A Method to Estimate Ball's State of Spin by Image Processing for Improving Strategies in the RoboCup Small-Size-Robot League

Yuji Nunome[1](✉), Kazuhito Murakami[2], Masahide Ito[2], Kunikazu Kobayashi[2], and Tadashi Naruse[2]

[1] Graduate School of Information Science and Technology, Aichi Prefectural University, Nagakute, Aichi 480-1198, Japan
im132007@cis.aichi-pu.ac.jp

[2] School of Information Science and Technology, Aichi Prefectural University, Nagakute, Aichi 480-1198, Japan
{murakami,masa-ito,kobayashi,naruse}@ist.aichi-pu.ac.jp

Abstract. This paper addresses an estimation problem of the ball's state of spin in RoboCup Small Size League (SSL). A spinning ball varies its speed after the ball bounces off the floor. This paper proposes an image-based estimation method of the ball's state of spin, in particular, by using inertia feature of co-occurrence matrix of the image sequence. The effectiveness of our proposed method is shown by some experiments.

1 Introduction

The RoboCup small size league (SSL) is one of the soccer leagues in the RoboCup [1,2]. The size of robot is limited less than 180 mm diameter and less than 150 mm height. Each team which consists of six robots plays the game on a field of size 8090 mm × 6050 mm. Four cameras are equipped above the field to overlook the entire field. The positions of the robots and the ball are recognized by the image. Based on the position information, each team decides an appropriate strategy.

Each robot can kick the ball in two different ways, straight-kick-type and loop-kick-type (called chip-kick), and also has a rolling mechanism which gives a strong spin to the ball. When the ball is chip-kicked with strong spin, the spinning ball varies its speed after the ball bounced off the floor. This makes it difficult to predict the locus of the ball. So, the estimation of the ball's state of spin is very important to dominate the game.

Few paper has been reported in the field of estimating ball's state of spin in the RoboCup SSL. In some ball games, several papers have been reported to estimate it by high-speed camera. Inoue et al. reported how to estimate the vector of spin axis and speed by tracing a seam pattern on the surface of the ball by using a high speed camera [3]. They obtained the rotation axis and spinning speed by comparing the input image with the image stored in database.

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Tamaki et al. reported a method to estimate spinning speed by image registration [4]. They utilized an information of the mark on the surface of the ball. Liu et al. proposed a method by using two high speed cameras to calculate both of ball's speed and spinning speed [5]. These methods could be applied if some kinds of mark patterns are attached or printed on the surface of the ball. In Robocup SSL, a golf ball is used, so it is difficult to apply these image processing methods straightly because there is no feature on the surface of the golf ball except maker logotype. And furthermore it is not so easy to set up and control expensive multiple high speed cameras.

Federico et al. reported how to estimate rotation of the ball without using high speed camera [6]. In their method, the vector of spin axis and speed are estimated by using the movement of the six marks that are placed on the surface of the soccer ball. However, their method could be used under the condition that the rotation speed of the soccer ball is 10 rps or less. In the RoboCup SSL, the rotation speed is very high (more than 30 rps), so it is difficult to apply this method.

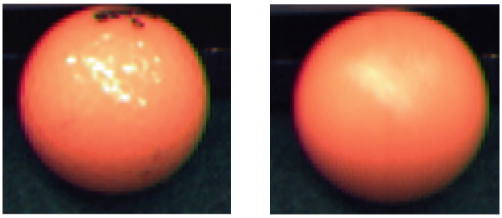
When a ball is spinning, some kind of blur is observed in the region of the ball. One of the principal factors of blur is the dimples on the surface of the ball. The degree of blur changes according to the exposure time of the camera and the rotational speed of the ball. This paper proposes a new method to estimate the ball's state of spin by using inertia feature of co-occurrence matrix of the image sequence. This method doesn't need a special pattern attached on the surface of the ball.

