., 2009) an initial angle of the ball should be about 52°, it can be assumed that in such a case we will be dealing with a correct throw. Analyzing the results it may be noted that among the surveyed players only one player came close to this value ($\alpha_1 = 52.82°$). Among the analyzed players, the greatest initial angle of ball is at the level of 53.59°.

According to Hamilton and Reinschmidt (Hamilton and Reinschmidt, 1997) the optimum speed (v_1), which is achieved when the ball is thrown, is approximately 7.3 m/s. Analyzing the data it can be seen that the lowest speed is equal to 5.54 m/s and the highest and therefore most similar to the standard is 6.62 m/s. The arithmetic average for this parameter is 6.18 m/s. Considering the initial velocity there may be noticed a certain regularity. Players whose amplitude of parabolic flight of the ball (h_2) reaches the greatest values (3.93 m and 4.03 m), throw the ball at a slower speed (v_1) 5.54 m/s and 6.13 m/s. It is also noted that the speed v_2 is lower (3.67 m/s and 3.90 m/s) in athletes whose parabola height (h_2) is also relatively high.

Another analyzed parameter is the angle α_2 (the ball angle at the highest point of the trajectory). The study shows that the obtained results oscillate between 6.94° to 13.55°. The majority of the players threw the ball at the speed above 4 m/s at the highest point of the trajectory (v_2). The lowest ball speed at this point was 3.67 m/s. In addition, studies show that the greatest angle of the ball falling into the basket (α_3) was 43.01° and the lowest 30.08°, whereas the arithmetic average reached 36.64°. For more than half of the monitored players the ball at this point reached the speed (v_3) of approximately 5 m/s.

While analyzing the ball trajectory charts, it can be deduced that the majority of the players failed to perform a clean throw. In four cases, the ball bounced repeatedly off the rim or the backboard (Figure 4 (a, b, d, f)) before falling into the basket. Two players accomplished a throw, where the ball once bounced off the basket (Figure 4 (c, g)). However, four players performed a clean throw (the ball did not hit the board nor the rim) (Figure 4 (e, h, i, j)).

The next element of the analysis is to examine the relation between the player's height and various parameters of the ball's trajectory (see Figure 5 and Table 3). The conducted analysis shows that in two

Frame #85 Frame #106 Frame #143

Frame #177 Frame #200 Frame #259

Figure 2: Ball tracking in selected frames of sequence 4.

Frame #47 Frame #73 Frame #105

Frame #153 Frame #177 Frame #250

Figure 3: Ball tracking in selected frames of sequence 6.

cases the correlation coefficient presents the statistical significance, i.e.: dependence with h_2 parameter ($r_{xy} = 0.78$, $p = 0.01$) and with v_2 parameter ($r_{xy} = 0.65$, $p = 0.04$). Figure 5 shows that the relation between the body height and h_2 is characterized by a positive direction. This implies that the higher player the higher positioned point P_2. However, it should be noted that the taller players, the flatter their throws will be. In the example of the second stated dependence, it is noted that the taller the player, the lower speed of the ball in the second phase of a ball's flight is (v_2). Therefore it can be concluded that the height of the body has the influence on the shape of the parabola line.

