Camera pose estimation based on concentric circles and parallel lines of a curling sheet

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Abstract: In this paper, we present a method for extracting the 4 feature points for camera pose estimation using concentric circles and parallel lines. Given a real curling sheet image, we recognize the concentric circles clearly and then locate the centers of projected concentric circles, resulting in 4 points to be used to estimate camera pose. Experimental results show satisfactory performance.

Keywords: Curling, camera pose estimation, concentric circles, parallel lines.

1. Introduction

Curling is the winter sports that players throw stone on a curling sheet and brush the ice for the purpose of controlling the stone's speed and path. Then, they score if they throw a stone closer to the center of the house than the stones of the other team. Through 2018 Pyeongchang winter Olympics, curling became more popular than the past. Before Olympics, people didn't have a lot of interest in curling but now many people know curling. Aside from this, many researches about curling have been processed from the past. There were researches about special environment such as ice's pebble [1], ice's friction [2], stone's material [3], how stone passes through the ice [4] and why stones have a curl on the ice [5]. Additionally, a deep learning approach [6] which can find more precise and newer strategy than curling players is also under active discussion lately. Recently, there are a lot of interests in sports science [7] and sports science can help players to develop their game skills.

For studying these researches or wide applications, researchers need visual data based on real curling sheet such as images or videos. Also, in order to use data meaningfully or interpret the data well, they should know camera's extrinsic parameters such as camera's rotation and translation. Studies about camera pose estimation which means calculating these extrinsic parameters also have long been studied from the past. Especially, using concentric circles [8,9,10] or parallel lines [11] are active. However, as our knowledge, there is no study about camera pose estimation on curling sheet especially using the 4 points with known world coordinates. If we use curling data and apply science to practical use, we should get the ability that can understand the curling sheet data firstly. We propose the method for camera pose estimation on curling sheet using concentric circles and parallel lines when the camera is in the curling sheet.

For analyzing and studying a curling sheet using camera which observes a curling sheet, we have to know camera's rotation and translation which mean camera's angle and location respectively. As well-known methods, we also use Perspective-n-Point method [12] and it signifies that we should find at least 4 points that we know their image coordinates and world coordinates. Since curling sheet has special patterns, we recognize these patterns and perform image process to get the 4 points.

This paper is organized as follows. In section 2, we introduce curling sheet, patterns on curling sheet and their projection to images. Section 3 describes how to find concentric circles and how to get the 4 points using concentric circles and parallel lines. In section 4, we present experimental methods, situations and their corresponding results.

2. Curling sheet and its projection

Most curling sheets have similar appearances and fixed sizes. The total length is 44.5m and width is 4.5m to 4.75m. Also the diameters of three circles in house are fixed as 3.66m, 2.44m and 1.22m respectively. This fact implies that we can know the world coordinate if we find special point in image.

As shown in Figure 1 (a), several patterns such as sideline and hogline exist in curling sheet. For convenience, we named left sideline as 'sideline 1', right sideline as 'sideline 2'. And we called border of the biggest circle in house as 'circle 1' and the second biggest circle as 'circle 2'.

When the patterns in the same plane are observed by cameras, they are projected in the image as shown in Figure 1 (b). The parallel lines change to the two lines intersecting with each other and their intersection is vanishing point. The concentric circles are projected to ellipses. Likewise, we called the biggest one as 'ellipse 1' and the second biggest one as 'ellipse 2'. Circle 1 is projected to ellipse 1 and circle 2 is projected to ellipse 2, respectively. It is noticed that the projected point corresponding to the center of circle and the center of ellipse are different because of projection properties. This difference has many characteristics [8]. We applied these characteristics to our method and We applied these characteristics to our m ethod for getting 4 feature points in the curling sheet.

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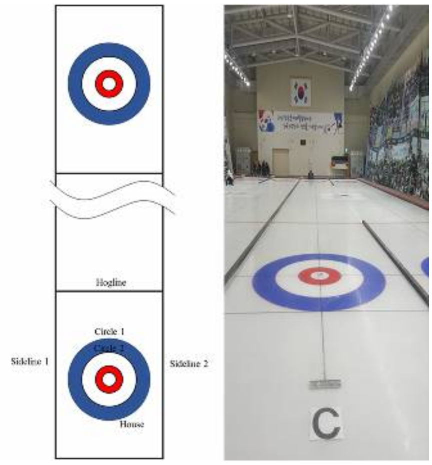


(a) (b)

Figure 1. Curling sheet and its example image.

3. Concentric circles and parallel lines

3.1 Method for finding ellipses equations

Curling sheet is composed of 3 colors; white, red, and blue. In real image, pixel values of white area are little more various than those of the other areas because they can be influenced easily by other environment such as brightness. Also, the white area inside the house has slightly different color than outside of the house because it is painted to clarify the house. So our method segments the curling sheet using k-means algorithm twice.

