Estimation of Curling Sheet Friction Factor by Pixelization

Ju-Hyung Lee [1], Hyan-Soo Bae [2], Jae-Hyeon Gwon[3], Nan-Hee Kim [4], Kamaloba Albina[5], Suk-Gyu Lee [6]

1. Yeungnam University, Gyeongsan, Korea
E-mail: nana970@naver.com

2. Yeungnam University, Gyeongsan, Korea
E-mail: bhs8017@naver.com

3. Yeungnam University, Gyeongsan, Korea
E-mail: kwon8598@naver.com

4. Yeungnam University, Gyeongsan, Korea
E-mail: kimnanhee97@naver.com

5. Yeungnam University, Gyeongsan, Korea
E-mail: dyupleks@gmail.com

6. Yeungnam University, Gyeongsan, Korea
E-mail: sglee@ynu.ac.kr

Abstract: This study estimates the coefficient of friction on the actual curling sheet with a pebble, without having to mount any devices on it. Existing studies have equipped the ice sheet with external devices to estimate the coefficient of friction. Another paper estimated friction coefficients, assuming that the pebble did not exist, because it was very difficult to estimate the coefficient of friction in the space where the pebble was located. In this study, it is possible to estimate the coefficient of friction of the actual curling sheet without fitting an external device onto the curling sheet. In addition, the friction coefficient estimation method attempted using image processing techniques may be most similar to the actual friction coefficient, reducing the outside influence, compared to the existing papers. It will also be an estimation method using image processing techniques, which form the basis of various friction coefficient screening methods.

Key Words: curling, friction factor, pixelization, image processing

1 Introduction

The recent Winter Olympics in PyeongChang has shown increased interest in curling. For the athletes, it is very important that the curling stones reach the house safely. Here, the friction between the curling stone and the ice determines the outcome of the competition. Curling sheets are made up of blocks of ice that are different from normal ice sheets, and friction factors are easily variable depending on temperature and friction. This study estimates the coefficient of friction on a curling sheet with actual pebble.

In the past, to estimate the coefficient of friction on the ice sheet, studies were conducted to determine the coefficient of friction by fitting external devices on the ice sheet [1]. However, this provides a reason why the pebble on the curling sheet may melt or change by fitting the device on the ice sheet, which may also affect the coefficient of friction. Another paper estimated friction coefficients assuming that the pebble does not exist because it is very difficult to estimate the friction coefficient for the space in which the pebble resides [2].

This study can estimate the coefficient of friction on the actual curling sheet with a pebble, without having to mount any device on it. The key idea that makes this possible, is proposing a method of estimating friction coefficients using image processing techniques. First, converts a 3D coordinate system to a 2D coordinate system for coordinates. The existing coefficient of friction inference method is used using the correlation between distance, velocity and acceleration based on the position of the moving curling stone. In the experiment, the friction coefficient for each pixel is estimated by considering the curling sheet as a set of several small, tiny pixels. After the coefficient of friction estimation has been made, compare it to the case where stone is thrown on the actual curling sheet.

2 Image processing

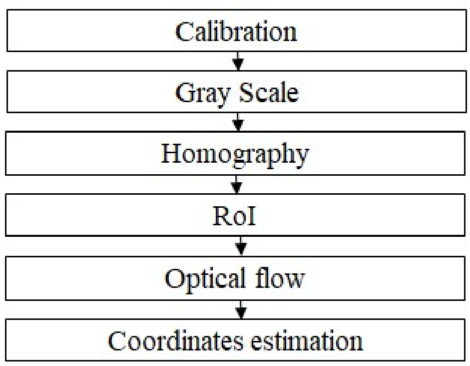


Fig. 1: Algorithm of image processing

The calibration process was performed to correct camera distortion in the image[3, 4].

*This work was supported by BK21+ (Brain Korea 21 Plus) Program funded by the Ministry of Education, Science and Technology.

Fig. 2: Getting image from video

Apply calibration to fig. 2. After that, convert the image to grayscale to save the amount of data in the subsequent process. To obtain 2D coordinates of the curling stone, convert the tilted curling sheet plane to the top view format. Call up the first converted image frame and specify four corners of the curling sheet. Then, with the coordinates of these four corners, proceed with the conversion of sheets into top view format using a homography matrix[5, 6].

$$\omega \begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} h_{12} h_{13} \\ h_{21} h_{22} h_{23} \\ h_{31} h_{32} h_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (1)$$

$h_{11}, h_{12}, h_{21}, h_{22}$: rotation, spread, reflection.
h_{13}, h_{23} : parallel translation(shifting).
h_{31}, h_{32} : change in perspective.
h_{33} : scaling.
x, y : each pixel.

