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Curling Stone Tracking by an Algorithm Using Appearance and Colour Features

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Abstract- Computer vision-based systems have been applied to sports broadcasting and sports analysis. In particular, object detection and tracking algorithms have been extensively adopted because they can be used to automatically annotate game elements. Curling is a highly strategic sport. The strategic is determined by a curling stone's trajectory and position. This paper presents the automatic annotation of curling stone position in broadcast videos, for which a mean-shift tracking algorithm is used to examine the appearance and colour information of curling stones. The algorithm uses a multi-dimensional histogram feature vector that contains a sampled pixel value of each RGB colour channel and edge information. The mean-shift kernel is a circular kernel. We also use a Kalman filter to track occluded stones. The experimental results show that the proposed method more precisely and rapidly tracks stones than does a general mean-shift method.

***Keywords*:** curling, stone tracking, mean-shift tracking, multi-dimensional histogram, Kalman filter

1. Introduction

Early computer vision technics have been applied to sports broadcasting and sports analysis (Thomas, 2011), specifically for the automatic detection and tracking of sports fields, players and balls. The data derived from detection and tracking can help sports coaches conduct game analyses. Additionally, annotated information in the form of graphic overlays and 3D reconstruction serves as visual support for commentators and experts (D'Orazio and Leo, 2010; Thomas, 2011), thereby improving spectator engagement with sports broadcasts.

A number of sports competitions have benefited from computer vision-based applications. The FoxTrax system, for example, was developed for the real-time detection of puck position during a hockey game; in this system, broadcast cameras equipped with a specialised tripod it can be encode camera poses in real time and multiple infrared cameras detect the position of a hockey puck (Cavallaro, 1997). The Pitch Tracking System, developed for baseball, can annotate the position of a pitched ball on input images captured by three cameras; the system uses number of pixels and blobs, intensity and colour as bases for annotation (Guziec, 2002). A recent development in these technologies is the use of high-speed cameras and high-performance computers in evaluation (Mcilroy, 2008; Owens et al., 2003). Despite the possibilities presented by these technologies, however, most applications have been directed towards popular sports events.

Curling can extend the opportunities of computer vision technologies. It has been an official sport in the Winter Olympic Games since 1998 and has been played by approximately a million people around the world. Curling is characterised by various tactics based on stone position and trajectory, thereby earning it the title 'chess on ice' (Bradley, 2009). Nevertheless, only a limited number of analytical applications have been developed for this sport. Some coaches use tablet applications to record the positions and trajectories of curling stones, but these applications are unsuitable for real-time game analyses and coaching because they require manual input.

To address this deficiency, we propose computer vision-based automatic annotation and tracking of curling stones. The tracking method features a mean-shift tracking algorithm (Comaniciu et al., 2000) that examines a curling stone's colour and appearance.

2. Proposed Method

As previously stated, the proposed method uses a mean-shift tracking algorithm for stone tracking in curling broadcast videos. In particular, we construct a histogram on the basis of convergent colours and edges and use a circular kernel for examining stone appearance. We also apply a Kalman filter to track stones occluded by players and sweeping manoeuvres.

2. 1. Mean-shift Tracking Using Colour and Appearance of Curling Stones

In mean-shift algorithm constructs, a one-dimensional feature vector is normalised by the probability density function (pdf). The pdf denotes the histogram of various values measured around a tracked object. A feature vector H of arbitrary object O is defined thus:

$$
\begin{aligned}
&H(l) = [H_0(0) \mid \ldots H_k(l_k) \mid \ldots H_l(l)] \\
&H_k(l_k) = \frac{h_o(l_k)}{N} \\
&0 \le H_k(l_k) \le 1, \quad \sum_{k=0}^{N-1} H_k(l_k) = 1
\end{aligned}
\tag{1}
$$

Where h_o is the histogram of object O and l denotes $l = 0, 1, \ldots, N-1$ (N is the dynamic range of pixel values).

The histogram can be the sampled object values, measured by suitable bins for the purpose of reducing performance time and complexity. Fig. 1 shows a feature vector of a grayscale image with a 256-step intensity value represented by 16 bins.

