Development of a Curling Stone Tracking System Using Infrared LEDs, and an Accompanying Application

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Abstract: The purpose of this study is the design and implementation of a real-time position measurement system for use on curling stones. Often called 'chess on ice', curling is a sport that requires a high level of strategy. Accordingly, how the stones move around the vast 40m curling rink constitutes important data. However, in the unique environment of the icy and vast rink, it is difficult to monitor the position of the stones by a simple method without hindering the players. Therefore, in our research, we proposed a system using infrared LEDs and an infrared camera. Infrared LED modules are installed on the stones and the rink, and infrared cameras installed around the edge of the rink film the LED modules and perform calibration. Then, using four coordinates of the LED modules on the rink, the system employs perspective transformation technology, which is a type of image processing. In so doing, it is possible both to measure the position of the stones, and solve problems. Through experiments, performance evaluation was conducted to asses what degree of error occurs in position measurement when the proposed system is used. Experiments were conducted on a curling rink. The average error was 0.189m in the experiment at the curling rink.

1 BACKGROUND

Curling is a sport in which players slide stones on ice, aiming to achieve a higher score than their opponents. Its high level of strategy and skill has led curling to be called 'chess on ice'. However, to form a strategy, it is necessary to consider various factors, such as the current positions of the stones, the condition of the ice, and the state of play, while skill is dependent upon a player's experience and intuition. Furthermore, there is, even now, no established theory regarding what causes the stones to curve as they travel (Murata, 2022). Due to the complex and advanced element of strategy and the fact that technique is dependent on players, there are few scientific approaches to curling, in comparison with other sports. Nevertheless, Masui et al. have started research titled 'Curling Science' which is an initiative to create new strategy support that integrates information technology'[1]. This project involves research on digital curling (Ito and Kitasei, 2015), tactical analysis, measurement of stone behavior, and sweeping (Gwon et al., 2020; Won et al., 2018).

Digital curling refers to the proposal of a virtual curling space, created using a computer's physical simulator, that acts as a space to enable discussion of curling strategy. This concept has been developed by a large number of people (Yamamoto et al., 2015).

In addition, systems, such as the Portable Tactical Support DB System, have been developed to record shots, stone layout, match scores, players taking part, and the condition of the ice, on a tablet device (Masui et al., 2015; Masui et al., 2016; Otani et al., 2016).

These works are examples of tactical support carried out on a computer, but we consider it necessary to apply the technologies to actual play and provide support in real time. It is thought that grasping the positions of the stones is important as one factor towards achieving this. The points that must be considered in actual measurement of stone position are as follows:

- Measurement on ice

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As curling is played on ice, room temperature is below 10 degrees, and the curling rink maintains a temperature of -5 degrees Celsius. Accordingly, the system must be able to operate in this environment. Also, it must be durable enough to run not only a few times, but throughout the entire curling season.

- Not hindering players

As curling is played on a 40m-long rink, it is possible that installing a system on the rink will hinder the players.

- Highly accurate position measurement

In curling, the stone closest to the centre of the house obtains points, which is why stone position information is important. The occurrence of a large calculation error would affect the outcome of a game. Therefore, we require a system that can measure positions across the entire 40m rink, without any large calculation errors.

In the peculiar environment of the icy and wide rink, it is difficult to monitor the positions of the stones by a simple method without hindering the players. To the extent of our knowledge, there is no existing stone-tracking system that meets the aforementioned requirements.

Therefore, in this research, we aim to develop a curling-stone tracking system. In the proposed system, where a hindrance to players is resolved by mounting infrared LEDs on the stones and having an infrared camera installed at the edge of the rink performing image processing. In addition, we develop applications that utilize the stone position information measured by the stone tracking system. This application provides a graphic presentation of the trajectories of the stones, by projection mapping on the surface of the rink.

2 RELATED RESEARCH

Many studies and methods have been implemented to measure the position of people or things. There is a method that uses Lidar, created by Velodyne Lidar Inc., to measure position information in real time[2]. Lidar is capable of measurement with an error of approximately 3cm. However, as Lidar measures on a horizontal, measurement cannot be performed if there is any obstacle between a Lidar sensor and the item to be measured. For this reason, we consider it difficult to use Lidar for position measurement in curling, which uses multiple stones. Lidar can recognize the shape of a stone if it is nearby, but fails when a stone is further away.