In equation (1), x is the coordinates of the whole image, and x' is the coordinates of the image after homography. As can be seen from (2), the transformed image can be obtained by multiplying the original image by a homography matrix.

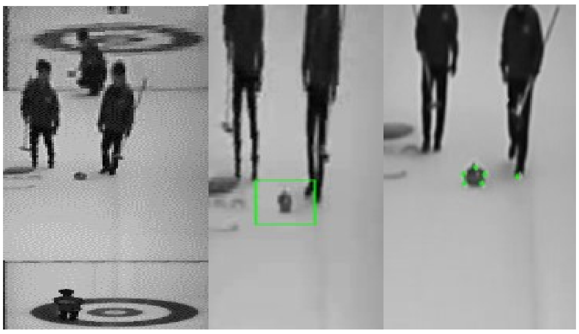
$$x' = \mathrm{H}x \quad (2)$$

Equation (2) makes it possible to create a plane corresponding to the top view type with four corner points of one plane. The following is the process of obtaining the transformed coordinates with the entered coordinates. First, the coordinates corresponding to the upper left corner are (x1, y1), (x2, y2) corresponding to the upper right corner, (x3, y3) corresponding to the lower left corner, and (x4, y4) corresponding to the lower right corner. (3) is the horizontal length of the transformed plane, (4) is the vertical length of the transformed plane.

$$(Horizontal\ length) = \frac{(x2 - x1) + (x4 - x3)}{2} \quad (3)$$

$$(Vertical\ length) = \frac{(y2 - y1) + (y4 - y3)}{2} \quad (4)$$

Draw a rectangle based on (x4, y4). The created rectangle corresponds to the transformed plane. It creates a homography matrix with four input corners and converts the saved image into top view format. When estimating the movement of curling stones after conversion, remove the outside of the sheet (the outer area of the four corner coordinates) to save unnecessary operations of curling stone and other moving objects. Save the image in overwrite format. Then we set the roi(region of interest) area near the stone to estimate the position of the desired curling stone. In this process, the tracking algorithm is applied only in the roi domain to reduce unnecessary operations.



(a) (b) (c)

Fig. 3: (a) A curling sheet converted to top view format with homography matrix applied. (b) roi is applied. (c) It shows the position of coordinate values to be saved by applying optical flow.

The tracking algorithm uses optical flow using Lucas - Kanade algorithm[7]. The modified curling sheets also transform the shape of the curling stones, so the optical flow algorithm is used. Obtain the coordinates of the stone in the roi area by taking the coordinates at the point where the change of motion occurs and averaging them. Optical Flow -The Lucas Kanade pyramid scheme- is a method of calculating the desired object movement by setting each pixel window of a frame and estimating where is the best match of its window in the next frame.

The amount of computation is small because it uses prominent feature points such as corners. Therefore, we use this algorithm because it is suitable for the mechanism to store many coordinate values. In addition, pyramid method is used to construct image pyramid according to image scale from original image in case that large motion can't be calculated.

3 Friction coefficient inference

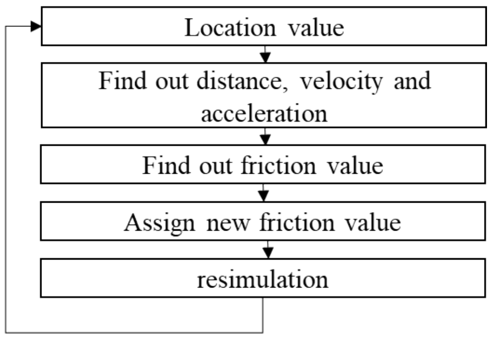


Fig. 4: Algorithm of friction coefficient inference

Chapter 3 uses the coordinate values of the curling stone estimated through image processing to obtain parameters to infer the coefficient of friction. After the parameters are entered into the relevant equation, the coefficient of friction is obtained. Obtain the distance travelled per hour of the stone from the pixels of the sheet and calculate the speed and acceleration of the stone using the travel distance. Calculate the coefficient of friction of the curling stone using the (7)(8) equation.