In this paper, Sect. 2 describes our basic idea to estimate ball's state of spin and Sect. 3 explains concrete methods to calculate inertia feature and co-occurrence matrix and Sect. 4 expresses experimental results to show the effectiveness of the proposed method, and after that, Sect. 5 discusses the rotation speed of the ball and application to strategy.

2 Basic Idea

In the RoboCup SSL, an orange golf ball is officially used. There are many dimples on the surface of the ball. These dimples cause the changes of reflection and this reflection changes according to the degree of blur. Figure 1 shows the differences of the images. Figure 1(a) is a static ball's image and some highlight regions exist in it, on the other hand Fig. 1(b) is a spinning ball's image and it looks like a smoothed image. It will be possible to estimate the ball's state of spin by analyzing the distribution of reflection.

In order to observe the surface of the ball, let an additional camera (i.e. PTZ camera) be installed to the vision system as shown in Fig. 2. The data flow of our vision system is shown in Fig. 3. In the RoboCup SSL, the standard vision system called SSL-Vision [5] is utilized and it sends the information of the position and ID of each robot and the ball. In addition to these information, to send the ball's state of spin realizes a new strategy to cope with an irregular bounce of ball.



(a) static ball (b) spinning ball

Fig. 1. Differences of the images

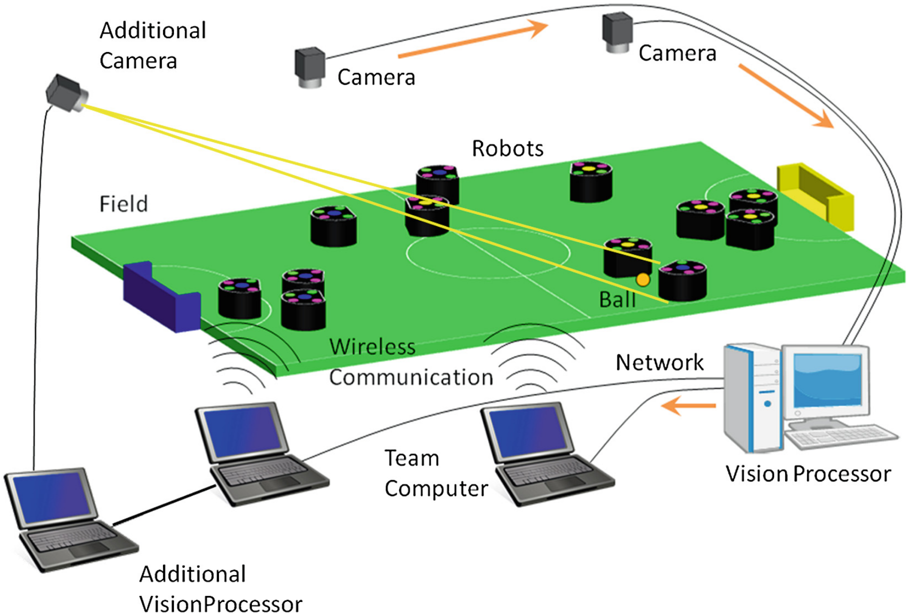


Fig. 2. Cameras' layout

3 Image Processing Method to Estimate Ball's State of Spin

The main flow of our image processing system is shown in Fig. 4. Our system is composed of 3 parts of image processing. First, the ball's region is extracted (*Step* 1), then co-occurrence matrix and inertia feature are calculated in the ball's region (*Step* 2), and finally the ball's state of spin is estimated (*Step* 3). Details of each step is as follows:

