Trajectory Estimation of a Fast and Anomalously Moving Badminton Shuttle

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***Abstract*— This paper proposes a method to estimate position of a small moving object. It is difficult to fit dynamic model of a target object moving fast and anomalously. We focuses on a phenomenon that a high-velocity moving object is observed as a line-shaped region in captured images by motion blur. Shape-from-silhouette technique is applied to estimate the 3D trajectory of the observed lines. We choose a badminton shuttle just after being shot as the target object, and confirm the effectiveness of our proposed method.**

Keywords— 3D Trajectory Estimation; Visual Object Tracking; Anomalously Moving; Shape-From-Silhouette; Badminton Shuttlecock

I. Introduction

Visual tracking of moving objects is one of the most important issues of Computer Vision research. Recently, some applications are developed for sports-events to understand the tactics and to improve the construction level advancing [1,2,3]. In order to realize the practical application, there are various problems to be solved. (e.g., detecting multiple objects such as players and balls, which move fast and anomalously, by using images captured at a large-scale space). In this paper, we focus on an issue to detect and stably track objects moving fast and anomalously by using multiple images.

We focus on a badminton shuttlecock (after this, we call it as shuttle) as the tracking target, since it has the cited problems conspicuously. A shuttlecock is composed of feathers of birds such as waterfowls, attached to the hemispheric cork with adhesive. Since it is much more lightweight than balls used for other games, attaching a transmitter or a marker for position sensing might be difficult. However, there is an additional problem to track the shuttlecock. Due to its structure, during the badminton game (rally) the moving velocity changes inconsistently and drastically during each rally due to the air resistance [4].

When an object moves fast, its image is observed with motion blur. We propose a visual tracking method for an object that has variously and drastically changes its moving speed by utilizing information provided by the motion blur [9]. By ellipsoidal regression to the blurred shuttle region, the speed and position can be estimated [10]. However, when the shuttle is just returned back, its speed is becomes the highest and more over it moves anomalously. As the result, it is difficult to accurately estimate the position and speed, since accurate ellipsoidal regression is not realized. In this paper, we focus on that a target object is observed as one curved-line by motion blur, when it moves very fast. And we propose a method to estimate the 3D trajectory by applying Shape-from-Silhouette technique with multi viewpoint images as shown in figure 1.

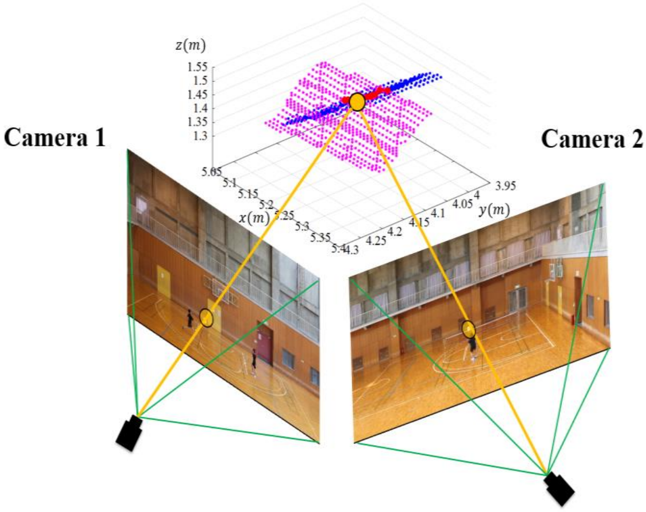


Fig. 1. 3D Trajectory estimation of badminton shuttle using Shape-From-Silhouette technique.

II. Related Work

One of the promised approaches to track a small and fast moving object as a microbe and a ball is using a super-high-speed camera [5,6]. However, it is not reasonable to install such approach to capture badminton shuttle. For example, in order to realize stable tracking, we need to capture target objects in short distance, appearance of background region should be uniform. More importantly, the camera is too expensive to lightly use and the shoot-able time is too short.

A visual object tracking methods for sports events (ball games) using normal color cameras are developing [1,2,3]. In the captured images, observation size of a ball is small, moreover, the ball moves fast and it has few characteristics such as color and shape. These methods solve the problem to assume that motion of the ball follows a simple dynamic model, and a spherical object like a ball is observed as a circular form in the captured images. Even when the target object is not observed by occlusion or aggravation of the observation condition such as decreasing the resolution, Kalman filter can compensate lost information for estimating the position [7,8].