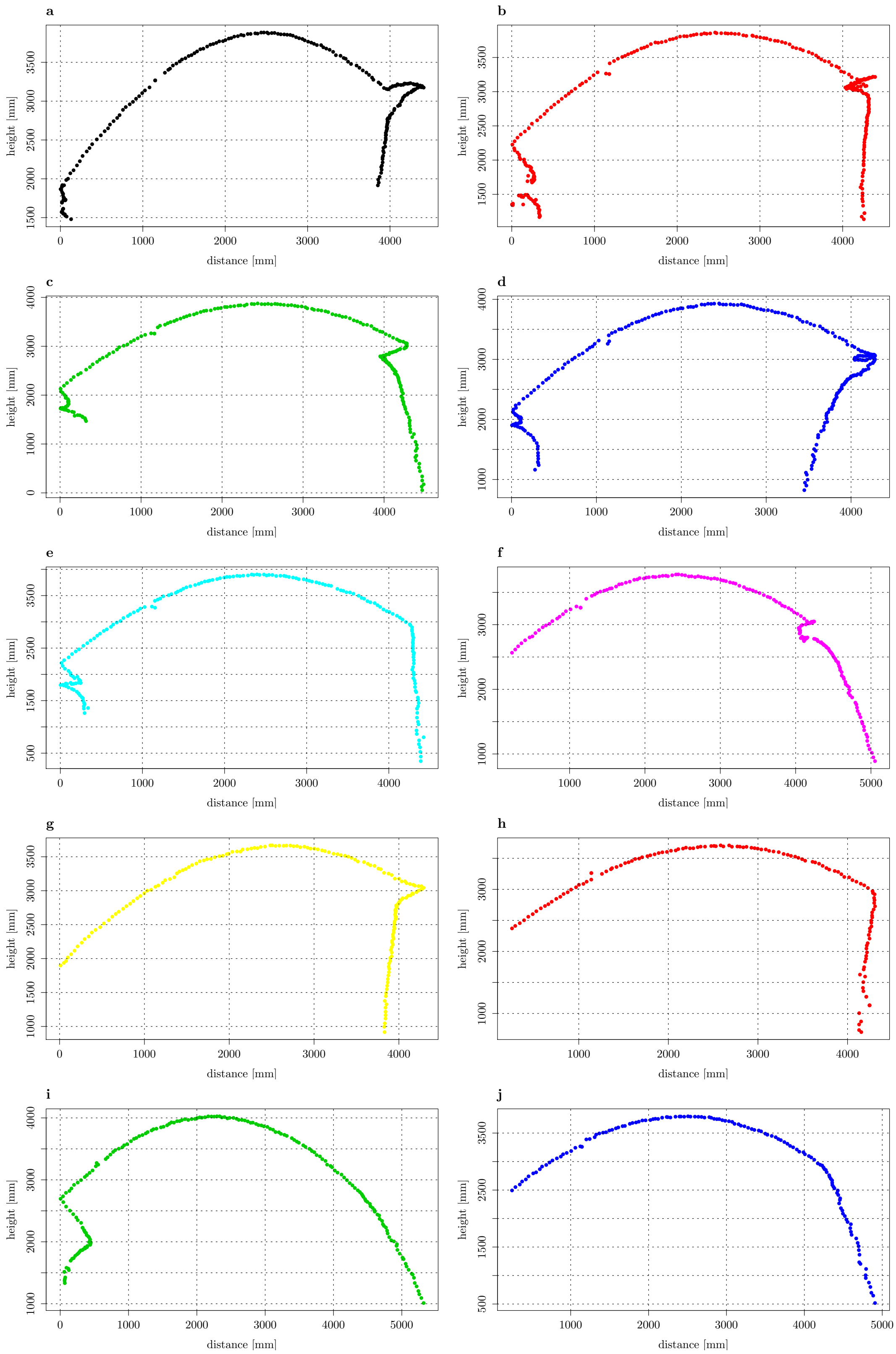

Figure 4: Ball trajectory for 10 sequences.

Table 2: Ball parameters of free throw trajectory.