Curling stones sliding on ice plates's movement is as shown in (5) and (6).

$$m\frac{dV_x}{dt} = \sum F_x \qquad (5a)$$

$$m\frac{dV_y}{dt} = \sum F_y \qquad (5b)$$

$$I\frac{d\omega}{dt} = \sum(r \times F) \qquad (6)$$

m = mass
F (Fx, Fy) = frictional force
I = moment of inertia of the stone
ω= angular velocity (positive in counter clockwise direction)

It is not only difficult to solve stone dynamics on a curling sheet, but also difficult to understand. Therefore, the average number of pebble and dynamics of the reference paper[8] is used to conduct the study. Fig. 5 is the process of finding dynamics in the q pebble.

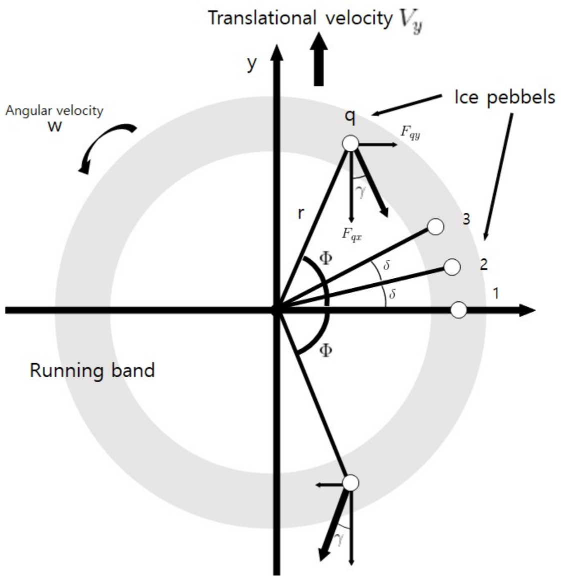


Fig. 5: Schematic diagram of a running band touching ice pebbles.
V (Vx, Vy) = translational velocity
r = radius of the running band
γ= angle between sliding velocity relative to ice and y-axis
J = total number of ice pebbles
$\delta = 2\pi/J$
$\varnothing = (q-1)\,\delta$

Obtain the total friction F acting on the running band.

$$F = \sum_{q=1}^{J} F_q = \sum_{q=1}^{J} \mu_k f \qquad (7)$$

The x and y components of the total friction force are obtained through (8).

$$F_x = \sum_{q=1}^{J} F_{qx} = \sum_{q=1}^{J} \mu_q f \sin\gamma \qquad (8a)$$

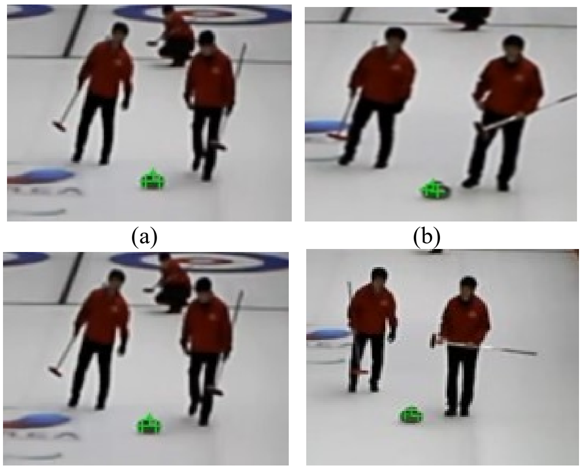
$$F_y = \sum_{q=1}^{J} F_{qy} = -\sum_{q=1}^{J} \mu_q f \cos\gamma \qquad (8b)$$

The coefficient of friction obtained by (7)(8) shall apply to the simulator. Apply the friction factor obtained for each unit seat to the curling sheet of the simulator.

4 Simulation

4.1 Optical flow

For the optical flow experiment, the camera is installed in a position where all the sheets of the curling sheet can be seen, and the curling sheet is photographed. Tracking the curling stone that pointed in real time using images acquired from the installed camera.



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

Fig. 6: Optical flow tracking point results
(a) Lucas-Kanade algorithm tracking point before the center line. (b) Lucas-Kanade algorithm tracking pint after the center line. (c) Pyramid Lucas-Kanade algorithm tracking pint before the center line. (d) Pyramid Lucas-Kanade algorithm tracking pint after the center line.

Looking at the results shown in Fig. 6 (a) and (b), Lucas-Kanade and the pyramid have similar results before the center line, but in (c) and (d) you can check the difference in the tracking points after the center line.