[2]https://en.wikipedia.org/wiki/Lidar

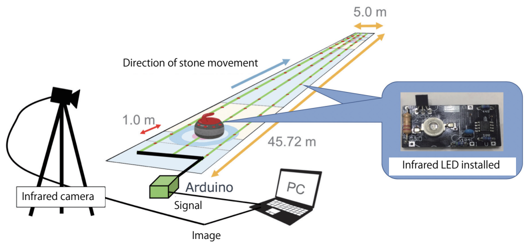

Figure 1: Measurement Conditions.

There has been research on measuring the position and angular velocity of curling stones, using video and camera images (Hattori et al., 2023). With an error of 2mm, the system is highly accurate. However, because the system is focused on accuracy and aims to measure curl ratio, i.e., the way the stones curl over a short distance, the photographic range is limited to approximately 4.5m. This differs from our research, which aims for simple and wide-ranging measurement. There is further research involving measurement by cameras, though not targeted at curling stones. In the research by Aoshima, measurement is accurate to within 1.0mm, but measurement range is limited to 1-4m (Tao et al., 2017). Furthermore, it is necessary to prepare several cameras and install them all facing the same direction. In contrast, our research aims for a simple measurement method that covers the wide area of the curling rink. There are also methods that use Bluetooth or wireless LAN (Sawada et al., 2016)(Tsuda et al., 2013). These methods are capable of measuring across a range of approximately 100m, however, measurement is only accurate to within several meters. This makes it difficult to apply such methods to curling, as an error of a few meters is too large for a sport in which a few millimeters can define a difference between winning and losing.

3 MEASUREMENT METHOD

3.1 System Installation

Figure 1 shows the conditions at the time of curling stone position measurement. In this system, an LED module is installed on top of each curling stone, and LED modules are also installed under the ice of the curling rink, with a module installed every 1m along the length of the rink, up to 10m, and a module installed every 1m across the width of the rink, up to 3m, making a total of 30 modules. Also, an infrared camera is installed at the edge of the rink.

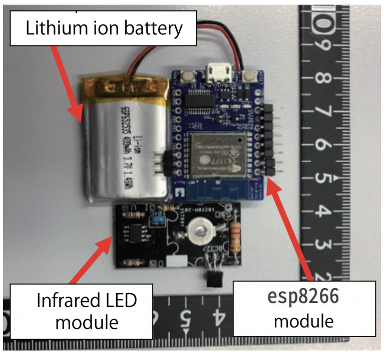

Figure 2: Modules Installed on the Stone.

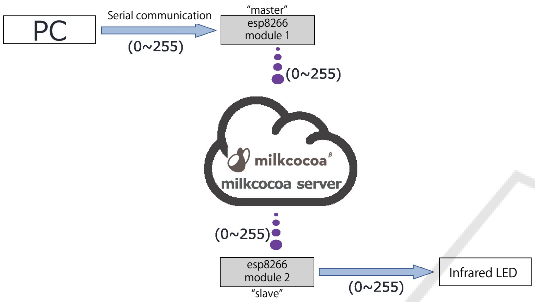

Figure 3: Flow up to Lighting Up/Turning off.

3.1.1 Stones

Figure 2 presents the LED module and esp8266 module that are installed on the top of a curling stone. To light up the LED module on the curling stone, an esp8266 module, capable of Wi-Fi connection, was used. This enables remote adjustment of the brightness of the LED module. In addition, the esp8266 module is powered by a lithium ion battery, meaning that it can be controlled wirelessly and so will not stop working during play. Next, the flow up to the lighting of the LED module is presented in Figure 3. First, esp8266 module 1 is wired to the computer and a value between 0 and 255, representing the light intensity of the LED module, is uploaded by serial communication. Then, the value received by esp8266 module 1 is sent to the data store of the Milkcocoa server. The value in the data store is received by esp8266 module 2, then sent to the LED module, causing it to light up or turn off. The LED module turns off when the value is 0, and lights up when the value is anything other than 0.

3.2 Flow of Position Measurement

- Calibration

The coordinates of the LED module, which are necessary for position measurement, are recorded. Then calibration is performed, by the following process.

1. Designate the range as the four corners of the rink at which LED modules are installed.
2. Light up the LED modules within the range, one by one.
3. Adjust the light intensity until the surface area of LED module light detected by the infrared camera is 10 pixels (+-3).
4. Extract the outline of the LED module light and record the coordinates at the centre of the outline.

As long as the infrared camera is not moved, calibration needs only be performed once. Also, LED module coordinate measurement at the time of calibration is carried out automatically once implemented. Thus, LED modules are lit up in consecutive order from no.1, and the program automatically measures the position, in meters, at which the modules are present on the rink.

