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*PAPERS*

# Basketball self training shooting posture recognition and trajectory estimation using computer vision and Kalman filter

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Self-shooting training is one of the fundamental criteria for success in basketball. Particularly, young players increase their performance with regular training. However, the training process becomes painful and time-consuming without a coach since the incorrect shooting posture causes missing shots, leading to reluctance. In this research, a self-shooting posture algorithm is developed to track the movement of basketball players and give them feedback about their position, angle, and basketball projectile trajectory information. The proposed algorithm uses computer vision techniques and Kalman filter to detect the best projectile trajectory using initial conditions such as acceleration due to gravity the initial velocity at the angle of launch having certain horizontal distance to the rim and the rim distance from the ground The acceleration of both gravity and air drag are altered by predefined parameters, including the drag coefficient basketball mass ball radius and silhouette area The proposed algorithm provides the shooting angle in real-time by placing the projectile angle on to the cropped image of the player posture and draws the projectile trajectory towards the basketball hoop According to the results, the players having a specified height can achieve the best shooting at the angle with air drag force. On the other hand, if there is no air resistance, the best shooting angle is deviated significantly. The other stats that are a total time of travel, maximum horizontal distance, maximum height and the time until the top are also given along with the results.

K e y w o r d s: posture recognition, image processing, projectile trajectory estimation, basketball, Kalman filter

## 1 Introduction

Basketball is a competitive sport that has a vast number of fans globally. This sport consists of various fundamental parameters such as assists, dribble, passing, rebound, steal, score, and shooting. The winner and loser are decided based on the scores accomplished by players through successful shootings [1]. Even though basketball is a team game that needs combat and coordination between players, it still needs individual shooting skills for winning the game since insufficient shooting level exposed the weakness of the team and reduced the willpower for success [2]. Thus, successful shooting in basketball has significant importance in terms of winning the game. Self-training has an essential role in increasing fundamental shooting skills in basketball [3, 4]. However, due to the challenges of self-training such as self-visual inspection, finding a good trainer with higher budgets, and time-consuming ineffective practices, players have hard times achieving their desired performances [5]. These challenges can be solved with Computer Vision(CV) and digital image processing techniques. Recently, CV algorithms and Deep Learning(DL) have been used to develop effective segmentation techniques to overcome real world problems, including pose detection, object detection, autonomous driving, robot controls, and surveillance [6]. However, CV and deep learning have benefits and drawbacks in terms of performance and power efficiency. For instance, deep learning needs high computing capability with a large number of data sets for a simple image segmentation task while CV algorithms only need a few lines of codes that are much more efficient. In addition, deep learning techniques need to be well constructed to perform well only within the provided training data set. Otherwise, it is highly possible to be failed in object detection [7]. Image segmentation which is one of the CV algorithms helps us to extract the characteristic of pixel regions or clusters on the images for decision-oriented applications [8]. Thus, its objective is to partition the image into several meaningful segments for analysis. These segments have high similarities in terms of pixel colors. Extracting these proprieties may also provide an efficient solution for self-training shooting posture recognition and projectile trajectory estimation. The basketball players usually wear colorful shorts and T-shirts. Using Image segmentation, one can segment the short, T-shirt, and basketball to determine the angle of the projectile and the related trajectories. All it takes is to find the slope of the basketball projectile by fusing the pixel coordinates of centroids extracted from segmented images. After finding the optimum angle, it is critical to find the optimum trajectory as well. Under real-world conditions, the environment contains many uncertainties affecting the trajectory of the object. Thus, a proper filter is required to optimize the projectile trajectory and determine the true path. In many trajectory applications, the Kalman filter is utilized to predict the moving objects position, velocity, and acceleration under the noisy environment. The main objective of the Kalman Filter is to reduce the prediction error recursively [9–11]. The projectile trajectory

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of a basketball can be predicted through Kalman filter and pixels centroids as well. In the literature, computer vision is used in many sports applications to detect players in the game rather than tracking players motion to fine their projectile trajectory. Okuma *et al* [12] utilized boosted particle filters which is one of the first successful implementations of CV algorithms followed the hockey game players. They utilize histogram of oriented gradients(HOG) along with a probabilistic approach. According to their proposed model, the mixture of local subspaces and online filtering is used to train the data for off-line learning and improve the robustness of the motion tracking. Evan *et al* [13] developed a movement tracking algorithm that locates players on basketball courts. Their main purpose is to gather as much information as possible to create a better evaluation mechanism for coaches. R. K. Meghana *et al* [14] implements the Gaussian mixture model (GMM) and achieved 87.6% player detection accuracy. According to their model, background subtraction helps them differentiate players based on teams. The algorithm is also supported by the Kalman filter and its extended version to maximize the estimating trajectory accuracy on the field. Jiang YC *et al* [15] introduces a novel shadow removal method along with computer vision algorithms to isolate the tennis player and the court using an adaptive search window. The proposed court model adaptively seeks for the minimum region containing the players. Next, the region of interest is classified with color selection and edge detection. After implementing the shadow removing method, the players are identified. Rong Ji *et al* [16] also works on basketball players action recognition based on features extracted from prior data. They get benefits from time and frequency domains that contain multi-dimensional motion features. Next, they apply feature selection and Gaussian hidden variables to classify shooting posture. According to their result, they have achieved 94% classification accuracy without providing trajectory estimation. Finally, Hao *et al* [17] develops an auxiliary basketball system using the combination of big data and sports events. According to his method, the player slum dunk score rate improved significantly. They follow the coach and players motion using kinect 3D-sensor, the sequence color image, image depth map information. By using these parameters background model is introduced to extract the features from the images.