Step 1. **Extraction of ball's region**

Let each frame of image sequences be inputted. An example of input image is

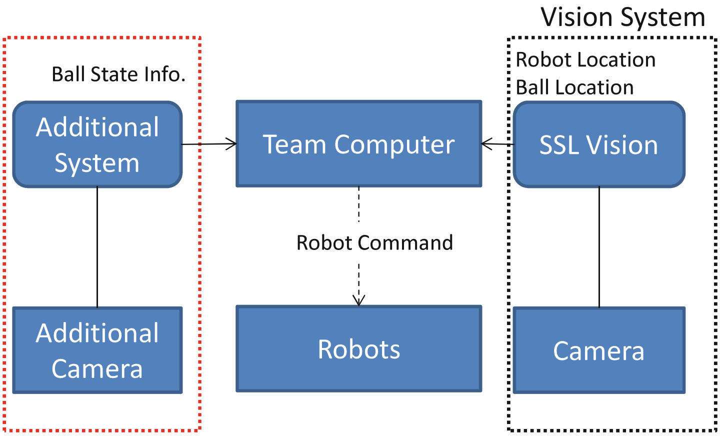


Fig. 3. Data flow of vision system

shown in Fig. 5. Then, make the grayscale image that is high value in the ball region (Fig. 6) and the grayscale image is threshold by discriminant analysis method. Threshold image is processed by expansion and contraction, then, threshold image is labelled. After the image is labelled, let the second largest region be that of the ball (Fig. 7). Then, extract the rectangle region that of the ball's region. In the rectangle region, covert to (R,G,B)=(0,0,0) except ball region. Then, let the rectangle region as shown in Fig. 8 be the processing region in the following processes.

Step 2. **Calculation of co-ocurrence matrix and inertia feature**
First, calculate co-ocurrence matrix $P_\delta(i, j)$ from the B-channel image of the extracted region in *step* 1. Here, Dx and Dy be the differences of x- and y-coordinates of two pixels, respectively, and $\delta = (D_X, D_Y)$ denotes the vector of them, and i and j are the values of these two pixels. The inertia feature Ine is calculated from $P_\delta(i, j)$ as

$$Ine = \sum_{i=0}^{n-1} \sum_{j=0}^{n-1} (i - j)^2 P_\delta(i, j) \tag{1}$$

Step 3. **Judgment of ball's state of spin**
For each frame, the intertia feature Ine is thresholded by an suitable value and the ball's state of spin is judged as follows:

$$BallState = \begin{cases} StaticState & (Ine > Threshold1) \\ UnknowState & (Threshold2 \leq Ine \leq Threshold1) \\ SpinningState & (Ine < Threshold2) \end{cases}$$

$Threshold1$ and $Threshold2$ are easily obtained, for example, by discriminant analysis, because the value of feature Ine are greatly different. $UnknowState$ is the transition between $StaticState$ and $SpinningState$.