- Stone Sliding

Position measurement is made possible by using the values obtained in calibration along with perspective transformation technology, which is a type of image processing. The flow of the stone position measurement is as follows:

1. Slide a stone onto which a LED module is mounted
2. Calculate four coordinate points (hereafter referred to as reference points) froom the nearest LEDs surrounding the stone's LED module
3. Using the four reference points, carry out perspective transformation

3.2.1 Perspective Transformation

Perspective transformation is an image processing technique for depicting a three-dimensional object position on a two-dimensional plane. In the layout of the proposed system, the infrared camera is tilted slightly downward to film the LED modules on the rink. However, as the camera image reflects a three-dimensional space, distances of the same length appear different in the foreground to the background. Therefore, perspective transformation is used to correct the image to a two-dimensional plane. During this process, first the image position of LED module on top of the stone is extracted in pixels. Next, a perspective transformation series is calculated from the surrounding four reference points obtained in calibration. By this process, the image is transformed to a two-dimensional plane, and stone position can be measured.

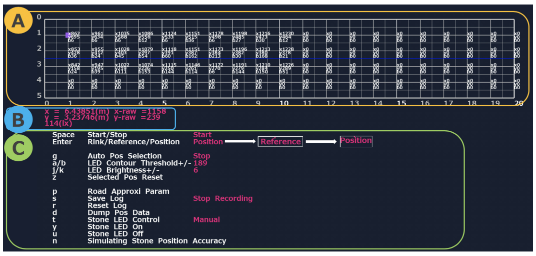

Figure 4: Program Execution Screen of Position Measurement Application.

3.2.2 Position Measurement Application

Figure 4 shows the program execution screen of the position measurement application. The application has three modes, and stone position measurement is made possible by implementing the three modes in order.

1. Rink mode: In this mode, the range of calibration is decided. This is done by setting red circles at the positions corresponding to the corners of the rink. The reason it is necessary to set the range is that, because curling is an indoor sport, sometimes indoor lighting or light reflection off walls can prevent calibration from being carried out successfully.
2. Reference mode: In this mode, the infrared LED modules within the range set in Rink mode are calibrated. Calibration comprises lighting up the LED modules one by one and recording the x and y coordinates and light intensity of each module.
3. Position mode: This mode records the position of a stone that has been thrown.

Next, we explain the program execution screen. ‘A’ in Figure 4 presents and records the x coordinate, y coordinate and light quantity of each LED module, obtained in calibration. The numbers from 0 to 5 on the vertical axis and 1 to 20 on the horizontal axis represent the positions of the LED modules installed on the rink, and correspond to 1m, 2m, ... 20m. The positions of LED modules for which current coordinates were obtained during calibration are represented by purple squares, the positions of which can be altered manually.

‘B’ in Figure 4 represents the position information of a stone thrown when using Position mode. Here, the distance in the x and y directions, and the pixel position, are expressed.

‘C’ in Figure 4 presents the keys used to operate the program, as well as the mode status and LED module light intensity. From left to right, the figure presents the keys used, a simple explanation of key operation, and the current mode and LED light intensity in red letters. The functions assigned to each key are described in detail below.

- ‘Space’ key This key is used to switch between ’Start’ and ’stop’ in the program. The program is in the ’Stop’ state at the time of start-up, at which time pressing the key once switches to ’Start’ status and the infrared camera starts up. Pressing the key once more switches back to ’Stop’ status, causing the camera to stop recording.
- ‘Enter’ key This key is used to switch between Rink mode, Reference mode, and Position mode. The program is in Rink mode at the time of start-up. In this state, pressing the enter key once transitions to Reference mode, and pressing the key once more transitions to Position mode. Pressing the key once more transitions to Rink mode again.
- ‘g’ key This key can only be used in Reference mode. Pressing the key initiates calibration, causing the LED modules to light up in order from the module closest to the connection point, and the x coordinate, y coordinate, and light quantity of each module to be recorded automatically.
- ‘j’ key, ’k’ key These keys can only be used in Reference mode. Pressing the ’j’ key increases the light intensity of the illuminated LED module. Pressing the ’k’ key decreases the light intensity. Light intensity can be adjusted within a range from 0 to 255.
- ‘z’ key This key can only be used in Reference mode. Pressing the key deletes the coordinates and light intensity data of the currently selected LED module.
- ‘d’ key This key can only be used in Reference mode. After calibration has ended, pressing this key saves the coordinates and light intensities obtained in calibration.

