

A New ICF-based Ball Tracking System with Multi-Exposure Cameras for Virtual Sports

Jong-Sung Kim, Myung-Gyu Kim

Creative Contents Research Division, ETRI, South Korea

js.kim@etri.re.kr, mgkim@etri.re.kr

Abstract—This paper proposes a new ball tracking system for virtual sports. In the proposed system, multi-exposure cameras are used to capture high-speed motion images of ball. Then, a new iterative circle-fitting algorithm based on the circular Hough transform, the OFF-cell filter, and the Hausdorff distance is adopted to track balls with unknown patterns from images. The effectiveness of the proposed ball tracking system is verified through experiments using real balls with various patterns. The usefulness of the proposed system is demonstrated by applying to a virtual sports platform in practice.

Keywords— Ball tracking, virtual sports, iterative circle fitting, circular Hough transform, OFF-cell filter, Hausdorff distance

I. INTRODUCTION

Virtual sports have studied to play various sports with 3D ball simulators in an indoor place for a decade. Nowadays, virtual sports are very popular for professional players as well as general users [1-5]. For such virtual sports, the 3D trajectory of ball should be simulated according to initial ball motion parameters. Therefore, the measurement of initial ball motion parameters is prerequisite for virtual sports. For this purpose, high-speed cameras have been widely used to track ball [1-3]. However, such high-speed cameras make the system cost too expensive. Multi-exposure cameras [6-8] has been introduced to solve this problem. However, the ball tracking with multi-exposure cameras becomes a challenging problem when the patterns of ball are unknown.

In this paper, a new ball tracking system is proposed for virtual sports. The proposed system has been applied to the virtual sports platform with multi-exposure cameras, which is shown in Fig. 1. The multi-exposure camera captures the high-speed motion images of ball without using high-cost, high-speed cameras. Examples of multi-exposed images of ball with patterns are shown in Fig. 2. Then, a new iterative circle-fitting algorithm (ICF) based on the circular Hough transform (CHT) [9][10], the OFF cell filter (OCF) [11], and the Hausdorff distance (HD) [12] is applied to track balls with unknown patterns from those images. In the ICT, a circle model is iteratively fitted to each region of interest (ROI) via the CHT while the pattern, if any, inside the ROI is removed via the OCF. Then, the HD is used to classify each circular region of interest (COI) into ball and non-ball regions. The effectiveness of the proposed ball tracking system is verified with experiments using balls with various patterns.



Figure 1. Virtual sports platform with multi-exposure cameras.

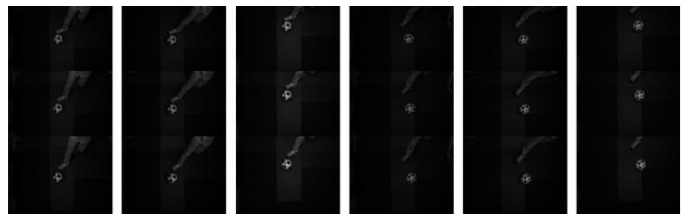


Figure 2. Multi-exposed images of balls with various patterns.

II. PROPOSED SYSTEM

A. Ball Image Capture

The proposed system adopts multi-exposure cameras to capture high-speed motion images of ball. As shown in Fig. 1, the camera module has four cameras. The left-positioned camera, the right-positioned camera, and the bottom-position camera are a multi-exposure camera and synchronized to each other within few microseconds. The top-positioned camera is a single exposure camera. The intrinsic lens parameters, such as focal length and optical center, and the extrinsic pose parameters, such as 3D position and 3D rotation, of all cameras, including multi-expose ones, are calibrated with a vision-based camera calibration technique [13]. The center-positioned sensor is a high-speed line-scan image sensor, which recognizes the instance when a ball passes over some virtual starting line and then sends a triggering signal to each multi-expose camera three times with latency between camera exposures. Each multi-exposure camera captures three images with a few milliseconds and then merges captured images into one multi-exposed image. Examples of multi-exposed images of balls with patterns are shown in Fig. 2. All of these images are captured by the multi-exposure camera system during playing a game in our virtual sports platform. As shown in Fig. 2, a ball appears three times per each multi-exposed image. The vertical resolution of multi-exposed image is higher than the original one due to the technical property of our multi-exposed imaging process.