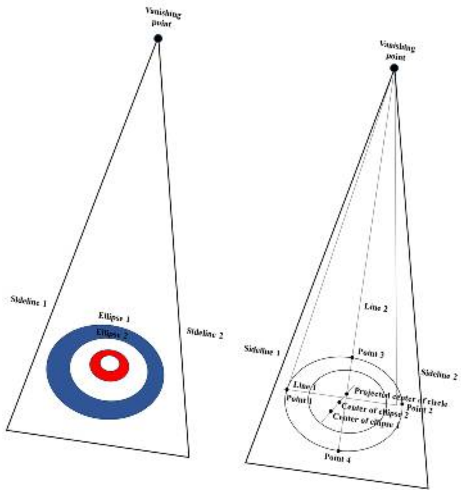
First k-means algorithm segments several regions including ellipse 1 and the others, due to huge difference of blue and white colors. After dividing the region, we can obtain the external contour of blue color segmentation. We exclude some contours which are not arc and line or contour size is too small. Also we judge contours are ellipse. These contours mean border of ellipse 1. Lastly, using the points on the border we can obtain ellipse 1's equation.

Next step is dividing internal ellipse 1. we also use k-means algorithm to divide ellipse 1. Ellipse 1 contains constant blue, red, white colors so it divides clearly. Repeating the former step then we can also get the ellipse 2's equation. By performing k-means algorithm twice, we can divide the colors in curling sheet clearly than once. Curling sheet patterns especially circles often covered with people or curling materials so sometimes it is hard to find the ellipse. Unless whole ellipses covered, we can find the ellipses in this method because there are four ellipses in the house.

3.2 Method for finding 4 points using concentric circles and parallel lines

Figure 2 (a) shows which patterns are used in this paper briefly and Figure 2 (b) shows how to find 4 points using concentric circles and parallel lines. For convenient description, two pictures in Figure 2 are drawn exaggeratively so that several geometric characteristics are not valid in those pictures. For example, we prevent the line of each centers of the two ellipses from aligning with the centerline. In the first step, if we find the intersection of sideline 1 and sideline 2, it makes the vanishing point. Then, by drawing the tangential lines from the vanishing point to ellipse 1, we can get the two tangential points. In sheet coordinate system, the two tangential points are parallel to sidelines and the center of concentric circles is on the 'line 1' which is the line of the two tangential points. Likewise, the projected center of concentric circles is also on the line 1. There is a study which proved relationship among the projected center of concentric circles and the center of ellipses [8]. The study proved that the center of projected circles always lies on the line defined by the ellipse centers for any projective transformations. We applied this invariance to the curling sheet. As we know ellipse 1's equation and ellipse 2's equation, we can obtain the centers of ellipses and connect them to get a line and named it as 'line 2'. At now, we have two different lines which pass the projected center of concentric circles. Thus, intersection of line 1 and line 2 can give us the projected center of concentric circles.

Lastly, our method extracts the 4 points for estimating extrinsic parameters. The two intersections of ellipse 1 and line 1 are the first two points and the two intersections of ellipse 1 and line 2 are the other two points. Consequently, we can get the 4 points we need. Then we call them point 1, point 2, point 3 and point 4 as Figure 3 (b) shows. Finding the 4 points is this paper's objective and we will also discuss our method's accuracy. Their world coordinates are (-1830mm, 0mm), (1830mm, 0mm), (0mm, 1830mm) and (0mm, -1830mm) when we assign (0mm, 0mm) to the center of concentric circles. Direction of sidelines toward the opposite side of the house is y-axis and direction of hogline from left to right is x-axis.



(a) (b)

Figure 2. Projection of the curling sheet.

4. Experimental results

4.1 Experiment

Our experiments are processed with Jetson tx2 board and OpenCV libraries. Before making dataset for our experiments, we pre-calibrated our camera usinsg MATLAB CALIBRATION TOOLBOX [13] so we calculated the distortion coefficients and experimented with undistorted images. We followed distortion models of J. wengs' [14]. Skew parameter is very small so we set skew parameter as 0. The intrinsic parameters of our camera are as follows.

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Table 1. Focal lengths and principal points of the camera

Focal length x -axis	Focal length y-axis	Principal point x	Principal point y
752.3896	565.0002	586.0002	355.7535

Table 2. Distortion coefficients of the camera

Distortion k1	Distortion k2	Distortion k3
-0.0437	0.0835	-0.0040

Data are filmed by ourselves in Icheon curling training center. We made videos for various situations. Firstly, we located the camera on the hack. Because, in the general cases, changing the angle of camera is more common than changing the location of camera. So, we recorded videos while changing the angle of camera from -15 degree to 15 degree. Our image resolution is 1280x720 and framerate is 15 frames per second. We chose the frames to have uniform angle increment.

Secondly, we got the data images in various locations; left and right to the hack and also behind the hack. It means if our algorithm performs good in these locations, it validates robustness to location. Lastly, we got the additional data when people or other devices hid the circles partially. Figure 3 shows our experimental environment.

Figure 3. Experimental set-up

Measuring rotation and translation is difficult because there are some constraints that installing sensor are restricted on the ice because ice could be damaged easily. Also using protractor for camera's angle is not accurate due to people's error when they measure. Thus, we made the ground-truth data by human labeling. People chose point 1, point 2, point 3 and point 4 respectively in the images and we can evaluate our method by comparing with the ground-truth.