3.3 Implementation

The program used when calibrating and measuring stones employs the following devices. The PC used was a Lenovo ThinkPad (CPU Intel(R) Core(TM) i7-4650U 1.70GHz); software development on the PC was carried out using Visual C++ and OpenCV library and openFrameworks library on Windows 10. To film the curling stones on the wide rink, from diagonally above, an infrared camera (DMK23UX236) was installed on top of a tripod with a maximum height of 3.6m (ManFrott SKU1004BAC), and an IR filter (NEEWER IR950) was attached to the infrared camera to block visible light.

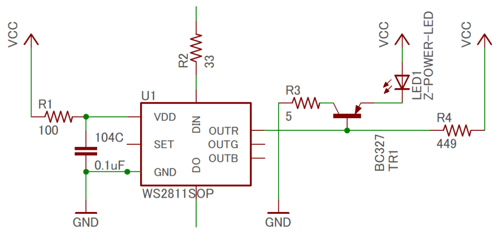

Figure 5: Infrared LED Module Circuit Diagram.

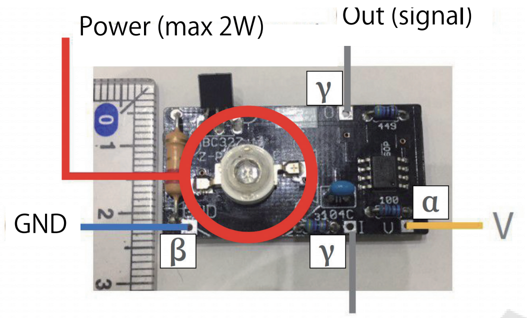

Figure 6: Infrared LED Module Circuit Board.

3.4 LED Module

3.4.1 Specification

Figure 5 shows the circuit diagram of the propsed LED module. The parts used in the circuit board consist of an infrared LED, resistor, capacitor, transistor and micro-processor. Next, Figure 6 shows the actual circuit board, with infrared LED attached, that was installed on the rink and the stones. The V, GND, In, and Out parts of circuit boards are connected to control multiple substrates. A circuit board itself, including its component parts, has a length of 2.4mm, width of 3.7mm, and height of 0.9mm. The red circle in the centre of the figure is the infrared LED.

3.4.2 Operation in Curling

In this research, we embedded infrared LED modules in the ice of a curling rink. The reason for this is that installing the modules on the surface of the rink would prove a hindrance to players, and modules would have to be re-installed every time the rink was used. However, there is still the problem that the LED modules are exposed, besides which it is uncertain whether they can operate for a long time within the ice. To resolve these issues, the LED modules were coated with crystal resin. First, the circuit board is inserted into an 8mm plastic case and affixed with a glue gun. Then, resin is poured into the case and left to harden for 24 hours.

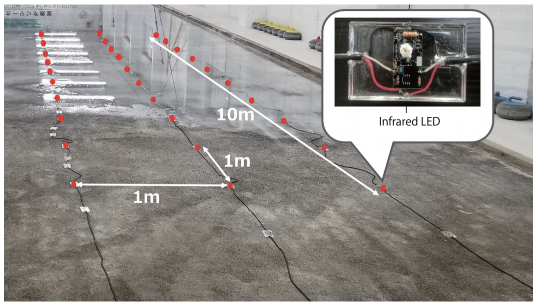

Figure 7: Distribution of LEDs Embedded in the Rink.

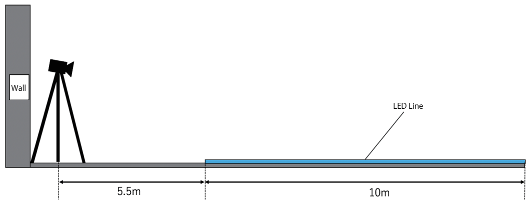

Figure 8: Arrangement of the System in the Curling Hall.

4 EXPERIMENTS

The aim of this experiment was to verify the accuracy of stone position measurement in the case of having altered certain conditions (distance between camera and LED lines, camera angle).

Experiment Environment. The experiment took place at the Kawanishi Construction Curling Hall, in Kitami, Hokkaido.

In addition, Figure 7 presents the LED lines laid out on the rink before it was covered with ice. 10m worth of LED modules were installed at 1m intervals along the length of the rink, and 3m worth at 1m intervals across the width of the rink.

The infrared camera was installed 5.5m in front of the edge of the rink. This is because the construction design of the rink makes it impossible to position the camera any further away, and the camera cannot detect all the LED modules if it is positioned any closer to the rink. The arrangement of the system in the curling hall is shown in Figure 8.

