P1-14
17th International Conference on Machine Vision Applications (MVA)
Fully Online, July 25–27, 2021.

Multi-physical and Temporal Feature Based Self-correcting Approximation Model for Monocular 3D Volleyball Trajectory Analysis

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Abstract

Benefiting from the low venue requirements and deployment cost, analysis of 3D volleyball trajectory from monocular vision sensor is of important significance to volleyball game analysis and training assisting. Because of the monocular vision limitation, complicated ball trajectory caused by physical factors and model drifting owing to distance information loss are two governing challenges. This paper proposes a multi-physical factors and self-correcting trajectory approximation model. Also, a trajectory correction algorithm based on temporal motion features is proposed. For the first challenge, air resistance factor and gravity factor which mostly impact volleyball during flying are considered to simulate ball motion status. The approximation model parameters are evaluated and corrected during model calculating to reduce calculation error. To limiting model drifting, volleyball movement characteristics based on temporal motion feature is applied to correct approximated trajectory. The success rate of proposed monocular 3D trajectory approximation method achieves 82.5% which has 47.0% improvement comparing with conventional work.

1. Introduction

Due to the development of computer vision, 3D sports analysis is of application prospects and commercial value. Monocular 3D ball trajectory analysis obtains 3D ball position and velocity based on low venue requirements and deployment cost [1]. It also has valuable application scenarios in volleyball game analysis and training assisting. Therefore, this paper aims at reducing 3D trajectory approximation error caused by unstable motion and monocular distance loss for volleyball game analysis.

In monocular 3D volleyball trajectory approximation, there are two key problems: complicated flight trajectory and model drifting [2]. For problem 1, volleyball is affected by a variety of external physical factors during the flight, such as gravity, air resistance, and the Magnus generated by the rotation of the volleyball during the volleyball game. [3] Problem 2, model drifting problem, caused by monocular vision distance information loss. It means that a same coordinates sequence on the image can represent multiple actual 3D trajectories with conspicuous position disparity. These key challenges in monocular 3D analysis bring about high calculation error in approximation result.

To solve the problem 1, there are several works aiming at monocular complex 3D ball trajectory analysis in recent years. Some works consider the influence of gravity to approximate the 3D motion trajectory of the ball in ball sports. [4-5] To correct the estimated 3D trajectory, affine transformation between the game image and the sports field is used in trajectory estimation in close-to-ground ball sports such as soccer and ice hockey. [6] However, volleyball is affected by a variety of external physical factors and always flies and rotates at high speed in the game. Volleyball is also basically not touching with the court, which leads to large deviations in the approximation of volleyball 3D trajectory by using these tasks.

For problem 2, some works focus on the model drifting problem in 3D information analysis caused by the lack of depth information of the monocular sensor. Camera movement can acquire information like multiple views on temporal which is applied to constrain the model drifting. [7] For regular court-touching balls, such as table tennis and tennis, the contact between the head and end in the trajectory and the court can restrain the estimation error caused by model drifting. [8] For monocular 3D volleyball analysis, the moving camera needs to calculate the camera pose in every frame, but the volleyball is also in high-speed movement, which brings huge computational overhead and position calculation error.

In this paper, multi-physical factors based self-correcting trajectory approximation model for varied volleyball flight trajectory adaptation is proposed. To limit the model drifting error in monocular vision system, a trajectory correction algorithm based on temporal motion feature in volleyball game is proposed.

The structure of this paper is as follows. Section 2 and Section 3 express the detail of our monocular trajectory approximation model, correction algorithm and proposals. The experiment result and conclusion are in section 4 and section 5.

2. Monocular 3D approximation method

Due to the lack of depth information caused by the monocular sensor, it is necessary to apply the temporal motion characteristics of volleyball. So the image sequence should be the input of the whole system. Based on camera matrix

P which calculated by Hartley's calibration method, we can obtain 3D volleyball trajectory from 2D volleyball coordinate sequence $\mathbb{C}_k$.

The overall structure of our frame work is shown in Fig. 1. The RGB image sequence obtained from a single image sensor is the input of the entire system. Image coordinates (u, v) of each frame are obtained by a high-precision image tracking system based on particle filter. [9] Trajectory model calculates the volleyball trajectory parameter P_k from the image coordinates sequence $\mathbb{C}_k$. Then calculated 3D coordinates (X, Y, Z) is projected onto the image plane for evaluation. Finally, the approximated 3D trajectory is corrected.