As it is understood, CV and DL algorithms are employed for many sports for different purposes. Using these algorithms mostly depends on the cost and the performance of the model. In this research, a series of CV algorithms will be introduced to achieve maximum performance with the highest amount of knowledge obtained from players, including posture information, projectile trajectory, and the time parameter such as velocity and the highest point of the ball during the travel. This article will also evaluate the trajectory estimation with air drag force and without air drag force conditions.

## 2 Material and methods

Learning how to get the perfect form in shooting is incredibly important for success. That is why every player focuses on shooting posture and grasping the perfect shooting mechanics in self-training. In this section, the proposed shooting posture algorithm will be evaluated in detail.

### *2.1 Understanding best shooting posture mechanics*

The power generated right from the legs and holding the basketball is highly related to accurate shooting. It is calculated that if the players distance to basket a height is known, then there is an optimum release angle ($\theta$) and velocity ($v_0$) that will lead to the greatest possibility to have a successful shot [18, 19]. Besides, keeping the arm less than $90°$ may cause miss shooting. Thus, the arm should be close to the $90°$ as seen in Fig. 1. In addition, Emad *et al* [20] stated that optimal arc ($\theta_{\rm opt}$) for shooting should be $45°$.

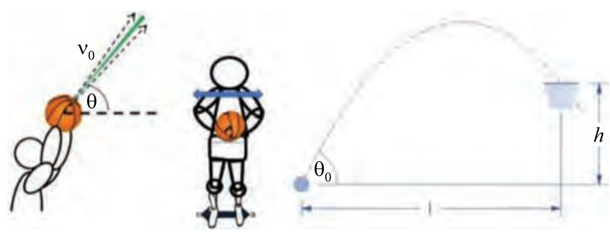


**Fig. 1.** The intended posture angle for a right shot

The perfect shooting depends on the components of velocity in the x and y directions. The mathematical expression of the release angle, the standard projectile motion equation, can help us find the amount of error a player can make. The derivation of projectile displacement is indicated in (1) to (5), [21, 22].

$$v_{0x} = v_0 \cos(\theta_0)\,, \tag{1}$$

$$v_{0y} = v_0 \sin(\theta_0)\,. \tag{2}$$

It should be noted that the acceleration is neglected in the horizontal direction (direction of $x$) since gravity does not affect the horizontal direction. The new form of horizontal projectile motion can be represented as the function of the time using time difference ($\Delta t$):

$$x(t) = l = v_0 \cos(\theta_0)\Delta t\,. \tag{3}$$

$$y(t) = h = v_0 \sin(\theta_0)\mathrm{d}t + \frac{1}{2g\mathrm{d}t^2}\,, \tag{4}$$

$y(t)$ is the vertical distance to the rim. For a successful shot, the initial velocity $v_0$ can be determined for a given initial angle $\theta_0$

$$v_0 = \frac{l}{\cos\theta_0}\sqrt{\frac{-g}{2(\mathrm{l}\tan(\theta_0) - h)}}\,, \tag{5}$$

where: $\theta_0$ is the initial release angle, $g = -9.8\,\mathrm{m/s^2}$ and, $h$ is the vertical distance to the center of the basket. It should be noted that this equation is only valid for a limited interval of $\theta_0$ since the body motion is towards forward. In other words, the angle should be in $0° < \theta_0 < 90°$. The equation also provides real values for $l\tan(\theta_0) - h > 0$.

(1) Projectile trajectory computation with air drag force

Air drag force is one of the important parameters in the projectile trajectory equation. However, it does not mean that solving the equation of velocity and position as a function of time will get quite easy. Including air drag force into Newtons second law will affect the basketball velocity significantly. The projectile velocity slows down during the flight due to the constant air drag, which leads to deviation from the actual measurements. The magnitude of air force $(f)$ is proportional to velocity of the basketball $(v)$, [23]

$$f = Dv_0^2. \tag{6}$$

Since it is assumed that $v_0^2 = v_{0x}^2 + v_{0y}^2$, the projectile force can also be separated into $f_x$ and $f_y$ using $\theta_0$

$$f_{x0} = -Dv_0^2 \cos(\theta_0)\,, \tag{7}$$

$$f_{y0} = -Dv_0^2 \sin(\theta_0)\,. \tag{8}$$

After implementing this to Newton's second law, the acceleration components $(a_{x0}, a_{y0})$ being affected by gravity and air drag force can be obtained as follow.