Experiment Method. Regarding the procedure, after filming with the infrared camera and performing calibration, an LED module representing a curling stone is placed at the point 1m on the length and 1m on the width of the rink, and position measurement is begun. Then, the measured value of the position on the screen is obtained. Once this value is obtained, the LED module is shifted 0.25m lengthwise, while

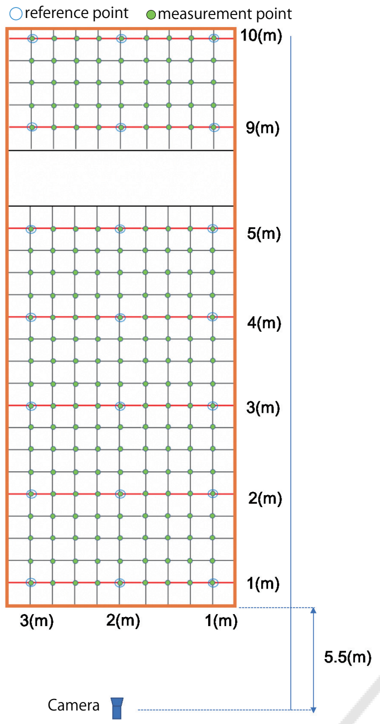

Figure 9: Measurement Points on the Curling Rink.

maintaining a position of 1m horizontally. This is repeated until the module reaches the 10m point. After reaching a length of 10m, the module is shifted 0.25 at a time along the width of the rink, until it reaches the 2m point. Then, the module is returned to the point 1m along the length of the rink and the whole process is repeated until the module reaches the 10m point. As shown in Figure 9, we measure 37 points on the length of the rink and 9 points on the width of the rink, making a total of 333 points measured.

Evaluation Indices. Once position measurement was complete, we compared the original values and the obtained values. We calculated the position measurement error in the case of having reduced the reference points as shown in Figure 10.

Results. The average error was 0.189m. The maximum error was 0.63m, at the point at length 9.75m and width 2.75m. There was no problem regarding the operation of the LED modules embedded in the ice.

Next, we describe the the results when reference points are reduced. The transition of the average error in the case of reduced reference points is presented in Figure11.

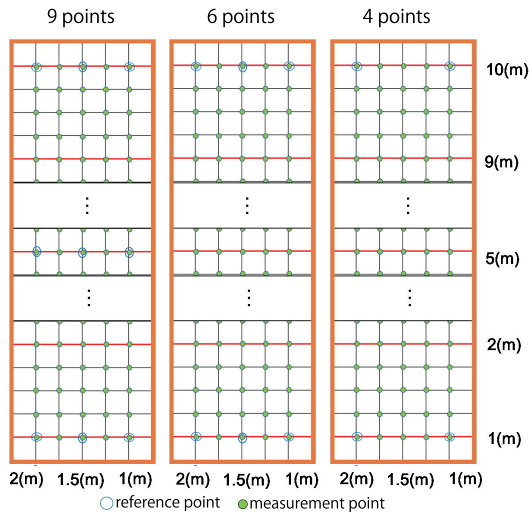

Figure 10: Measurement Range when Reference Points are Reduced (On Curling Rink).

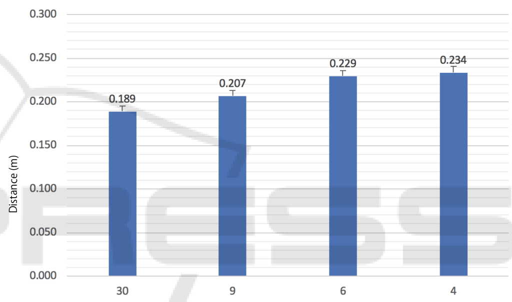

Figure 11: Transition of Average Error When Reference Points are Reduced (Curling Rink).

Consideration. Regarding position measurement accuracy, in the same manner as the preliminary experiment, the further away the measurement point was, the larger the measurement error became. This is because, at a distant point, measurement error becomes large if detection of the LED support is out by even one pixel.

Overall, the error was larger than in the preliminary experiment. This was because refraction was caused by the ice of the curling rink, causing the optical axis of the LED module to shift forward. At every point on the rink, it was confirmed that even if the stone LED was actually placed in the correct position, the measurement result was further away. As a revision method to compensate for for refraction, we reduced all the length measurement results in the estimated values by 0.100. In this case, the average error became 0.129m.