Player	h_1 [m]	h_2 [m]	l_1 [m]	l_2 [m]	v_1 [m/s]	v_2 [m/s]	v_3 [m/s]	α_1 [°]	α_2 [°]	α_3 [°]
1	1.17	3.88	2.40	1.50	6.34	3.67	4.47	52.82	12.38	36.95
2	0.86	3.86	2.45	1.83	6.38	4.18	5.03	47.83	7.93	36.16
3	0.93	3.87	2.43	1.84	6.62	4.14	4.40	49.09	9.33	35.60
4	0.96	3.93	2.43	1.79	5.54	3.90	4.19	53.59	11.01	36.04
5	0.99	3.90	2.38	1.58	6.43	4.10	4.90	49.33	10.13	35.27
6	0.41	3.78	2.16	1.73	5.97	4.28	4.90	41.38	9.39	35.67
7	1.14	3.67	2.43	1.70	6.30	4.10	4.28	49.67	6.94	30.08
8	0.53	3.71	2.29	1.70	6.14	4.38	5.10	42.51	9.56	38.15
9	0.22	4.03	2.33	1.94	6.13	4.19	5.41	44.15	13.55	43.01
10	0.38	3.79	2.22	1.72	5.94	4.08	4.86	42.32	12.52	39.55
$\bar{x}$	0.76	3.84	2.35	1.73	6.18	4.10	4.75	47.27	10.27	36.64
SD	0.11	0.34	0.10	0.13	0.31	0.20	0.40	4.42	2.10	3.31

Table 3: Correlation between body height and parameters of free throws; r_{xy} – correlation coefficients, p – p-value.

	h_1	h_2	l_1	l_2	v_1	v_2	v_3	α_1	α_2	α_3
r_{xy}	0.11	0.78	0.27	0.11	-0.24	-0.65	-0,08	0.49	0.56	0.35
p	0.77	0.01	0.44	0.77	0.50	0.04	0.83	0.15	0.09	0.33

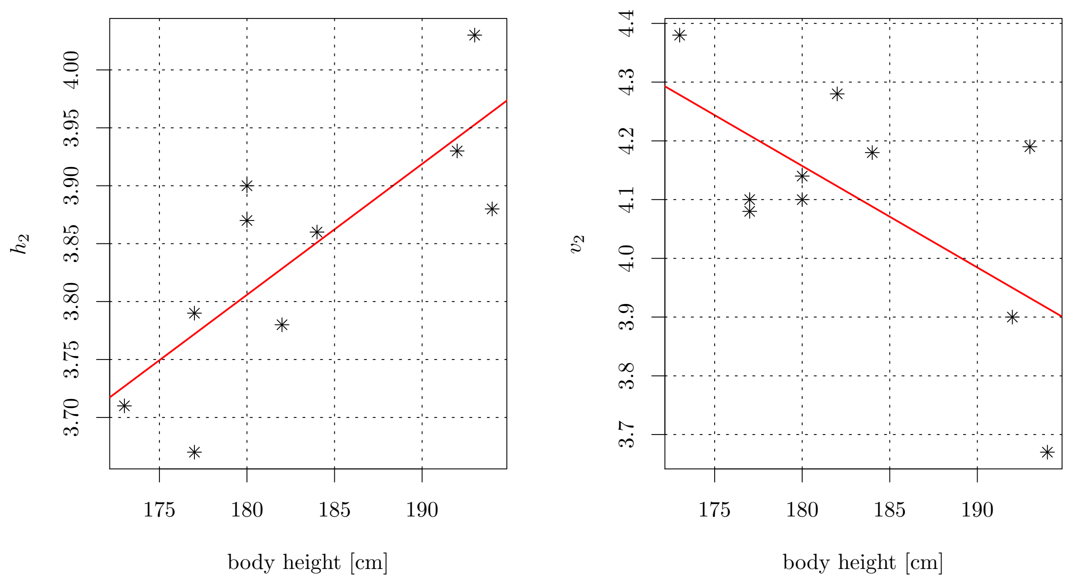

Figure 5: Relationships between body height and parameters h_2 and v_2; red line shows regression line (directions of correlation).

4 CONCLUSIONS

The paper presented the method for detection and tracking the ball during a basketball free throw. The experimental results were conducted on 10 sequences. The values of 10 parameters were measured. Additionally the analysis of the relationship between body height and parameters of trajectory was calculated.

The suggested method can be used in the training process as a tool to improve performance of free throws. Coach using this application will be able to monitor the trajectory of the ball which will help to improve the correct motor habit. In consequence player's throws will be executed with the correct timing and with optimal trajectory.

The future work will focus on developing and improving the system for obtaining a free throw trajectory and developing an expert system that would allow the automatic evaluation of performed free throws.

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