$$\sum F_{0x} = -Dv_0^2 \cos\theta_0 = m\, a_{0x}\,, \tag{9}$$

$$\sum F_{0y} = -Dv_0^2 \sin\theta_0 = m\, a_{0y}\,, \tag{10}$$

$$a_{0x} = -\frac{Dv_0^2 \cos\theta_0}{m}\,, \tag{11}$$

$$a_{0y} = -g - \frac{Dv_0^2 \sin\theta_0}{m}\,. \tag{12}$$

The variable $D$ is proportional with air density $(\rho)$, the area of the front face of the basketball $(A)$ and drag coefficient $(C)$. $D$ is [24]

$$D = \frac{\rho C A}{2}\,. \tag{13}$$

By determining the drag coefficient acceleration components, the changes in velocity can be determined using time differences $(\delta t)$ between two locations. During the time interval $(\delta t)$, the $a_{0x} = \delta v_{0x} \delta t$ and the $a_{0y} = \delta v_{0y} \delta t$ which lead the velocity parameters to be $v_{0x} = a_{0x} \delta t$ and $v_{0y} = a_{0y} \delta t$, respectively. While observing changes in projectile's velocity and acceleration, the coordinates of estimated values $(x_0, y_0)$ are also changing with air drag force by the average of first $(v_{0x}, v_{0y})$ and the last $(v_{0x} + \delta v_{0x}, v_{0y} + \delta v_{0y})$ parameters. The differences and final location of the basketball is [25]

$$\delta x_0 = \frac{v_{0x} + \delta v_{0x}}{2} \delta t = v_{0x} \delta t + \frac{1}{2} a_{0x} (\delta t^2)\,, \tag{14}$$

$$\delta y_0 = \frac{v_{0y} + \delta v_{0y}}{2} \delta t = v_{0y} \delta t + \frac{1}{2} a_{0y} (\delta t^2)\,. \tag{15}$$

Next, if the equation of motion is reorganized for $x_0$ and $y_0$ coordinates,

$$x_0 + \delta x_0 = x_0 + v_{0x} \delta t + \frac{1}{2} a_{0x} (\delta t^2)\,, \tag{16}$$

$$y_0 + \delta y_0 = y_0 + v_{0y} \delta t + \frac{1}{2} a_{0y} (\delta t^2)\,. \tag{17}$$

Lastly, the equation's final form is represented as a function of the time

$$x(t) = l = x_0 + v_{0x} \delta t + \frac{1}{2} a_{0x} (\delta t^2)\,, \tag{18}$$

$$y(t) = h = y_0 + v_{0y} \delta t + \frac{1}{2} a_{0y} (\delta t^2)\,. \tag{19}$$

(2) The Kalman filter — is an advanced recursive filter that predicts the state and measurement equations from erroneous states containing white Gaussian noise (WGN). It has a wide variety of applications, including flight navigation, signal processing estimations, and computer vision [26].

$$x(t) = Ax(t-1) + Bu(t-1) + \epsilon(t),\ \ \epsilon(t) \approx N\big(0, Q(t)\big), \tag{20}$$

$$y(t) = Cx(t) + \omega(t),\ \omega(t) \approx N\big(0, R(t)\big)\,, \tag{21}$$

where $A, B$, and $C$ are called the state transition, input, and output matrices, respectively. Since real-world problems generally have noises, the $\epsilon(t)$ and $\omega(t)$ which are called the observation, and white Gaussian noise are added to (20) and (21), respectively. Here $Q(t)$ and $R(t)$ are the related covariance matrices. Kalman filter goes through state estimation and measurement updates to make predictions. State estimation is

$$\hat{x}(t \mid t-1) = Ax(t-1) + Bu(t-1)\,, \tag{22}$$

$$P(t \mid t-1) = AP(t-1)A^\top + Q(t)\,. \tag{23}$$

In this equation $\hat{x}(t \mid t-1)$ is estimated using prior state estimation vector $(x(t-1))$ at time $t-1$. Similarly, the $P(t \mid t-1)$ is estimated prior information and process noise of $Q(t)$. The next the measurement update takes place as

$$K(t) = P(t \mid t-1)C^\top \big(CP(t \mid t-1)C^\top + R(t)\big)^{-1}, \tag{24}$$

$$\hat{x}(t) = x(t \mid t-1) + K(t)\big(y(t) - Cx(t \mid t-1)\big), \tag{25}$$

$$P(t) = (I - K(t)CP(t \mid t-1)\,, \tag{26}$$

where: $y(t) - Cx(t \mid t-1)$ is the residual of the measurements. In these recursive updating systems, the estimated covariance matrix is determined in the final step. The flow of the Kalman filter recursive updating system is shown in Fig. 2.