Even inside the ice, the LED modules within the LED line operated successfully. This is because the modules were protected from moisture and cold by a

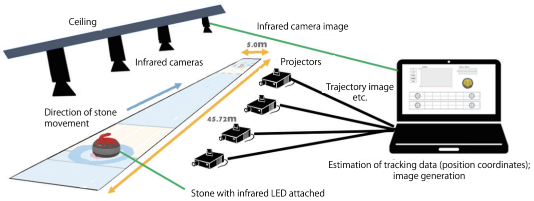

Figure 12: System Structure.

resin coating.

When the reference points are reduced, the four reference points surrounding the stone LED, which are used in perspective transformation, become further away. As a result, the influence of LED support detection error at these reference points becomes greater.

5 APPLICATION

As mentioned in Section 1, this research is targeted at curling beginners, children, spectators, etc., and aims to enable people to enjoy curling, and learn all its component techniques. The target users are beginners with no special knowledge or skill related to curling, and curling spectators. The games developed in the Curling Projection Mapping research include a game played on the rink and a game that uses a smartphone application.

5.1 Curling Projection Mapping

The system structure of Curling Projection Mapping is presented in Figure 12. Infrared LEDs are attached to the curling stones, and the trajectory of those stones is recognized by multiple infrared cameras installed on the ceiling. The corresponding position information is estimated by a computer, which generates an image. Then, the generated image is projected on the rink in real time by multiple projectors.

In Curling Projection Mapping, there are a total of three games that we have developed: 'MiracleFlower' and 'CoinCollector', which are games projected onto the rink, and 'StoneSpeedChecker', which is a tablet application. Each type of game is described below.

Here we explain about 'MiracleFlower' and 'CoinCollector', which are the games involving projection on the rink.

MiracleFlower. As shown in Figure 13, 'MiracleFlower' is a simple game in which flowers bloom following the trajectory of a curling stone. Players are free to slide the stones however they wish, without considering direction, velocity, and so on, which means that even beginners or people with no curling knowledge can enjoy the game. In addition, spectators can also enjoy watching the graphics of MiracleFlower.

Figure 13: Actuar usage of 'MiracleFlower'.

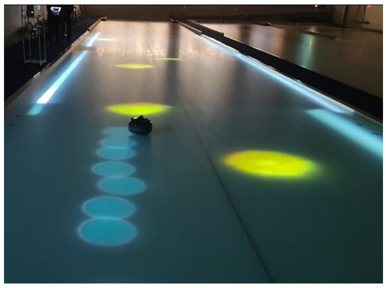

Figure 14: Actuar usage of 'CoinCollector'.

CoinCollector. As shown in Figure 14, 'CoinCollector' is a game in which players aim to slide stones onto coins scattered across the rink, with the winner being the player who collects the most points. With its concept of aiming for as many targets as possible in a single turn, this is a novel game that does not conform to existing curling rules, although it enables players to experience the thrill of competing.

5.2 Tablet Application

Here we introduce our tablet application, 'StoneSpeedChecker'. In StoneSpeedChecker, as shown in Figure 15, a tablet is installed on a stone and the current velocity of the stone is presented in real time, based on the position information generated by the tracking system. The aim of this application is for the sweepers to get an accurate grasp of the speed of the stone. The sweepers announce to their team members the ten-zone value that expresses where on the house the stone will stop. Accordingly, it is essential for sweepers to grasp the speed of the currently sliding stone in real time. The speed display meter is equipped with a function that rotates the meter in response to the rotation of the stone, to enable the sweepers to read the speed smoothly even when the stone rotates. The angle of rotation is estimated based on the tablet's internal geomagnetic sensor. In addi-

Figure 15: Actuar usage of 'StoneSpeedChecker'.

tion to aiding practice, this application can be used to confirm the state of the stones and rink in night practice.

6 CONCLUSION

In this research, we developed an image-processing based real-time curling stone tracking system. AS a result of analyzing the peculiarities of the curling rink and the game itself, we adopted an image-processing based measurement method by infrared LED and infrared camera. In addition, we actually implemented the system and, after conducting a preliminary experiment, involving altering the infrared camera position, inside the university, we conducted an experiment in the real environment of the Kawanishi Construction Curling Hall in Kitami. The average measurement error was 0.189m in the curling venue experiment, demonstrating that it was possible to measure with a high degree of accuracy while using a single camera. Furthermore, as applications that utilize our tracking system, we developed two kinds of game incorporating projection mapping on the rink.

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