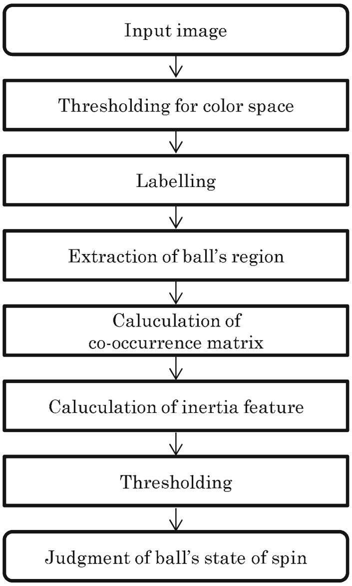


Fig. 4. Flowchart of image processing

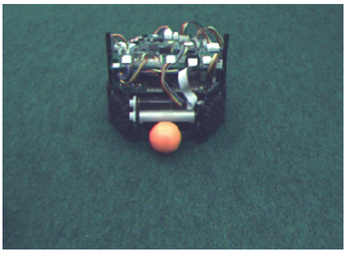


Fig. 5. Original image

Fig. 6. Grayscale image

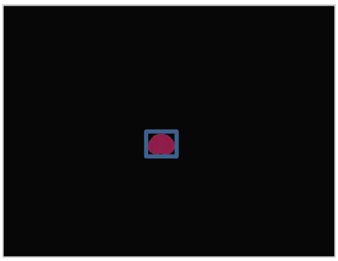


Fig. 7. Ball's region**** C ****

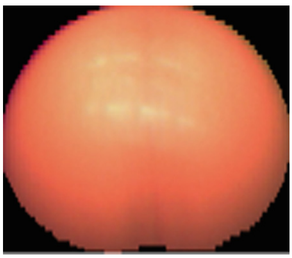
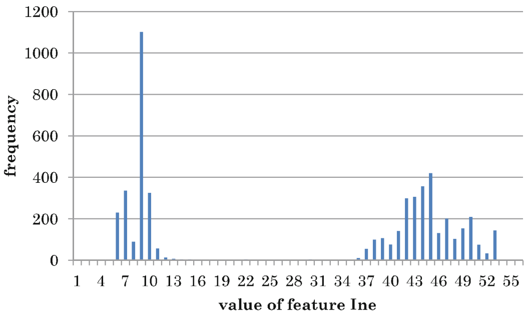


Fig. 8. Enlarged image to be processed

(a) The changes of the inertia feature



(b) Distribution of frequency

(c) Average and standard deviation of Ine in each state

	$StaticState$	$SpinnningState$
Ave.	44.978	9.201
S.D.	3.177	1.124

Fig. 9. An example of the inertia feature for an image sequence (spin and stop is repeated)

4 Experiment

Figure 9(a) shows an example of the changes of the inertia feature for an image sequence in which the ball repeats spinning and stopping. It is known from the figure that Ine is changed largely between the ball's state is spinning and stopping. Figure 9(b) shows frequency of feature Ine and Fig. 9(c) shows average and standard deviation of Ine in $StaticState$ and $SpinningState$. Spinning and stopping images are taken by A601fc (Baslar make) [6] and the parameters of the camera are as follows:

-frame size:	656×490 pixels
-frame rate:	30 FPS
-exposure time:	1/60 s

The performance of our proposed method is evaluated by calculating success rate. The ball's state was estimated by proposed method, where $Threshold1 = 35$

and $Threshold2 = 13$. Let BS_n and BS'_n be the ball's state in the n-th frame by image processing and its truth, respectively. $SUCEESS$ or $FAILURE$ was given by

$$\begin{aligned}
&if \quad ((BS_n == StaticState)\&\&(BS'_n == StaticState)) \\
&\qquad\qquad SUCCESS \\
&else\ if((BS_n == SpinningState)\&\&(BS'_n == SpinninngState)) \\
&\qquad\qquad SUCCESS \\
&else \\
&\qquad\qquad FAILURE
\end{aligned}$$

6054 of 6100 frames succeeded, thus the success rate in this case was about 99.2 %.

5 Discussions

5.1 Relation Between Inertia Feature and Rotation Speed

In order to obtain the relation between the value of Ine and the spinning speed, we experimented by changing the rotation speed of the ball. The result of the inertia feature for the rotation speed is shown in Fig. 10. It is shown from Fig. 10 that the value of inertia feature Ine decreases according to the increase of the spinning speed of the ball, so it will be possible to estimate the spinning speed of the ball if this curve could be modeled by some experiments at the venue of the competition [9].