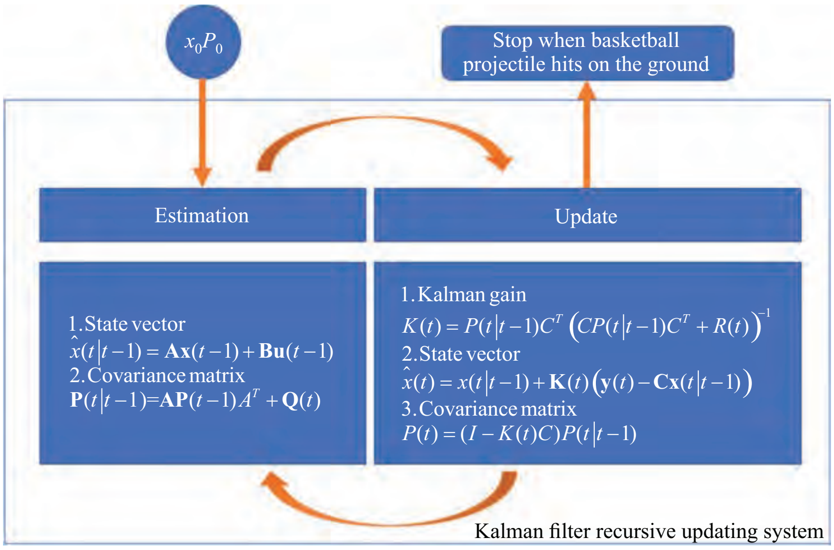


**Fig. 2.** The Kalman filter recursive updating system

*2.2 Image color segmentation (ICS)*

Within the last decade, the application of image segmentation has been incredibly skyrocketing due to the advancement in computer technology. ICS is also another CV technique that is vastly used since it is cost-efficient in terms of time and speed [28]. Numerous image segmentation techniques utilize a combination of different algorithms such as histograms, thresholds, and clusters. These algorithms make it possible to separate the objects and backgrounds by segmenting outdoor colors. As it is known, all images have three color channels(red, green, blue) digitally leveling from 0–255 levels. These channels can be digitally manipulated using statistical tools such as standard deviation, confidence interval, and Euclidean distance. However, using RGB channeling, and statistics are not sufficient to properly segment the image [29]. Therefore, some other CV algorithms, including median filter, binarization, area opening, bounding boxes, should be overlapped with the RGB channeling and statistics.

(1) Median filter – is one of the essential noise removing and smoothing filters for digital image processing. This filter replaces a particular pixel value with the median value of surrounding pixels after the sorting process. The median values are [30]

$$M = \begin{cases} x_{(n+1)/2}, & \text{if } n \text{ is odd,} \\ x_{n/2} + x_{n/2+1} & \text{if } n \text{ is even.} \end{cases} \tag{27}$$

The sorting and replacing of the median filter start with a window with a predefined size such as $3 \times 3$. This window moves from top to the bottom and replaces all pixels with the median ones, as seen in Fig. 3.

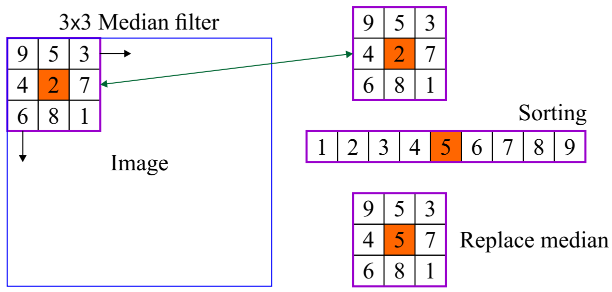


**Fig. 3.** Median filter representation


**Fig. 4.** RGB channels and corresponding filters: (a) – original image, (b) – red, (c) – green, (d) – blue, (e) – red-median, (f) – green-median, and (g) – blue-median,


**Fig. 5.** Binarization of the red channel

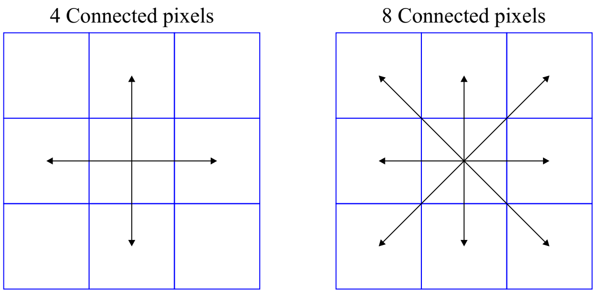


**Fig. 6.** Two-dimensional open area connectivity

The actual implementation of the filter also is represented in Fig. 4. It is seen that the original image is separated into three channels as RGB, and a $3 \times 3$ median filter is applied to the image to differentiate the red color from the original image, which will be meaningful in the next section of this paper

(2) Binarization – is a process based on a threshold ($th$) leveling to extract desired information from a digital image. The key point is that the threshold mainly depends on the pixel values and the characteristic of the image, such as document type, color, and lighting. Thus, having strict requirements can be considered a drawback for this approach. Regardless of its drawback, binarization is so crucial for ICS. Equation (28) is used for the binarization process. Figure 5 indicates a binarization representation of red channel [31].

$$I(x,y)_{\mathrm{Bin}} = \begin{cases} 1 & \text{if } I(x,y) > th\,, \\ 0 & \text{if } I(x,y) < th\,. \end{cases} \tag{28}$$