Although, to be precise, the shape of a shuttle is not spherical, it is possible to track the shuttle with switching Kalman filter and Particle filter by referring the state (speed) of the shuttle [10]. Because the observation precision of the position is high when the speed is slow, we input to a Kalman filter "position (Observation position)" and "distance between the observed positions in the former and present frame (Observation speed)". When the speed is fast, we input to the Kalman filter "observed velocity (Observation speed)" and "estimated position (Observation position)".

However, as shown in figure 2, shortly after hitting, the shuttle does not follow a simple dynamic model. We solve this problem by applying 3D reconstruction method. Shape-form-Silhouette [11] reconstructs the 3D shape of target objects merging silhouette images generated from multiple-view images. When the shuttle moves very fast and anomalously, we estimate the 3D position as a 3D trajectory rather than the each position. When a shuttle moves very fast, it is observed as a single curved-line by motion blur in a captured image. We call the curved-line as observation line and extract them in every multiple-view image. By merging the extracted observation lines using Shape-from-Silhouette technique, the 3D trajectory is generated.

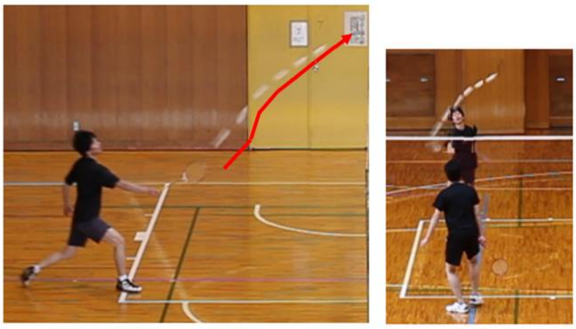


Fig. 2. The example that the movement of the badminton shuttle is observed anomalously.

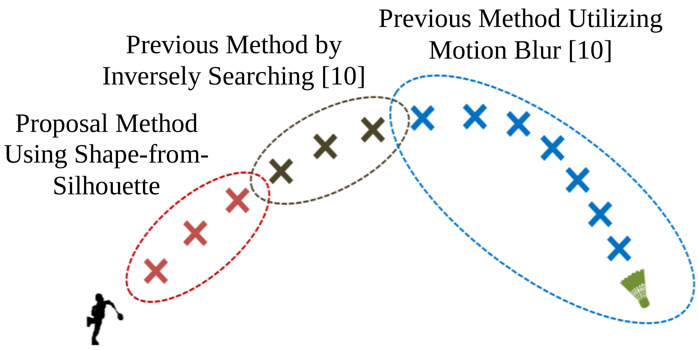


Fig. 3. The region being applyed our previous method (enclosed by the black and blue dotted line oval) and the proposed method (enclosed by the red oval).

III. Trajectory Estimation of Badminton Shuttle Using Shape-from-Silhouette

We capture a fast and anomalously moving shuttlecock using synchronized multiple cameras. The shuttle region is detected as a single continual curved-line region in each frame. The 3D trajectory is reconstructed by applying Shape-From-Silhouette to the observation lines detected in multiple-view images as shown in figure 1.

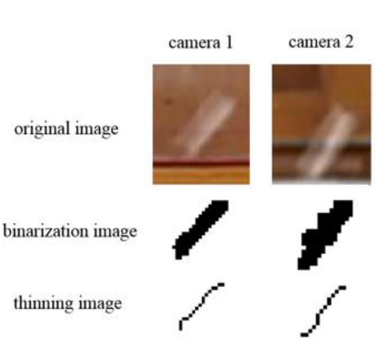
As shown in figure 3, the target shuttle region containing the observation line is clipped out by referring the result of our previous tracking method [10]. As shown in figure 4(a), thinning image processing applied to the captured image to extract an observation line.

Then, we set on 3D voxel space around the approximate 3D position of the shuttle as shown in figure 4(b). The spatial resolution of the voxel space is defined by referring the resolution of captured images. Each voxel is projected onto a captured image to examine whether an observation line exists at the projected pixel as shown in figure 4(c) and (d). When an observation line is not observed, it means that the 3D trajectory of a shuttle does not exist at the voxel. Thus, it is deleted from the voxel space (figure 4(e)). By executing similar process to all other captured image, 3D shape of the observation line is estimated as a bunch of voxels as shown in figure 4(f).