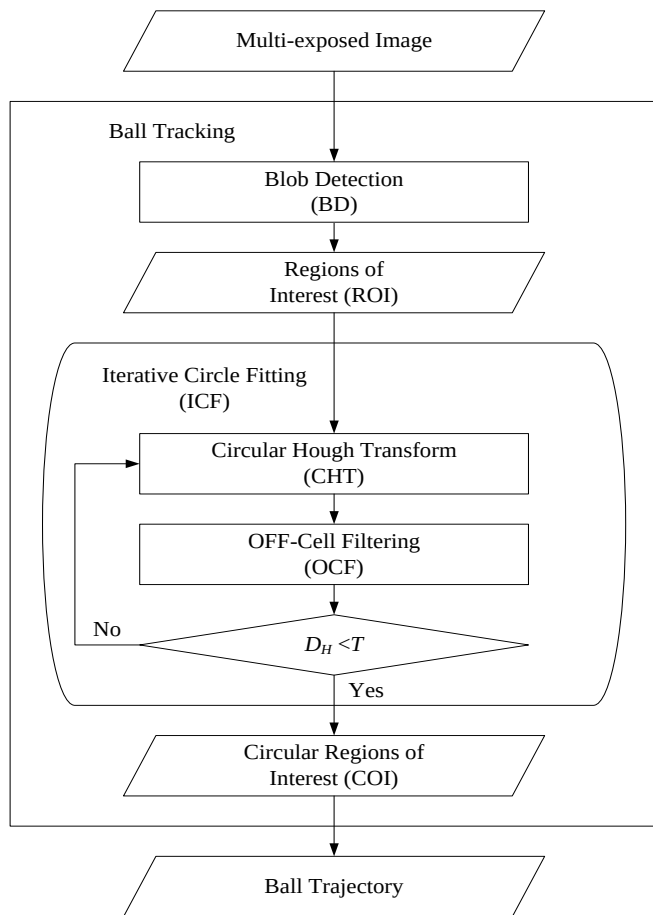


Figure 3. Ball tracking process.

B. Ball Tracking

The ball tracking process is illustrated in Fig. 3. As shown in that figure, the ball tracking process finally outputs ball trajectory, including the center position and the radius of ball. For applying the proposed system to a virtual sports platform in practice, the overall process should be automatically conducted in real time. In addition, balls with unknown patterns should be tracked automatically. The proposed system solves these problems with the ICF based on the CHT, the OCF, and the HD. As shown in Fig. 3, the first step is the blob detection (BD), which extracts ROIs of ball from multi-exposed images through fully-automatic vision techniques, including an image binarization technique [14] and a connected-component labeling technique [15], and so on. Examples of the ROIs detected from multi-exposed images of balls by the BD are given in Fig. 4.

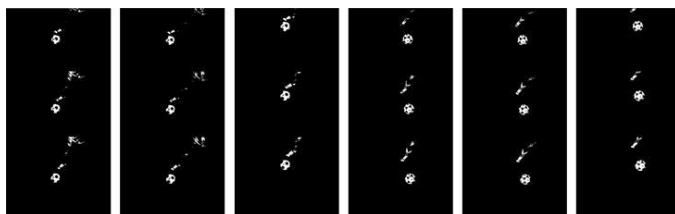


Figure 4. ROIs detected from multi-exposed images of balls via the BD

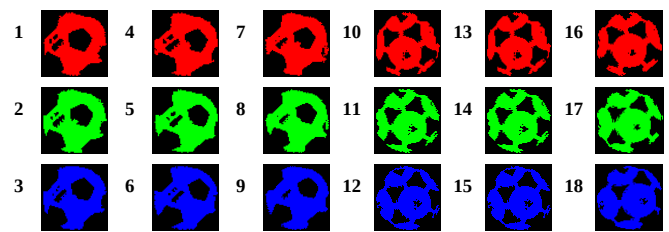


Figure 5. ROIs of ball before ICF.

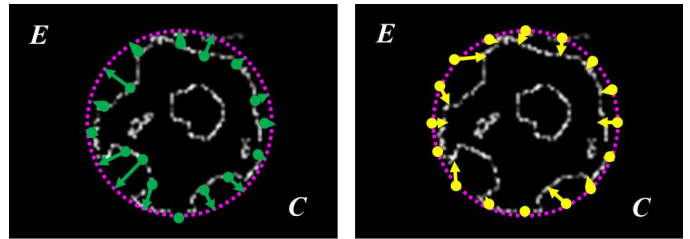


Figure 6. Hausdorff distance between the edge and the circle model of ball.