(3) Area opening – is a technique based on finding the connected components or clusters in a binary image and removing the pixels with lesser pixels than the specified $P$ number. The obtained binary image from binarization contains many areas which can be filtered out concerning the size of the area. Equation (29) shows the open area process on binary images. Figure 6 demonstrates the filter which fulfills area $> 300 \times 400$ pixels. By obtaining the area, we can identify the basketball [32, 33]

$$I(x,y)_{\mathrm{BW}} = \begin{cases} \text{keep} & \text{if } I(x,y)_{\mathrm{Bin}} > P\,, \\ \text{remove} & \text{if } I(x,y)_{\mathrm{Bin}} < P\,. \end{cases} \tag{29}$$

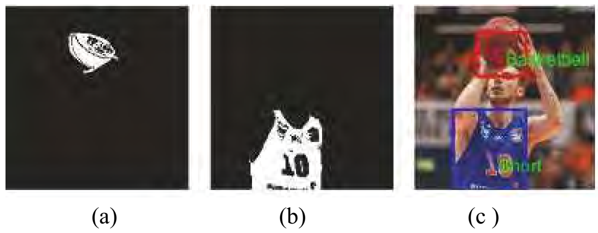


**Fig. 7.** Labelling detected objects using bounding boxes: (a) – basketball, (b) – T-shirt, (c) – original image

(4) Finding bounding boxes and labelling – are usually used for object detection in computer vision. They can be considered as imaginary boxes which enclose the detected object. Bounding boxes also provide the coordinate of the detected object. They are determined using centroid and minimum pixel location [34]. Thus, they help us to label the object. Figure 7 represents detected bounding boxes and corresponding labels for basketball and T-shirt.

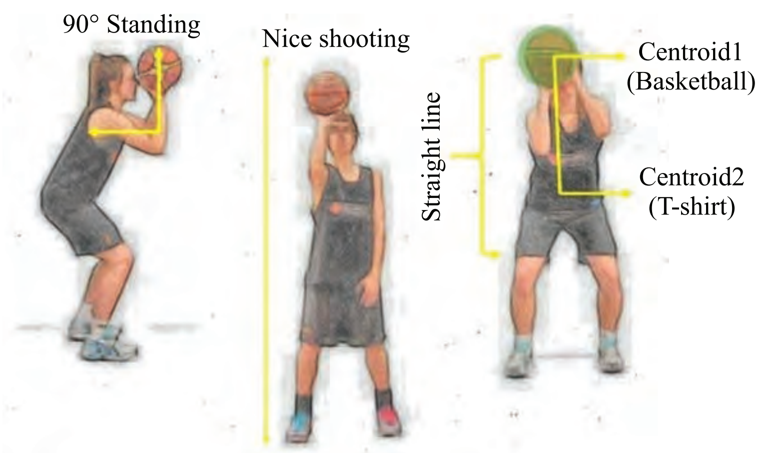


**Fig. 8.** A nice shoot criteria presentation

Algorithm 1. Motion tracking and Best Posture Recommendation Algorithm

Require: Video Reader()
**while** isdone(Video Reader) **do**
Video Frame $\leftarrow$ Video Reader()
$\mathrm{Red}_{\mathrm{Channel}} \leftarrow$ Video Frame()
$\mathrm{Red}_{\mathrm{g}} \leftarrow$ Color to Gray $(\mathrm{Red}_{\mathrm{Channel}})$
$\mathrm{Red}_{\mathrm{Pure}} \leftarrow$ imsubtractpred$(\mathrm{Red}_{\mathrm{Channel}}, \mathrm{Red}_{\mathrm{g}})$
$\mathrm{Red}_{\mathrm{Filtered}} \leftarrow$ Median Filter$(\mathrm{Red}_{\mathrm{Pure}}, \text{Filter} = 3 \times 3)$
$\mathrm{Red}_{\mathrm{BW}} \leftarrow$ Image to Binary(Red)Filtered, $\mathrm{Th}_{\mathrm{BW}} = 0.215)$
$\mathrm{Red}_{\mathrm{OpenArea}} \leftarrow$ BW Open Area $(\mathrm{Red}_{\mathrm{BW}}, \text{Area} = 300 \times 400)$
$\mathrm{Red}_{\mathrm{Label}} \leftarrow$ BW Label(RedOpenArea,8)
Image Show(Video Frame)
**Hold on**
$\mathrm{Red}_{\mathrm{Boundingbox}} \leftarrow$ Find Bounding Box $(\mathrm{Red}_{\mathrm{Label}})$
$\mathrm{Red}_{\mathrm{Centroid}} \leftarrow$ Find Centroid $(\mathrm{Red}_{\mathrm{Boundingbox}})$
Plot$(\mathrm{Red}_{\mathrm{Boundingbox}})$
**Repeat process for Blue Channel**
$\theta_{\mathrm{s}} \leftarrow$ Find Angle $(\mathrm{Red}_{\mathrm{Centroid}}, \mathrm{Blue}_{\mathrm{Centroid}})$
**if** $30 < \theta_{\mathrm{s}} < 60$ **then**
$\theta_{\mathrm{Best}} \leftarrow$ Pick Best Posture Angle $(\theta_{\mathrm{s}})$
Draw$(\theta_{\mathrm{Best}})$
$\mathrm{Trajectory}_{\mathrm{Best}} \leftarrow$ Find Projectile Trajectory $(\theta_{\mathrm{Best}})$
$\mathrm{Trajectory}_{\mathrm{Kalman}} \leftarrow$ Kalman Filter $(\mathrm{Trajectory}_{\mathrm{Best}})$
Draw$(\mathrm{Trajectory}_{\mathrm{Kalman}})$
**end**
**end while**