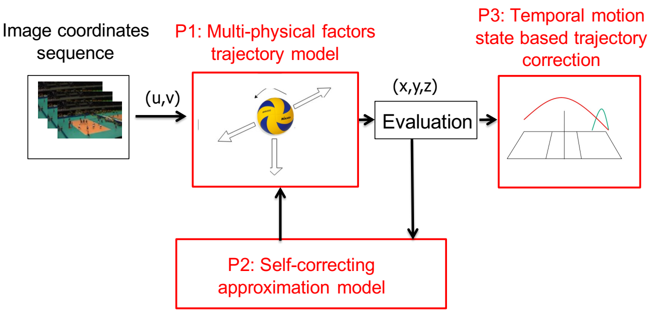


Figure 1. Overview structure of monocular 3D volleyball trajectory approximation system.

Eq. (1) shows the mapping relationship between the 2D image coordinates (u, v) and the 3D coordinates augmented matrix W based on the camera matrix P.

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = PW^T = \begin{bmatrix} p1 & p2 & p3 & p4 \\ p5 & p6 & p7 & p8 \\ p9 & p10 & p11 & p12 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \tag{1}$$

The first proposal is the improvement in trajectory model. Multi-physical factors trajectory model considers air resistance and gravity influence in ball trajectory model. It aims at simulating the physical model of realistic flight conditions of volleyball.

The second proposal aids the evaluation step in approximation model. A self-correcting approximation model which evaluates approximation result and rectify model parameters dynamically is proposed. By evaluation for the approximation model, trajectory model's parameters can be corrected dynamically by proposed method.

The third proposal target for limiting the model drifting error approximated 3D volleyball trajectory in monocular vision. Based on temporal movement feature of volleyball motion states, model drifting deviation in approximation result is constrained.

3. Proposals

3.1. Multi-physical factors trajectory model

In volleyball game, external physical factors such as gravity, air resistance, Magnus caused by volleyball rotation, leading to the complex and unstable volleyball flight trajectory. Among them, gravity and air resistance are the external physical factors that affect the volleyball flight trajectory mostly.

Due to the lack of depth information caused by monocular vision, single 2D image coordinates (u, v) cannot calculate the target 3D coordinates (X, Y, Z), so we calculate ball flight trajectory based on the physical characteristics of volleyball movement.

$$\begin{cases} Px_{k+n} = Px_k + V_x t - a\ \ V_x\,(nt)^2/2 \\ Py_{k+n} = Py_k + V_y t - a\ \ V_y\,(nt)^2/2 \\ Pz_{k+n} = Pz_k + V_z t + g(nt)^2/2 - a\ \ V_z\,(nt)^2/2 \end{cases} \tag{2}$$

As Eq. (2) shown, the 3D position of volleyball in frame $k+n$ which is n frame after initial frame k can be obtain based on initial position coordinates Px_k, Py_k, Pz_k and the initial velocity in each direction V_x, V_y, V_z in frame k. The time interval between each frame is fixed and known. a is the air resistance coefficient of the volleyball during the flight, which can be calculated from the weight and radius of the standard volleyball.

3.2. Self-correcting approximation model

The overview of proposed self-correcting approximation model and the conceptual difference with conventional work is presented in Fig. 2.

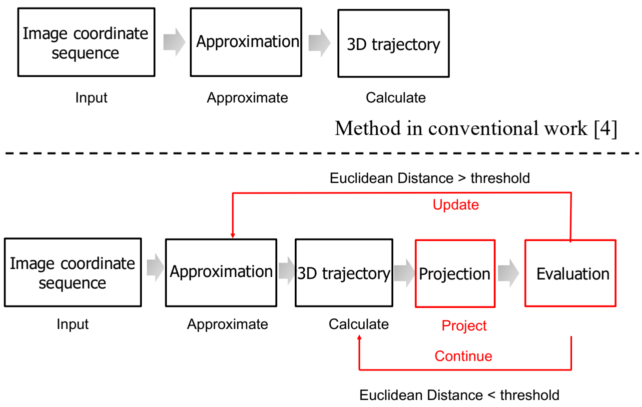


Figure 2. Overall structure of conceptual difference between conventional approximation model and self-correcting approximation model.

For the conventional volleyball approximation model, flight trajectory estimated by an stable model contain error which increase rapidly over time. Therefore, the parameters calculation error of the motion model should be detected and self-corrected immediately, which can significantly reduce the error of the trajectory approximation model.

In order to improve the model's estimation accuracy of the volleyball 3D trajectory, the dynamic self-correcting algorithm is applied to the approximation model. The least square method based on input image coordinates is used to calculate the trajectory model parameters to reduce the estimation error of the approximation model as much as possible. Euclidean distance E_d between the input coordinates (u, v) obtained by the high-accuracy volleyball tracking system based on particle filter and projected image coordinates (u_p, v_p) which obtained from volleyball 3D coordinates estimated by proposal 1. The specific update strategy is as follows.