4.2 Friction coefficient application

Table 1: Spec of curling sheet

Simulation curling sheet	Real curling sheet
Width(m): 4.5	Width(m) : 4.27~4.75
Length(m) : 44.5	Length(m) : 44.5

Table 2: Spec of curling stone

Simulation curling stone	Real curling stone
Weight(kg) : 19.96	Weight(kg) : w <= 19.96
Diameter(m) : 0.21	Diameter(m) : d <= 0.29
Height(m) : 0.15 (include handle)	Height(m) : h >= 0.1143

Construction: $0.5 \times 0.5(m^2)$ Plane, 801(9×89) units

This experiment was conducted in an unity 5.6.0f3 environment. Because it is a process to determine the error rate of the friction coefficient inference algorithm, the estimated coordinates through image processing are assumed to be accurate. The coefficient of friction of a curling sheet changes partially with each pitch, so it is necessary to extrapolate the curling sheet in detail. To extrapolate the coefficient of friction as closely as possible, the coefficient of friction should be divided as finely as possible. As shown in Fig. 7, divide the curling sheet into 9 x 89 (801) squares to increase the precision of the distribution of friction coefficients. If you want to increase the precision, you can increase the number of grids. The weight and size of the curling robots and the curling stones were the same as actual curling robots and curling stones.

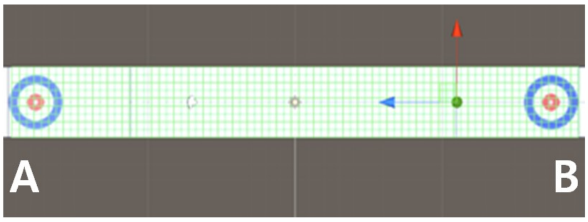


Fig. 7: Pixelization of curling sheet

The friction factors for all units of curling sheets are equally applied the area from Hogline to the next Hogline, except where the curling robot would drive together with the stone. The simulator can determine the initial speed and angle of the curling robot and the direction of rotation of the pitch as shown in Fig. 7. The direction of rotation is not taken into account as it determines which direction is the curl of the curling stone, and because the initial angle also determines the direction of the pitch, the initial angle is zero degrees and the rotation direction is fixed.

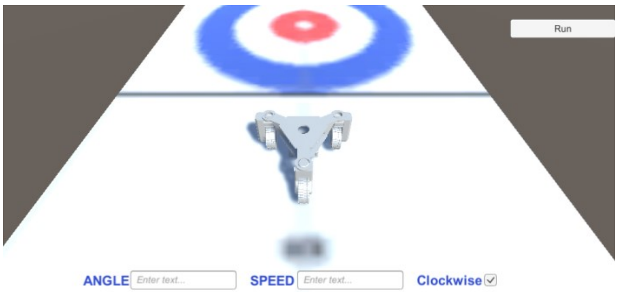


Fig. 8: Simulation screen

The experiment was carried out by changing the number of pitches, setting the initial speed of the pitches at the same speed. The initial value of friction coefficient for the curling sheet is 10 divisions of the range (0.00182 to 0.002) that the actual curling sheet can have. The initial speed of the pitch is set at 1.6 m/s and the result is to determine the accuracy of the expression by obtaining the error rate of the measured and theoretical values according to the number of pitches taken. The measurement is the average value of all values obtained.

At Fig. 9 and Fig. 10, blue line is for theoretical value, red line is for measured value.

Table 3: Initial velocity 1.6m/s, number of pitches 2

Theoretical value	Measured value	Error rate(%)
0.00182	0.001821067	0.058608059
0.00184	0.001851111	0.603864734
0.00186	0.001862963	0.159299084
0.00188	0.001871111	0.472813239
0.0019	0.001911111	0.584795322
0.00192	0.001912	0.416666667
0.00194	0.001960488	1.056072416
0.00196	0.001979388	0.989171179
0.00198	0.002006486	1.337701338
0.002	0.001994545	0.272727273