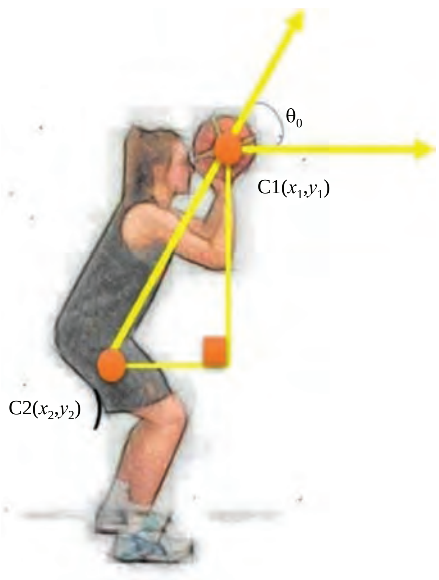


**Fig. 9.** Proposed angle calculation based on detected centroids

### *2.3 Motion tracking and best posture recommendation algorithm*

Motion tracking, which provides releasing angle and player posture, is essential for a successful shot in basketball [35]. Therefore, in this research, these two parameters will be detected using digital image processing. The proposed algorithms start with loading the video frame, an image, from a video. Later the video frame is separated into three RGB channels. These channels information can be used to segment the desired color from the video frame, such as basketball, player T-shirt, or some bracelets which have colors close to red, green, and blue. Extraction of these clusters can be combined with the player's body information to track the player's posture. From Fig. 8, it is seen that an excellent shooting mainly depends on getting close to the 90° standing position from a side view. In addition, the player should keep the basketball over her head but parallel to his body center.

According to the proposed model, the video frame first is converted to grayscale to extract desired color. The desired colors are red and blue since the basketball and T-shirt colors are close to red and blue. The median filter having a window size of $3 \times 3$ is used to reduce the noises from the video frame. The following process is to convert the filtered frame into a binary frame with the red channel having 0.215 threshold ratio and the blue channel having 0.2 threshold ratio. By means of the obtained binary frame, the connected pixels having an area higher than the size of $300 \times 400$ pixels are extracted. This process will remove all the not related small objects and the noise from the environment. Finally, through bounding boxes and labeling, the object(basketball) and corresponding coordinates and centroids will be detected. These procedures will let the algorithm to automatically detect the player's T-shirt or shorts from the player's side view. Using this information, the player angle can be detected with given centroids located on the coordinates of $C1(x_1, y_1)$ and $C2(x_2, y_2)$ as seen in Fig. 9. The player's posture angle $\theta$ is continuously computed for the best trajectory using predefined parameters such as $v_0$ and horizontal distance to the rim, and distance between ground and rim.

Once the best projectile angle is determined, the corresponding trajectory can be also calculated. In this re-