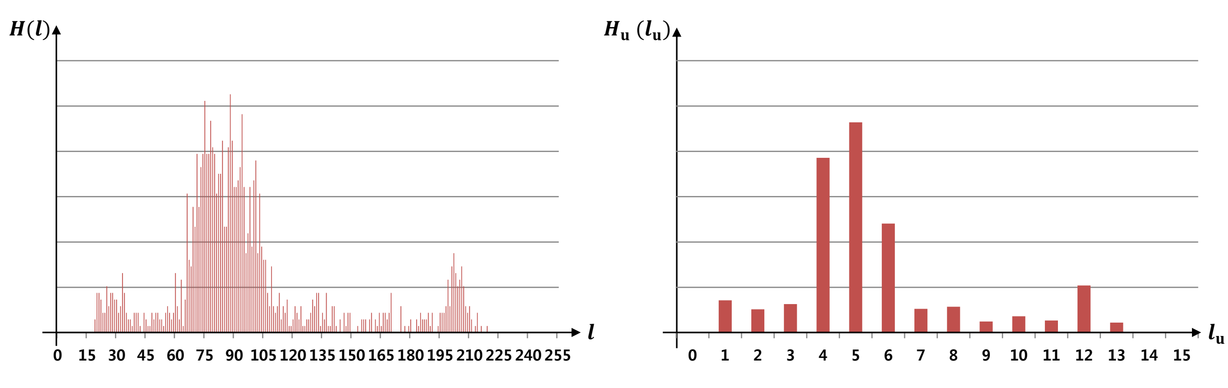

Fig. 1. Probability density of grayscale image (left); probability density sampled by a 16-bin histogram (right).

The performance of a mean-shift tracking algorithm depends on how discriminately it represents the random variables of an object. A general mean-shift tracking algorithm weakly distinguishes the textural information of an object because it uses only colour or intensity information (Cuce and Cetin, 2004). To rectify this problem, many researchers proposed multi-dimensional histograms that use various feature information. Cuce and Cetin (2004) put forward the application of convergent intensity and edge information for distinguishing FLIR sequences. In this approach, data dimensions are doubled, thus creating a theoretical histogram length of N^2, although the proposed histogram represents only $2N$. The approach enables more accurate distinction because of the use of intensity and edges and only minimally increases computation time.

In curling competitions, two teams are distinguished from each other by the colours of the stone handles used (WTF Secretariat, 2014). A curling stone is characterised by a considerable number of edge details, such as the borders of a stone and a handle, as well as that between a handle and granite. Fig.2, shows edge image of a red stone. With these considerations, we formulate a mean-shift feature vector $X(N)$ that is a multi-dimensional histogram integrating R (H_R), G (H_G) and B (H_B) colour information and edges (H_E). This vector is defined as follows:

$$X(N)=[H_E(N_E)H_R(N_R)H_G(N_G)H_B(N_B)] \tag{2}$$

We can determine the most accurate performance by examining each colour channel sampled by 4 bins. The proposed length of the feature vector is 128.

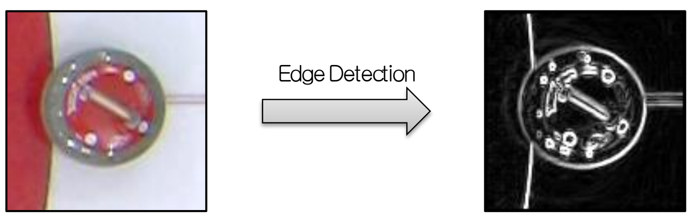

Fig. 2. Appearance feature of curling stone (edge information).

2. 2. Robust Tracking Method to Occlusion Using Kalman Filter

Curling stones do not always clearly appear in video sequences. Sometimes, these elements are imperceptible because of occlusions from sweepers and other players occupying a frame. This issue decreases excellent tracking performance. To resolve this problem, we incorporate a Kalman filter into a stone tracker to predict stone position in occluded situations. We define state equation $\hat{x}_{\bar{k}} = A\hat{x}_{k-1} + w_k$ and measurement equation $z_k = Hx_k$. Eqs. (4)–(7) describe state vector $\hat{x}_k$, measure vector y_k, state transition matrix A and measurement matrix H.

$$\hat{x}_k = [x, y, \Delta x, \Delta y]^T \tag{3}$$

$$y_k = Hx_k \tag{4}$$

$$A = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}^T \quad (6)$$

The central position of a kernel traced by mean-shift tracking is denoted as (x, y), and the variations in central position are represented as $(\Delta x, \Delta y)$. Fig. 3 summarises the robust procedural structure of the occlusion tracking method that uses the Kalman filter.