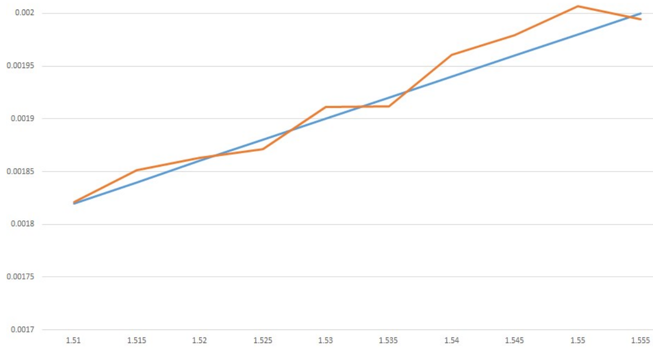


Fig. 9: Graph of table 3

Table 4. Initial velocity 1.6m/s, number of pitches 5

Theoretical value	Measured value	Error rate(%)
0.00182	0.00181737	0.144524773
0.00184	0.001830172	0.534107946
0.00186	0.001860159	0.00853388
0.00188	0.00187209	0.420768498
0.0019	0.001904035	0.212373038
0.00192	0.001908194	0.614872685
0.00194	0.001933125	0.354381443
0.00196	0.001951935	0.411454905
0.00198	0.001991525	0.582092108
0.002	0.002004082	0.204081633

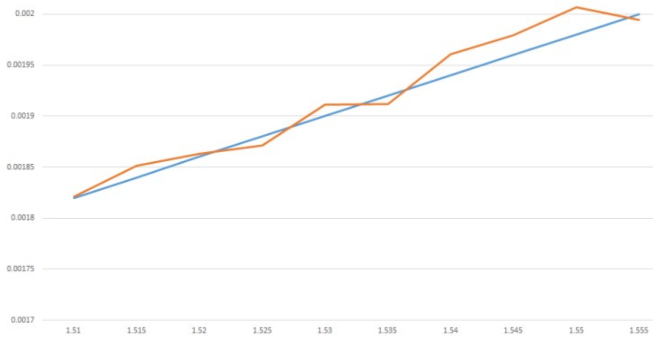


Fig. 10: Graph of table 4

5 Conclusion

In one experiment with a constant initial speed of 1.6 m/s, the friction coefficient values similar to those applied to the actual curling sheet can be determined through fig.10 and fig.11. In this experiment, it can be found that the number of pitches with the same initial speed is higher, the more accurately the coefficient of friction can be estimated.

This paper proposes image processing techniques in such a way that the friction coefficient can be estimated without any device on the curling sheet in image processing. This is the most likely way to minimize control variation depending on the circumstances compared to the existing paper.

The use of the pyramid Lucas Kanede algorithm as image processing algorithm to obtain the coordinates of Stone on the curling sheet was a major achievement. In addition, the fact that the friction coefficient was estimated through all pixelizing on the curling sheet clearly reflects that all the friction factors on the ice sheet are different than in the previous paper. In other words, friction factors can be estimated for each tiny pixel, suggesting that the friction factors that change for each passing part of the curling stone can be applied in a short period of time via image. Furthermore, if the estimation of the coordinate values received in the image and the coordinate values of the simulators is made correctly, the friction coefficient per space of each curling sheet can be more accurately estimated. Using algorithms that have the advantage of this algorithm, and which can compensate for its shortcomings, will result in a better estimate of the coefficient of friction. Finally, this simulator and the method of estimating friction coefficients will be an objective source of data for athletes who are practicing with intuition throwing stones.

References

[1] Yoon Chang Ho, Evolution of contact area between a high-speed slider and ice surface, *Master's Thesis, Department of Mechanical and Aerospace Engineering, Seoul National University*, 2017.

[2] A. Raymond Penner, The physics of sliding cylinders and curling rocks, *American Journal of Physics*, 2001.

[3] Z.Zhang, A Flexible New Technique for Camera Calibration, *IEEE Trans. Pattern Analysis and Machine Intelligence*, 22(11), 2000: 1330-1334.

[4] R. Y. Tsai, A versatile camera calibration technique for highaccuracy 3D machine vision metrology using off-the-shelf TV cameras and lenses, *IEEE Robotics and Automation*, RA-3(4), 1987: 323-344.

[5] Y. Ma, S. Soatto, J. Kosecka, and A. A. Sastry, An Introduction to 3-D Vision From Images to Geometric Models, Springer, 2004.

[6] Ki-Yong Lee, Joon-Woong Lee, Ground Plane Detection Using Homography Matrix, *Journal of institute of control, robotics and systems,* 17(10), 2011.

[7] M. J. Black and P. Anadan, A framework for the robust estimation of optical flow, *Fourth International Conference on Computer Vision*, 1993: 231 – 236.

[8] Norikazu Maeno, Dynamics and curl ratio of a curling stone, *Sports Engineering*, 17(1), 2014: 33-41.