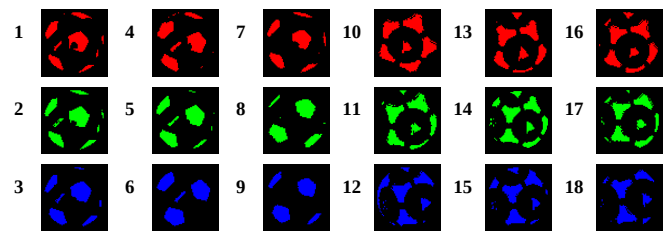


Figure 7. Ball patterns extracted from ROIs of ball via the OCF.

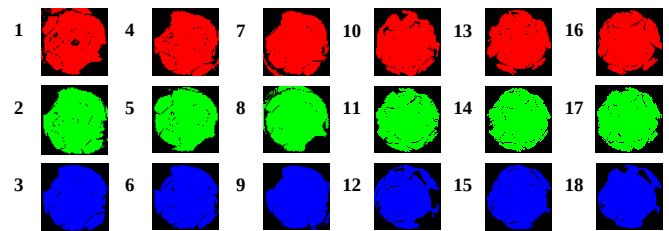


Figure 8. COIs of ball after ICF.

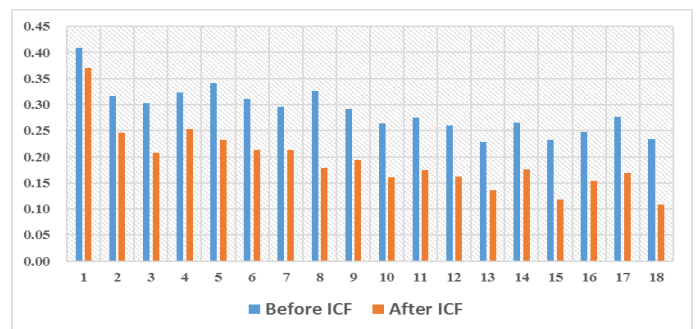


Figure 9. HD values before and after ICF.

As shown in Fig. 4, the ROIs detected from multi-exposed images of balls include non-ball regions as well as ball regions. In addition, Figure 5 shows that the shape of ROIs of ball is far from a circle due to the ball pattern. To automatically and numerically detect ROIs of ball, the proposed system adopts the HD measure, which is defined by

$$D_H = \frac{1}{2} \left(\text{avg}_{e \in E} \left(\min_{c \in C} (d(e, c)) \right) + \text{avg}_{c \in C} \left(\min_{e \in E} (d(c, e)) \right) \right) \quad (1)$$

where e is a pixel in the set of pixels on the edge of ROI, denoted by E , and c a pixel in the set of pixels on the circle model of ROI, denoted by C . The Hausdorff distance of the proposed method is illustrated in Fig. 6. To measure the Hausdorff distance, a circle model should be fitted to each ROI, which is conducted with the CHT in general. However, the shape of ROI is far from a circle due to the ball pattern, which makes it difficult to detect ROIs of ball. In the proposed system, this problem is solved with the ICF, which iteratively fits a circle model to each ROI with the CHF while removing the ball pattern with the OCF. Originally, the OCF has been introduced to extract black characters from scanned or old documents [5], which well described the OCF in details. Therefore, the OCF can be effectively applied to extract the ball pattern from each ROI, which is the key idea of this work. Figure 7 shows the ball patterns extracted from ROIs of ball via the OCF. Then, the ICF removes the ball patterns extracted via the OCF during the iterations of CHF. Figure 8 shows the COIs of balls tracked by the ICF, which outputs the ball trajectory, including the center position and the radius of ball. Figure 9 shows the comparison result of the HD values before the ICF and after ICF. As shown in that figure, the ICF effectively reduces the HD measure, which makes it easy to simply classify the COI with lower than a positive threshold, denoted by T , as a ball region.

III. EXPERIMENTAL RESULTS

The effectiveness of the proposed ball tracking system was verified through experiments with real balls with various patterns. For experiment, 60 multi-exposure images of balls with 4 different patterns are captured with the multi-exposure camera system in our virtual sports platform and 180 COIs of ball are tracked by the proposed system. All of the 180 COIs of ball are numerically analysed in terms of recall rate, i.e., the ratio of the number of true ball region to the number of tracked ball region. Figure 10 shows the comparison result of the recall rates with respect to T before and after the ICF. That figure clearly shows that the ICF effectively enhanced the recall rate. Figure 11 shows some results of the ball tracking with the ICF-based ball tracking system. That figure verifies that the proposed system can automatically track balls with unknown patterns in practice.