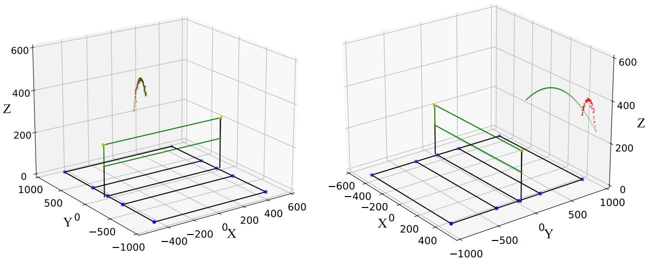
(1) If the Euclidean distance E_d between (u, v) and (u_p, v_p) is greater than the radius of the volleyball on the image plane, which means the old trajectory model is not correspond to current flight trajectory. New trajectory model parameters are calculated and updated for the trajectory model.

(2) If the Euclidean distance E_d is less than the radius of the volleyball on the image plane, trajectory model continues use current parameters.

For model parameters updating, a set of coordinates will input to calculate the new trajectory model parameters. In order to ensure the continuity of the approximated 3D trajectory, the 3D coordinates which are calculated in the previous frame are assumed as the initial coordinates, and only the speed parameters V_x, V_y, V_z are recalculated.

3.3. Movement features based trajectory correction

Volleyball matches have very obvious sequential temporal characteristics. For example, any round of volleyball matches starts with tossing the ball, and the order includes serving, receiving, passing, spiking and other events. These events are all have clear motion characteristics. Therefore, we propose to use the motion characteristics of the volleyball events to constrain the model drifting deviation caused by monocular vision in some cases to correct 3D trajectory which calculated by approximation model.



(a) (b)

Figure 3. Model drifting problem (a) Two trajectories are seen same in camera vision (b) Actually different trajectories in space.

As Fig. 3. shown, there are two identical trajectories on the image plane (green and red), but they are actually two completely different trajectories in the three-dimensional space. Due to the lack of depth information caused by the monocular sensor, they cannot be distinguished on stable camera vision.

A typical volleyball match event sequence is shown in Fig. 4. For different events, such as tossing and spiking, the movement characteristics of volleyball have very significant differences, especially the speed of movement in the three directions of the XYZ axis. Based on the temporal motion characteristics of different events, the model drifting problem in the approximated trajectory can be constrained in a small interval, which significantly improves the accuracy of the monocular 3D trajectory approximation model.

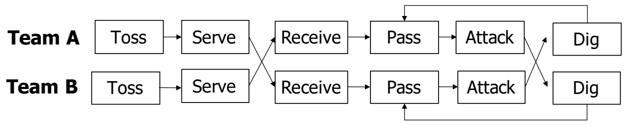


Figure 4. Typical volleyball match event sequence and their spatial characteristics.

4. Experiment result

4.1. Experiment environment

The experiment is based on the volleyball games videos obtained in the Game of 2014 Japan Inter High School of Men Volleyball by 1 camera which located at grandstand. The video's resolution is 1920×1080, the frame rate is 60 fps. Since our research target is to analysis the 3D trajectory based on the image coordinates sequence, in order to reduce the trajectory estimation error caused by the image coordinates deviation, we selected 20 volleyball game rounds video sequence include toss, pass, receive, spike and so on, which measure up 98% accuracy in image by particle filter based 2D volleyball tracking system.

4.2. Ground truth and evaluation method

Although the deployment cost of the multi-camera volleyball 3D tracking system is high and the site requirements because of high 3D tracking accuracy. [10] Therefore, it is applied to checking the result of our proposed monocular 3D trajectory approximation model as ground truth.

To evaluate the proposed trajectory approximation model, we calculate the spatial distance D^i between the ground truth 3D position (X_g^i, Y_g^i, Z_g^i) and the 3D position (X^i, Y^i, Z^i) approximated by our model for frame i. $Success\ frame$ is defined to reduce the influence of individual frame estimation deviation. The evaluation of the $i\ th$ frame is shown in the Eq. (3). The definition of $Success$ in frame and $Success\ rate$ is shown in Eq. (4) and Eq. (5)

$$D^i = \sqrt{(X_g^i - X^i)^2 + (Y_g^i - Y^i)^2 + (Z_g^i - Z^i)^2} \quad (3)$$

$$frame\ (i - th) = \begin{cases} success & D^i \le threshold \\ fail & D^i > threshold \end{cases} \quad (4)$$

$$Success\ rate = \frac{\sum Success\ frame}{Total\ frames} \times 100\%. \quad (5)$$

4.3. Experimental result and analysis

For comparison, conventional work and the contributions of three proposals in our work are respectively evaluated. As it shown in Table 1, proposed multi-physical and temporal feature based self-correcting model achieves 73.3% accurate in error range 150 mm, and 82.5% in error range 200mm which improve 45.0% and 47.0% comparing with conventional work [4]. Some 3D trajectories which approximated by our work and their ground truth is shown in Fig. 6.