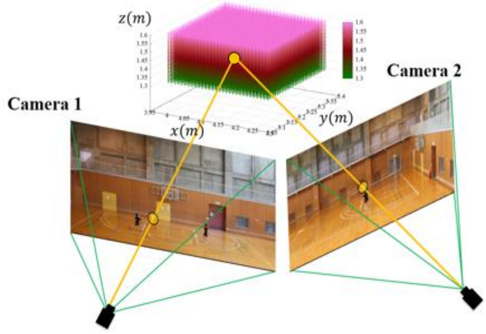
A. The thinning process of shuttle region(motion blur)

We extract observation line from the clipped out region from the captured image shown in upper space of the figure 4(a), as a pre-process for the 3D reconstruction. In our developed system, the resolution of input image is 1,920 pixels x 1,080 pixels, and the observation size of a shuttle (motion blurred) region is about 30 pixels x 30 pixels.

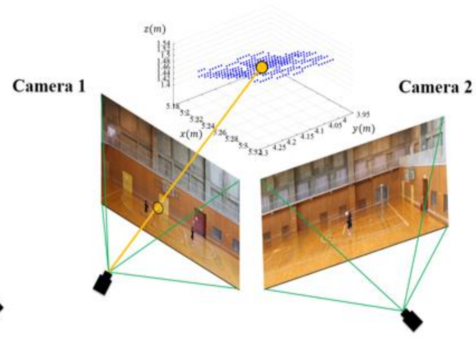
Figure 4 (a) shows examples of the thinning process. We extract the silhouette image by executing background subtraction and binarization. Then, we extract the observation line by applying thinning process to the binary image. This process is applied to multiple captured images.



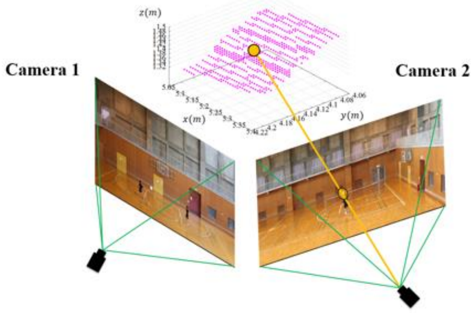
(a) Thinning process of shuttle region



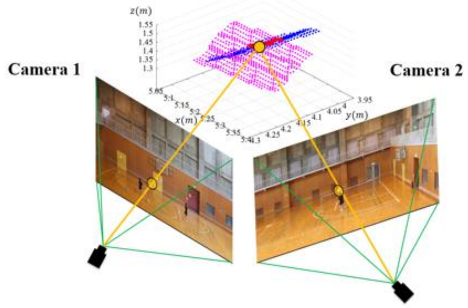
(b) The 3D voxel space



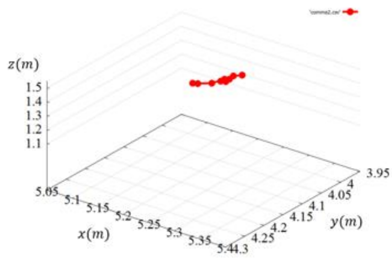
(c) We project an element of the voxel onto Camera1. When an observation line is not observed, we deleted the element from the voxel space



(d) We project an element of the voxel onto Camera2. When an observation line is not observed, we deleted the element from the voxel space



(e) 3D trajectory estimation using Shape-from-Silhouette



(f) 3D shape of the observation line is estimated as a bunch of voxels.

Fig. 4. Flow of the process of trajectory estimation of the badminton shuttle using Shape-From-Silhouette technique

B. Shape-From-Silhouette using thinning image of shuttle

In order to estimate the 3D trajectory, we apply Shape-from-Silhouette to the extracted thinning image of the shuttle region (observation line). Here, all cameras are calibrated in advance. Firstly we set on 3D voxel space around the approximate 3D position of the shuttle as shown in figure 4 (b). In our system, according to the spatial-resolution of captured image, the distance between each element of the voxel is set 1cm. A voxel element is projected onto a captured image (e.g., camera 1) by using camera parameters derived from camera calibration result. Then, we examine whether an observation line exists at the projected position (pixel) or not, we delete the element that the observation line is not observed at the position. In order to respond flexibly to projection error (i.e., camera calibration error), we set thickness to the observation line. Specifically, we calculate the distance between the projected point and the observation line, and if the distance is less than a threshold, the point is regarded as existing on the observation line. As repeating similar process to all other images, as shown in figure 4(e), we estimate the 3D shape of the observation line as shown in figure 4 (f).