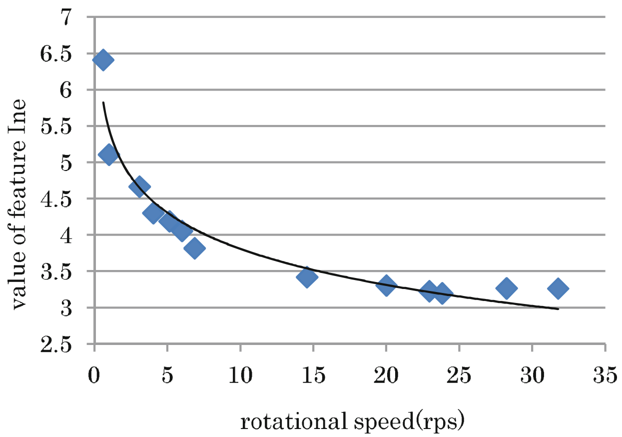
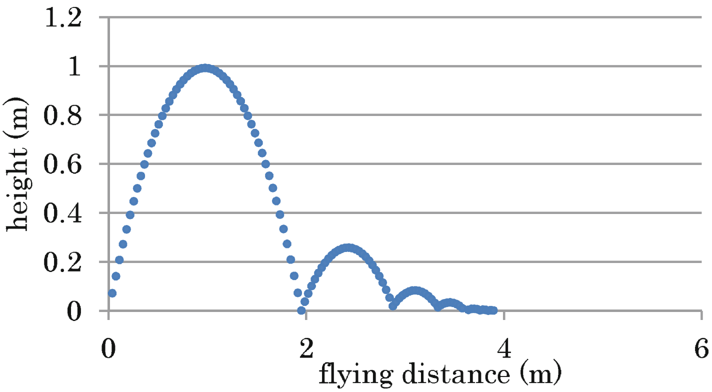
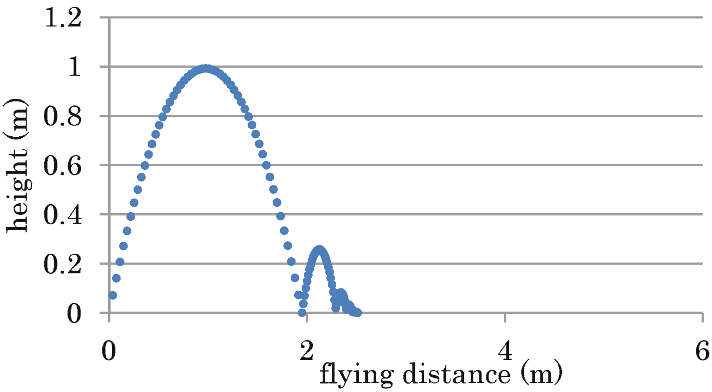


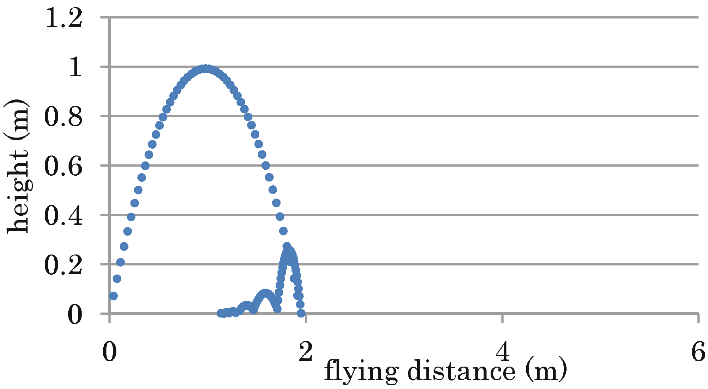
Fig. 10. An example of the changes of the inertia feature for an image sequence (spin and stop is repeated)



(a) in the case of 0rps



(b) in the case of 10rps



(c) in the case of 20rps

Fig. 11. Trajectory simulation with different rotational speed

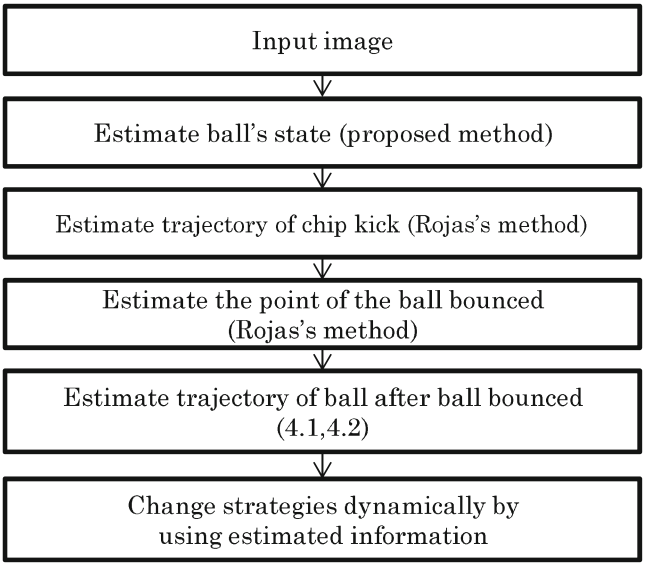
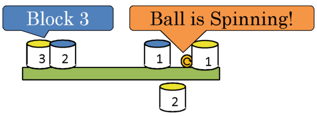
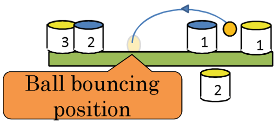