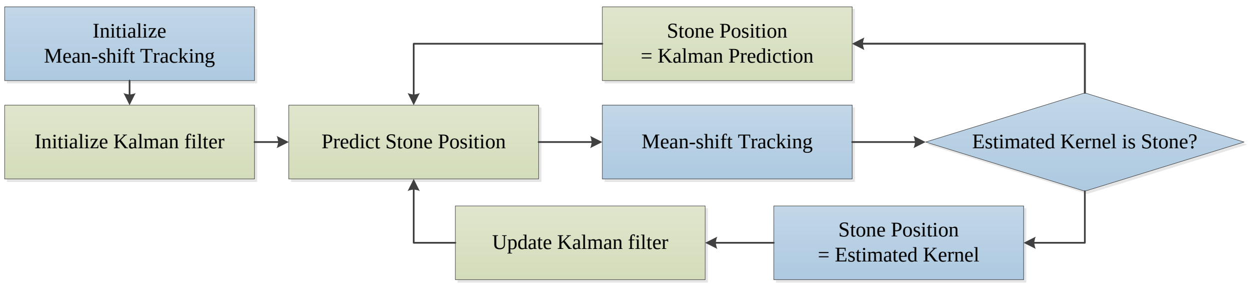

Fig. 3. Summarised procedure of occlusion tracking by Kalman filter

The estimated region is verified by Bhattacharyya distance that calculated compare between histogram of estimated region and histogram of initialised region.

3. Experiments and Results

To evaluate the performance of the proposed algorithm, we conduct a test on 10 broadcast sequences (1070 frames in total). The video used is the broadcast of Vancouver's game in the 2010 Winter Olympics. Tracking accuracy is evaluated by the Euclidean distance of the central position of the curling stone between the ground truth and estimated position, whereas tracking speed is determined on the basis of how many frames are processed in 1 second (frame per second: fps).

3. 1. Mean-shift Tracking Using Multi-dimensional Histogram Feature Vector

Table 1 lists the results of accuracy evaluation for the kernel shape and feature vector used with or without edge information. Whether a circular kernel is suitable for stone tracking can be determined in instances wherein a circular kernel-based tracker is more accurate than a rectangle kernel-based tracker. Furthermore, although the tracker uses any kernel, its feature vector more efficiently retains edge information. To ensure excellent accuracy, we choose a circular kernel and a feature vector that contains edge and colour information (each colour channel is sampled by 4 bins) for the mean-shift tracker.

The average frame rate of our proposed method is 74.80 fps, which is suitable for the analysis of curling broadcast videos because general broad cast video's frame rates are 25 or 30 fps.

Table. 1. Accuracy evaluation of kernel shape with or without edge information.

Kernel	Edge	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10	**Average**
Circular	Y	2.85	2.19	2.30	1.23	1.96	1.83	1.60	3.64	4.41	6.00	**2.80**
	N	3.18	2.53	2.27	1.41	3.04	2.17	1.68	4.17	4.38	5.79	**3.06**
Rectangle	Y	5.53	4.71	5.50	2.70	6.48	7.47	2.90	4.66	9.74	7.42	**5.71**
	N	5.97	4.93	5.28	2.25	48.08	7.37	4.33	3.31	5.21	9.80	**9.99**

3. 2. Robust Tracking Method to Occlusion Using Kalman Filter

Fig. 4 and 5 indicate that tracking is maintained by Kalman prediction for occluded situations on the Dataset 10. In the Fig. 4, two trajectories represent the distance between the top-left corner of a frame and the central position of a stone.