IV. EXPERIMENTAL RESULTS

We conduct on experiments to confirm the effectiveness of our proposed method. The multiple videos are captured using 10 digital single-lens reflex cameras (Canon EOS 5D Mark-II) with 1,920 pixels x 1,080 pixels resolution, at 30 frames/sec. The shutter speed is set 1/60 sec. We choose sequences that capture a shuttle moving very fast and anomalously from some types of rally sequences (e.g., smash, drop and clear). All processes are executed by a computer which equips an Intel(R) Core i7-3770 3.4 GHz processor, 8.0 GB RAM, and is operated on Windows-8.

Figure 5 shows a 3D tracking estimate result of our proposed method. The shuttle is hit in the left side and flies toward the right side with drawing a parabola. It means the speed of the shuttle is highest at the left end. The pink crosses show the ground truth position of a shuttle extracted manually. The black crosses show the estimated position by using Kalman filter [7,8]. As you see, it is difficult to track the shuttle when the speed is high (in the left side). In such frames, by applying time-reversal technique, it is possible to track the shuttle [10]. However, when the speed becomes vary fast (in frames #340-#344), the estimation error becomes large (about 15 cm). Even in such frames, as blue curved lines show, it is possible to estimate the accurate 3D trajectory of the shuttle by applying our proposed method.

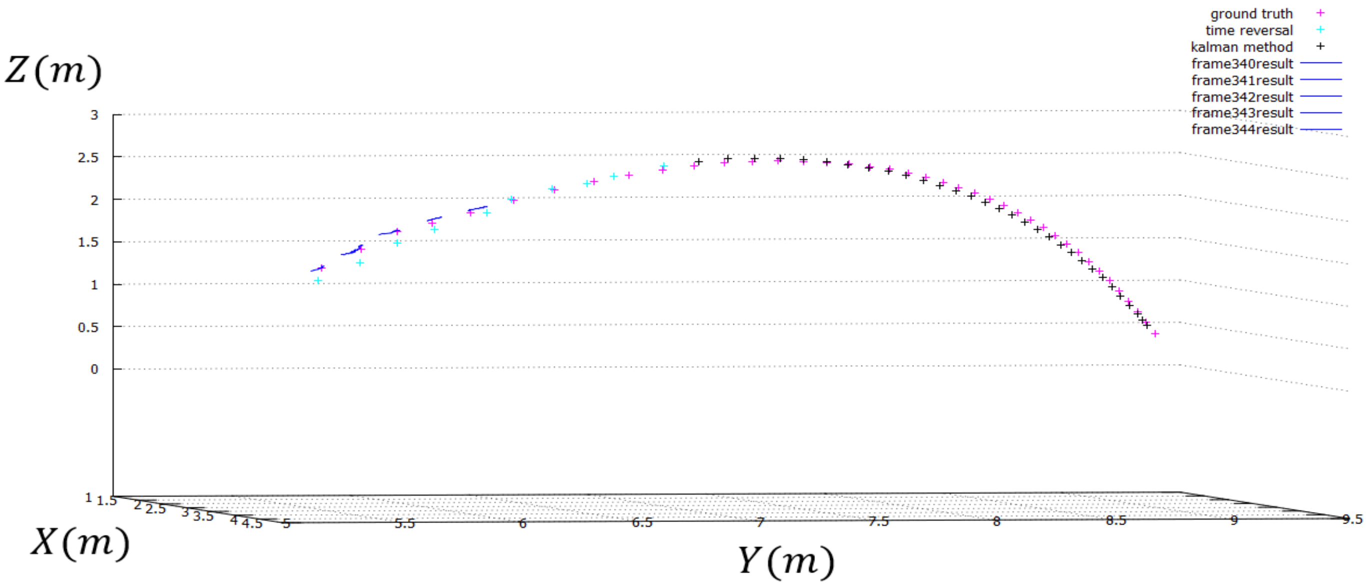


Fig. 5. Comparison experimental results of suggestion technique and the previous technique（3D position estimate of the shuttle）

V. CONCLUSIONS

This paper proposes a method to estimate position of a small moving object such as a badminton shuttle. Shape-from-silhouette technique is applied to estimate the 3D trajectory of the observation lines in the multiple-view images. As the result of experiment, we confirmed that our proposed method could estimate the 3D trajectory even when the shuttle moves very fast and anomalously. Part of this work was supported by JSPS KAKENHI Grant Number 23300064.

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