Table 1. Experiment

Experiment work	Success rate in T1[1]	Success rate in T2[2]
Convention work	28.3%	35.5%
P1[3]	39.1%	43.7%
P1+P2[4]	67.4%	75.8%
P1+P2+P3[5]	73.3%	82.5%

[1]T1: Threshold1 in Eq. (4) (150mm)
[2]T2: Threshold2 in Eq. (4) (200mm)
[3]P1: Multi-physical factors trajectory model
[4]P2: Self-correcting approximation model
[5]P3: Movement features based trajectory correction

However, there are some aspects that can be improved in future work. Firstly, proposed correction algorithm achieves redress for huge model drifting error but not sensitive for small model drifting. So, model drifting problem still cause approximated 3D trajectory fail comparing with real trajectory. Also, because of the Magnus caused by ball rotation, trajectory model parameters error lead approximated trajectory shift.

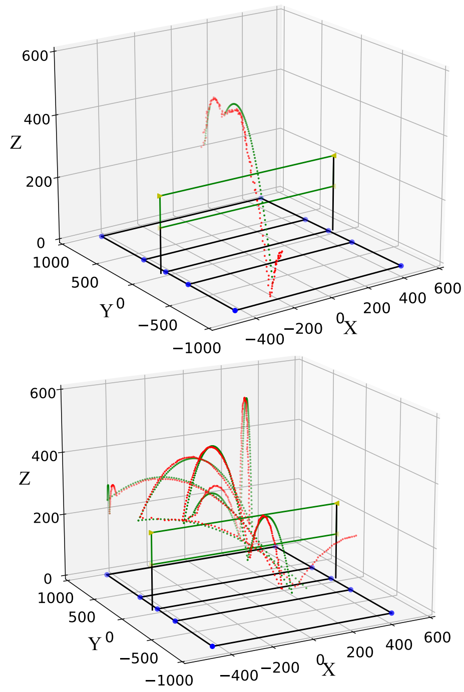


Figure 6. Approximate 3D volleyball trajectory.

5. Conclusion

This paper proposes a multi-physical factor based self-correcting trajectory approximation model and a trajectory correction algorithm based on temporal motion feature to achieve high precision 3D volleyball trajectory approximation in monocular vision. In proposed trajectory model, the influence of gravity and air resistance factor affecting factors are applied to the trajectory model, in order to simulate real model. Proposed self-correcting approximation model adopts an automatically correcting trajectory approximation model to dynamically correct model parameters and reduce estimation errors. Proposed model drifting correction algorithm uses temporal motion feature based on events to constraint model drifting problem in monocular vision. Experiment based on 20 sequences recorded in official volleyball match and achieves 73.3% accurate in error range 150mm, and 82.5% in error range 200mm.

6. Acknowledgement

This work was supported by KAKENHI (21K11816) and Waseda University Grant for Special Research Projects (2021C-242).

References

[1] B. Tekin et al.: "Learning to fuse 2d and 3d image cues for monocular body pose estimation," *Proceedings of the IEEE International Conference on Computer Vision* , pp.3941-3950,2017.

[2] P. Siva et al.: "Weakly supervised object detector learning with model drift detection," *2011 International Conference on Computer Vision*, pp. 343-350, 2011

[3] S. Kao et al.: "A mathematical model for the trajectory of a spiked volleyball and its coaching application," *Journal of applied biomechanics*, pp.95-109, 1994.

[4] H. Chen et al.: "3D ball trajectory reconstruction from single-camera sports video for free viewpoint virtual replay," *2011 Visual Communications and Image Processing (VCIP)*, pp.1-4, 2011.

[5] H. Chen et al.: "Physics-based ball tracking and 3D trajectory reconstruction with applications to shooting location estimation in basketball video," *Journal of Visual Communication and Image Representation*, pp.204-216, 2009.

[6] Y. Liu et al.: "Extracting 3D information from broadcast soccer video," *Image and Vision Computing,* pp.1146-1162, 2006.

[7] J. Yoon et al.: "3d semantic trajectory reconstruction from 3d pixel continuum," *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition,* pp.5060-L.

[8] L. Shen et al.: "3D reconstruction of ball trajectory from a single camera in the ball game," *Proceedings of the 10th International Symposium on Computer Science in Sports (ISCSS)*, pp.33-39, 2016.

[9] X. Cheng et al.: "Court-Divisional Team Motion and Player Performance Curve based Automatic Game Strategy Data Acquisition for Volleyball Analysis", *IEICE Trans. Fundamentals*, Vol.E101-A, No.11, pp.1756-1765, Nov. 2018.

[10] X. Cheng et al.: “Anti-occlusion observation model and automatic recovery for multi-view ball tracking in sports analysis”, *41st IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, pp.1501-1505, 2016.