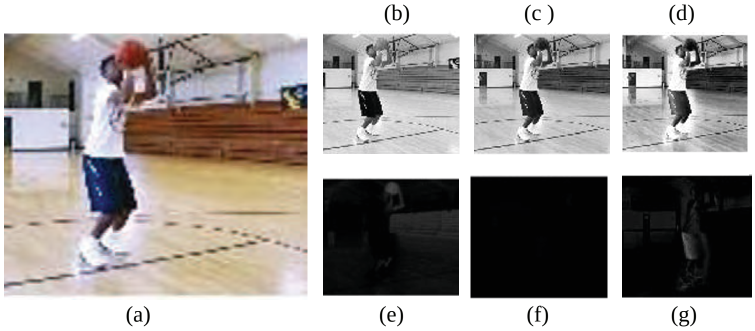


**Fig. 10.** Median filter applied RGB video frames

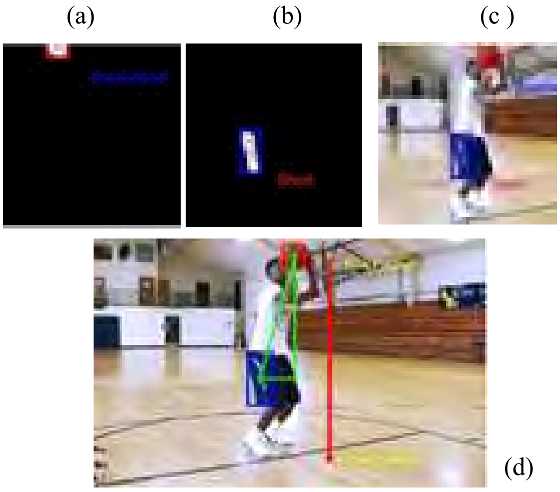


**Fig. 11.** Obtained desired objects: basketball and short

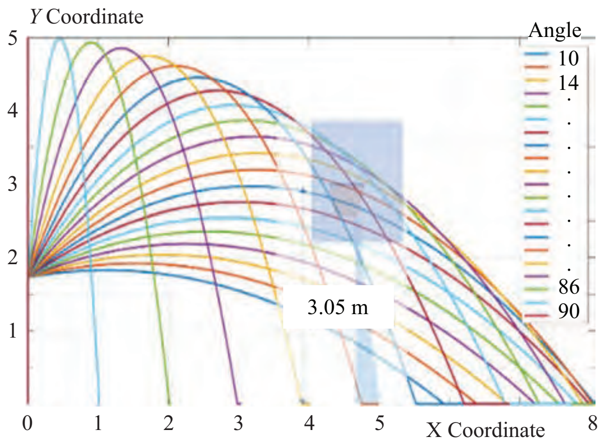


**Fig. 12.** Possible projectile trajectory

search, the air drag force will not be neglected. However, the trajectory calculation without air drag force will be also provided since both conditions will let us compare real-world application with simulation environments. It should be noted that the environment with air will be a noisy medium. Thus, Kalman filter will also use to correct prediction error. The projectile trajectory angle ($\theta_0$) found by $C1(x_1, y_1)$ and $C2(x_2, y_2)$ and related path is

$$\theta_0 = \tan^{-1} \frac{y_2 - y_1}{x_2 - x_1}, \tag{30}$$

$$y(t) = KFx(t) = x_0 + v_{0x}(\theta_0)\delta t + \frac{1}{2}a_{0x}(\theta_0)(\delta t^2) + N(0,\sigma), \tag{31}$$

$$y(t) = KF\big(y_0 + v_{0y}(\theta_0)\delta t + \frac{1}{2}a_{0y}(\theta_0)(\delta t^2) + N(0,\sigma)\big), \tag{32}$$

where $N(0,\sigma)$ is white Gaussian noise with zero mean. The proposed algorithm is explained by the pseudo-code in Algorithm 1.

## 3 Analysis and results

In this section, computer vision techniques and projectile trajectory model helped us to detect related self-training posture and provide corresponding best angle stats. The hardware and software used to implement the proposed algorithm are HP OMEN Laptop with the specification comprising Intel Core I7-7700HQ CPU@ 2.8 GHz and 2.81 GHz, 12 GB RAM, NVIDIA GE-FORCE GTX 1050 Ti, and MATLAB 2021a student version. The video that used for this experiment is obtained from Coach Howard and called "The Perfect Shooting Form" [36]. The predefined parameter which are used for the proposed method when there is no air resistance, are $g = -9.81\,\mathrm{m/s}^2$, $V_0 = 8\,\mathrm{m/s}$, $h = 3.05\,\mathrm{m}$, and $l = 4.6\,\mathrm{m}$. In this study, the video is read by a while loop to extract every frame and apply the intended image segmentation technique. The RGB video frames are separated using color channelization, and a $3 \times 3$ Median filter is also applied, as seen in Fig. 10.

Next, the binarization and BW area opening is applied to the median filtered video frames. Since the basketball and the player's shorts are the regions of interest, only red and blue are identified in Fig. 11. The corresponding centroids are also detected in the location of $C_1(x_1, y_1)$ and $C_2(x_2, y_2)$. The vertical and horizontal lines are drawn on the video frame for centroids.

The angle $\theta_0$ is calculated as the video frames are processed using the proposed method. If the best angle is recognized by the algorithm, it shows a straight line

**Table 1.** Trajectory of different angles for: $h_{\text{projectile}} = 1.73\,\text{m}$, $v_0 = 8\,\text{m/s}$, $l = 4.6\,\text{m}$ and $h = 3.05\,\text{m}$

| $\theta$ | $t_F$ | $x_F$ | Range | $x_T$ | $y_T$ | $t_T$ | $v_T$ | $v_F$ |
|---|---|---|---|---|---|---|---|---|
| 10 | 0.75 | 5.91 | 0.75 | 1.1 | 1.83 | 0.14 | 7.87 | 9.88 |
| 20 | 0.94 | 7.07 | 0.94 | 2.1 | 2.11 | 0.28 | 7.51 | 9.92 |
| 30 | 1.13 | 7.83 | 1.13 | 2.84 | 2.55 | 0.41 | 6.92 | 9.9 |
| 40 | 1.32 | 8.09 | 1.32 | 3.19 | 3.08 | 0.52 | 6.12 | 9.92 |
| 50 | 1.49 | 7.66 | 1.49 | 3.19 | 3.64 | 0.62 | 5.14 | 9.92 |
| 60 | 1.63 | 6.52 | 1.63 | 2.84 | 4.18 | 0.71 | 4.00 | 9.9 |
| 70 | 1.74 | 4.76 | 1.74 | 2.11 | 4.61 | 0.77 | 2.73 | 9.93 |
| 80 | 1.8 | 2.5 | 1.8 | 1.11 | 4.89 | 0.8 | 1.38 | 9.87 |
| 90 | 1.82 | 0.00 | 1.82 | 0.00 | 4.99 | 0.82 | 0.00 | 9.85 |