4.2 Results

We performed the algorithm to our real image dataset. We decided error measure as Euclidean distance of each points and finally calculated the average. Figure 4 shows our experimental results. Left image is input, real image of curling sheet, center image is our output image describing the process of our algorithm and right image is ground-truth.

(a) (b) (c)

Figure 4. Input, output and ground-truth of data

Next figure 5 and Figure 6 show that our data are robust to the angle of the camera. Figure 5 is some output images of our algorithm for various angles. We checked that our algorithm shows similar errors for every angles as shown in Figure 5. The ground-truth is not perfect so the error less than 5 pixels are ignorable.

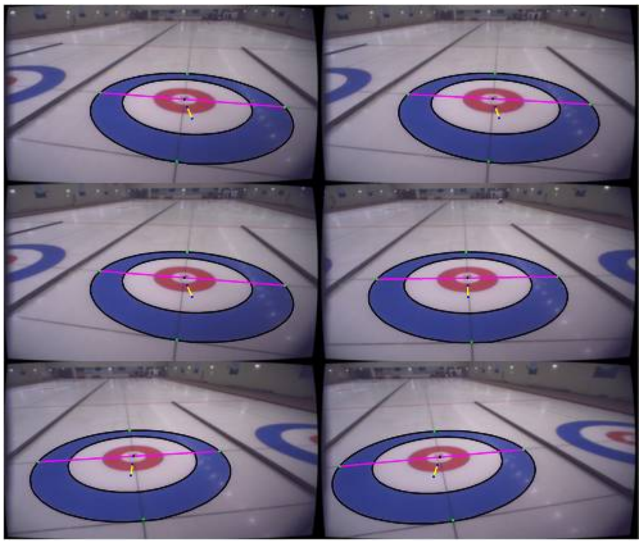

Figure 5. Output of the algorithm for various angles.

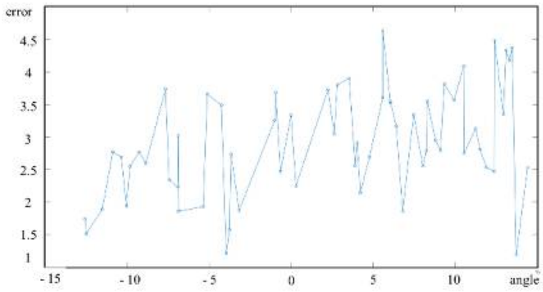

Figure 6. Estimated error with respect to angle.

Table 3 shows our errors with ground-truth data. Our errors of individual 4 points are less than 5 pixels in images and the average is less than 3 pixels. Considering existing error in ground-truth, it can be said that our performance is competitive to that of human. On the other hand, the major cause of error is because concentric circles or parallel lines are hidden or too dark.

Table 3. Error per each point and average error

Point 1	Point 2	Point 3	Point 4	Average
4.2237	1.4134	3.9560	2.1017	2.9237

Our next experiment is changing the location of camera. We identified that our method is robust to the location in the curling sheet. Figure 7 (a), (b) and (c) are the output images when the camera is on the left, right side and behind the hack of the curling sheet. They show if camera can see the parallel lines and the concentric circles, it is not important where the camera is. Last experiment is in the situation when a person occludes circles or

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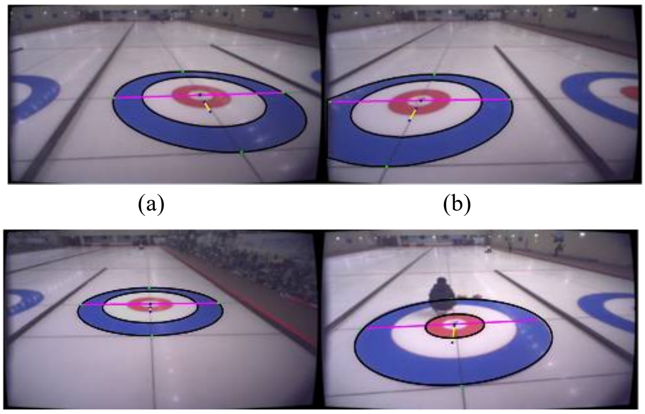
one of the particular points as shown in figure 7 (d). In this case, as mentioned above, algorithm finds circle 1 and the third biggest circle in house rather than circle 2 and obtain the 4 points correctly.



(a) (b) (c) (d)

Figure 7. Results of the algorithm for various locations and the occluded image.

5. Conclusion

In this paper, we proposed a new method for camera pose estimation using 4 feature points. We proposed and effective way to divide the curling sheet by colors clearly and get ellipses' equations. Also, we described how to find the projected center of concentric circles using concentric circles and parallel lines. We finally located the 4 points with their image coordinates and world coordinates.

We built our own dataset which consists of the real images of curling sheet and the 4 manually marked points of each image as ground-truth datasets. In our dataset, our method shows satisfactory performance. Our algorithm also performed well even if the camera is rotated or moved to other locations in the curling sheet.

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