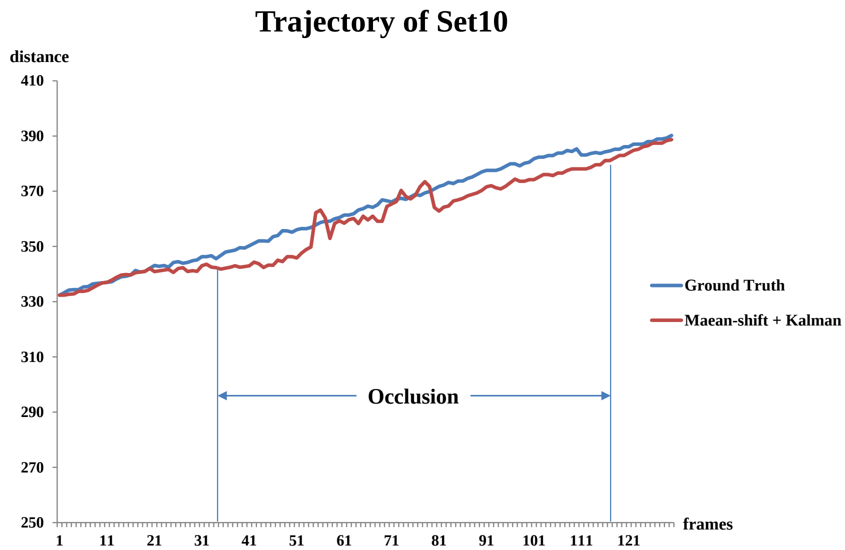

Fig. 4. Trajectory result of occluded stone.

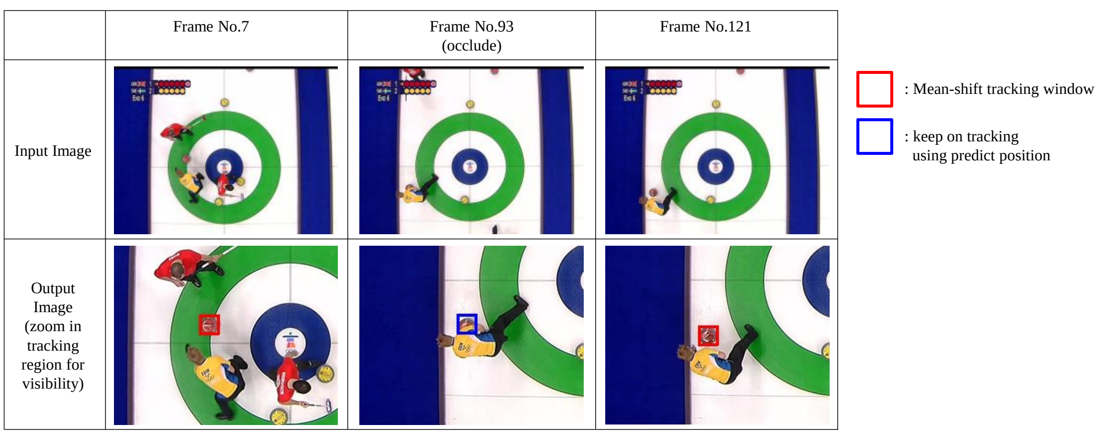

Fig. 5. Tracking result of proposed algorithm.

Occlusion proceeds from the 32nd to the 112th frame during stone occlusion, but the tracker maintains tracking by Kalman prediction. After the occlusion, the tracker uses the position estimated by the mean-shift tracker, an approach that also reduces error.

4. Conclusion

This paper presents a curling stone tracker based on a mean-shift method that examines stone appearance and colour. Curling stones are circular in nature, thus prompting us to choose a circular mean-shift kernel. The feature vector of the tracker uses a multi-dimensional histogram that comprises edge and colour information. The experimental results indicate that the proposed method improves accuracy and computation time. It also solves the problem posed by occluded stones because of the Kalman filter incorporated into the tracker. Our method can be applied in analysing curling sports broadcast footage and automatically annotating stone position and trajectory. The information derived would facilitate the analysis of curling games.

A limitation of this study is that although sports broadcast cameras frequently vary camera parameters, such as pan, tilt and zoom, the consideration of these parameters is not incorporated into our method. Future research can address this issue by examining whether these affect the performance of a curling stone tracking algorithm.

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