F– final, T – top

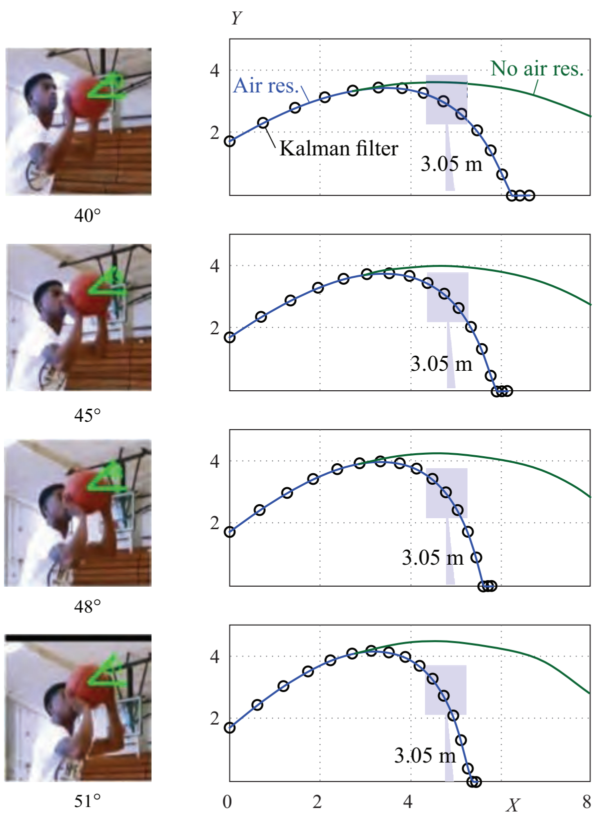


**Fig. 13.** Best possible projectile trajectories

and informs the player whether the player have a nice shooting posture or not. The possible best angles and corresponding trajectories are represented in Fig. 12. A real size of backboard which has 3.05 m rim height is place to the plotting in order to visualize actual success of the projectile trajectories.

According to Fig. 12, a player with a height of 1.73 m with an initial velocity of 9.5 m/s has a higher chance for a successful score in the interval of $38° < \theta < 60°$. The trajectory parameters are provided with possible trajectory angles as indicated in Tab. 1.

The algorithm also picks possible best four angle and concerning projectile trajectories including air drag force and Kalman filter are plotted in Fig. 13. The detected best angles are 40°, 45°, 48°, and 51°. It is observed that the air drag force significantly affect the trajectory of the basketball leading to the successfully score at 51°. If best shooting posture ($\theta_{\text{best}} = 51°$) is evaluated, it can be seen that the total time of travel is approximately 1.8 s and the maximum distance towards $x$-direction ($x_{\max}$) from the launch is 5.47 m.

In contrast, when the air force drag is neglected, $x_{\max}$ becomes 10.76 m. Likewise, the maximum distance towards $y$-direction ($y_{\max}$) is 4.5 m with 0.74 s arrival time. However, when adding the air drag force, the result turns out to be $y_{max} = 4.17\,\text{m}$ and arrival time= 0.6353 s. In addition, the velocity without air force drags at the top and endpoint are 5.97 m/s and 11.16 m/s, respectively whereas adding air force drag changes the velocity at the top and endpoint to 5.29 m/s and 13.31 m/s, respectively. In other words, the speed to toward $y$ direction is increasing while the $x$ direction is decreasing. It should be noted that these results only obtained with predefined parameter for a human height of 1.73 m with initial velocity ($v_0 = 9.5\,\text{m/s}$). If the conditions change, the parameter configuration is required.

## 4 Conclusion

In basketball, shooting success has particular importance for youths since it is the most significant factor for winning the game. Therefore, in this research, an automatic self-shooting posture recognition and projectile estimation is developed to increase the score and overcome the player reluctance related to missing shots. The proposed method contributes to self-training with different ICS-aided approaches such as RGB color channelization, median filtering, and area opening. It also provides information about the best projectile angle ($\theta_0$), which has a higher chance for a successful score using constant environmental variables such as player height, horizontal launch distance to the rim, and acceleration due to the gravity g. According to the results, the proposed image segmentation method successfully classifies the objects(Basketball and Short) and computed the centroids to determine the best player's posture with angles 40°, 45°, 48°, and 51°. After the visualization of projectile trajectories, the best angle is determined as 51° and time-related stats. In future work, this algorithm can be implemented to a mobile base application to increase the worldwide players shooting performance.

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