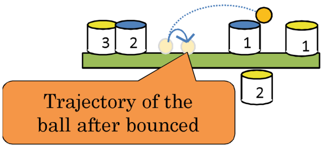
Fig. 12. Overview of the application to strategies



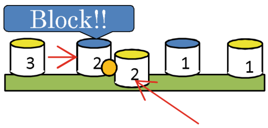
(a) *Step* 1: estimate the ball's state



(b) *Step* 2: estimate the position of the bounced ball



(c) *Step* 3: estimate the trajectory of the ball



(d) *Step* 4: change strategy by using estimation

Fig. 13. Application to strategies (blue mark robots : our robots; yellow mark robots : opponent robots) (Colour figure online)

5.2 Relation Between Rotation Speed and Ball's Trace After the Ball Bounced Off the Floor

It will be possible to predict the ball's movement by estimating the rotation speed of the ball. Figure 11 shows the trajectory simulations that the ball is kicked at 5 m/s and 60 degrees with different rotation speed. In the case of *StaticState*, the kicked ball is traced as shown in Fig. 11(a) and reaches to 4 m distance. In the case of 10 rps rotation speed, the kicked ball is moved as shown in Fig. 11(b). In the case of 20 rps rotation speed, the kicked ball is come back by strong spin as shown in Fig. 11(c).

The spinning ball varies its speed after the ball bound off the floor. Thus if the rotation speed of the ball can be estimated, the trajectory of the ball after the bound off the floor will be predicted more accurately.

5.3 Application to Strategies

The proposed method described can be applied to various strategies in the RoboCup SSL. Overview of the application to our strategies is shown in Fig. 12. It is possible to apply the strategies, if the trajectory of the ball can be predicted.

New defense strategies will be possible as shown in Fig. 13 (in this figure, the blue robots are ours, the yellow ones are opponent robots). In the defense, the following situation is expected:

Figure 13 shows an example of a defense strategy improved by the proposed method. We here suppose the following situation:

1. The yellow ID1 is going to kick the ball and the blue ID1 blocks the straight-kick pass.
2. The yellow ID3 is in the position where the ball will come after chip-kick by the yellow ID1,
3. And the blue ID2 is in the position where this robot can block the yellow ID3 as shown in Fig. 13(a).

In this situation, (*Step* 1) the ball's state of spin is estimated by the proposed method as shown in Fig. 13(a). Then, (*Step* 2) the point of the ball bounced off the floor is estimated by Rojas's method [10] as shown in Fig. 13(b). Next, (*Step* 3) the trajectory of the ball after bounced is estimated as shown in Fig. 13(c), and finally (*Step* 4) even if the yellow ID2 moves to the position of the ball after bounce, the blue ID2 robot is able to move to around the yellow ID2 robot for blocking shoot as shown in Fig. 13(d). Accordingly, we can prevent disadvantageous situation.

By estimating the rotation of the ball, it is possible to correspond to defense. Furthermore, by estimating the rotation speed, it is possible to improve the positions of robots for defense.

6 Conclusion

We have proposed a method to estimate the ball's state of spin by using inertia feature of co-occurrence matrix of the image sequence. The effectiveness of our proposed method was demonstrated some experiments. We also discuss the following things: (1) the possibility to estimate the spinning speed of the ball by the relation between the value of Ine and the spinning speed, and (2) an application to a defense strategy of the RoboCup SSL.

The proposed method works well in our prototype system. In future work, we need to confirm the robustness in various environment. It is also important to implement our method to a strategic learning system.

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