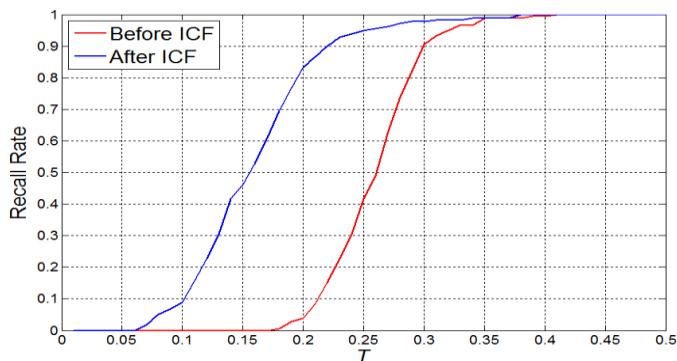


Figure 10. Recall rate with respect to T before and after the ICF

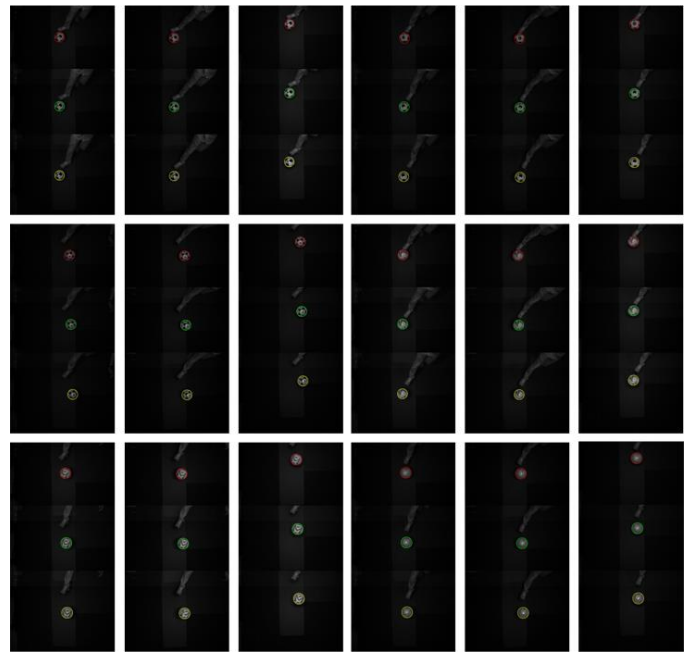


Figure 11. Results of the ball tracking with the ICF-based ball tracking system.

IV. CONCLUSIONS

We proposed a new ICF-based ball tracking system with multi-exposure cameras for virtual sports. In the proposed system, multi-exposure cameras were used to capture high-speed motion images of ball as an alternative to high-cost, high-speed cameras. Then, a new ICF algorithm based on the CHT, the OCF, and the HD was adopted to automatically track balls with unknown patterns from those multi-exposed images. The effectiveness of the ICF-based ball tracking system was verified through experiments using real balls with various patterns. The proposed system was applied to a virtual sports platform in practice.

ACKNOWLEDGMENT

This research was supported by the Sports Promotion Fund of Seoul Olympic Sports Promotion Foundation from Ministry of Culture, Sports and Tourism [s072016122016].

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Jong-Sung Kim received his BS degree in radio sciences and engineering in 2000 from Korea University, Korea, his MS degree in electrical and electronic engineering in 2002, and his PhD degree in 2008 from POSTECH, Korea. In 2002 he worked at Microsoft Research Asia in Beijing, China, as a visiting student. Currently, he is a senior researcher with the S/W & Content Research Laboratory, ETRI, Daejeon, Korea. His research interests include image processing, computer vision and virtual reality.



Myung-Gyu Kim received his BS and PhD degrees in physics from Seoul National University, Rep. of Korea, in 1989 and the University of Maryland, College Park, USA, in 1994, respectively. He is currently working for the SW & Content Research Laboratory, Electronics and Telecommunications Research Institute, Daejeon, Rep. of Korea, as a principal researcher with interests in physical simulations and digital content.