A Dance Performance Environment in which Performers Dance with Multiple Robotic Balls

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ABSTRACT

In recent years, as robotics technology progresses, various mobile robots have been developed to dance with humans. However, up until now there have been no system for interactively creating a performance using multiple mobile robots. Therefore, performance using multiple mobile robots is still difficult. In this study, we construct a mechanism by which a performer can interactively create a performance while he/she considers the correspondence between his/her motion and the mobile robots' movement and light. Specifically, we developed a system that enables performers to freely create performances with multiple robotics balls that can move omunidirectionnally and have full color LEDs. Performers can design both the movements of the robotic balls and the colors of the LEDs. To evaluate the effectiveness of the system, we had four performers use the system to create and demonstrate performances. Moreover, we confirmed that the system performed reliably in a real environment.

CCS Concepts

•Human-centered computing → Human computer interaction (HCI);

Keywords

Dance; Performance; Mobile robot; Choreograghy; Ball;

1. INTRODUCTION

In recent years, as robotics technology progresses, various robots have been developed to dance with humans[1, 2, 3]. There have ever been attempts in which mobile robots dance as the alternative of a human performer[4] and perform with another human[5]. However, up until now, there has been no system for interactively creating a performance using multiple mobile robots. Therefore, performance using multiple mobile robots is still quite difficult. In this study, we construct a mechanism by which a performer can interactively create a performance while he/she considers the correspondence between his/her motion and the mobile robots' movement and light. Our system consists of a control system for the mobile robots and an application for creating patterns of the movement and light of the mobile robots. A user can create and confirm his/her choreography and the movement and light of mobile robots on the application at the same time. It is possible to program the mobile robots to conform to the patterns that the user has created. In this study, we applied Sphero2.0[6], a robotic ball, as a mobile robot. We felt that a type of sphere-shaped ball would be compatible with body expression in many genres, as can be seen from several artistic forms, such as MOVEment[7], Moon Beams[8], and Metamorphose(s)[9], sports gymnastics, freestyle football, mime, magic, and juggling. Additionally, a sphere shape can absorb and disperse the most shock, and is durable in case of collision with a performer.

The remainder of this paper is organized as followed. Section 2 introduce related works and Section 3 explains the system requirements and configuration. We introduce two applications, one for creating the movement and light of robotic balls and one for controlling the robotic balls, in this section. Section 4 presents results we obtained from experiments and considerations on the evaluation system. Section 5 presents two demonstrations and we conclude in Section 6 with a brief summary and our plans for future studies.

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2. RELATED WORK

There have been some attempts at collaboration between humans and mobile robots. Kosuge et al.[10] developed a robot that can be a social dance partner and moves by estimating human steps. Higuchi et al.[11] developed a system that decides on control parameters to move four quarters or a rotation in concurrence with the body movements of a human crouching and walking. Graether et al.[12] examined four themes—embodiment, control, personality, and communication—to provide an understanding of how to design robots for physical activities. Tominaga et al.[13] developed a mobile robot with a display that can provide a runner's form in real time by filming and following a runner continuously from a certain distance. Futami et al.[14] developed a mobile robot with a Web camera to solve the problem of self-haircut when both hands are unavailable for use. PHENOX LAB[15] created “Phenox”, which can autonomously fly by determining the surrounding conditions and recognizing the movement of a person. In this study, we created a system that makes it easy for the user to dance with multiple mobile robots.

Here, let us briefly list some attempts that cover the expansions of various things using a sphere. Izuta et al.[16] created “Bouncing Star”, a rubber ball for sports that is equipped with electronic devices such a wireless module, acceleration sensor, sonic sensor and LED. The ball’s color and the graphics of a playing field can be manipulated, suggesting exciting opportunities in the creation of new digital sports. Yamaguchi et al.[17] implemented Digital Juggling, which stably projects an image on a sphere for toss juggling by applying a Kalman filter and a movement model and making an orbit estimation. Michaud et al.[18] designed Roball to for a variety of common household situations. For example, Roball can attract the attention of children and make them smile. Nitta et al.[19] proposed a flying ball based on quadcopter technology. They developed some basic interactions such as the balls floating up when a player raises a hand. TeamLab [20] developed “teamLabBall” that can change color and light and emit sound in accordance with the movement of a person near it. Thus, new possibilities are created by adding power, sensors, visuals, and light. In the same vein, body expression with the coordination of persons can be expected with the robotic balls used in this research.

Furthermore, in recent years, many directors and artists have tried extending the body’s expression by using moving objects. Manabe et. al.[21] developed a system that enables the performer to recognize an object intuitively by using quadcopters controlled by the relationship between the body and the data in real space. DreamWorks Animation LLC.[22] was created performances in 3D space that cannot be expressed by computer graphics. William Forsythe [23] prepared the space which has many pendulum which was hanged on a ceiling. When the viewer enters this space, he or she must move and dodge in accordance with the pendulum engraving a periodic rhythm. This results in a situation that looks like dancing. Daniel Wurtzel[24] created Pas de Deux, where a cloth is made to look as though it is dancing by using a device placed on the floor that creates wind. The performer freely creates a dance to fit the cloth dancing. TOVIA Co.[25] developed Ninja Light, which can make a sphere group move up and down to match the moving of a performer’s body.

It is possible for the performer to express him or herself just like manipulating space. CONNECTED, made by CHUNKEY MOVE[26] uses an expression similar to the Ninja Light. Bot & Dolly[27] created Box, a combination of human performance and the movement of two white plates with a projected image. As mentioned above, there are many approaches to the collaboration of mobile robots with the body expression of people. We developed a system for users to interactively create a performance while considering the correspondence between their body’s expression and that of a mobile robot.

Table 1: Specs of Sphero2.0.

Size	74 mm
Weight	168 g
Maximum speed	2 m/s
Communication distance	max 30 m

3. PROPOSED SYSTEM

3.1 System Design

The purpose of the proposed system is to enable users to create a performance with multiple robotic balls easily. We developed a system by which a performer with no knowledge of programming can create patterns of the movement and light of robotic balls to certain music and choreography by mouse operation.

It is not easy for a performer to confirm his/her choreography by virtually moving robotic balls because it takes a long time to charge robotic balls, set the communication environment, and save a large place to set up an infrared camera and them finally dance with the balls. Therefore, it is necessary to create a mechanism to easily confirm the choreography of dancing with robotic balls on a simulator.

3.2 System Configuration

The procedure the proposed system uses is as follows.

1. A user creates the movement and light of robotic balls that synchronizes with music by using the developed application.

2. The user confirms his/her choreography of dancing with the robotic balls on a simulator by using Microsoft Kinect [28]. The user then modifies his/her choreography by fitting the movement and light of the balls created in the first step.

3. The user saves the patterns of movement and light to mobile phones and a PC for control.

4. The user fits the movement and light in sync with the music.

We used a robotic ball called Sphero2.0 as the hardware. The specs are given in Table 1. We prepared two types of external shells one made from ABS resin with a 3D printer (MakerBot, Replicator 2X) and one created by sharpening commercially available plastic capsules. Examples of both are given in Fig. 1.

We developed two following applications to realize the proposed system.

3.2.1 *Aplication for Creating the Movement and the Light of Robotic Balls*

The UI of the developed application is shown in Fig. 2. We developed the application using openFrameworks and the development environment was Xcode. This application can change the number of robotic balls in accordance with the scale of a performance. We will explain the functions of this application shortly.

The display for creating formations is shown in Fig. 3. It is possible to create formations of the robotic balls by

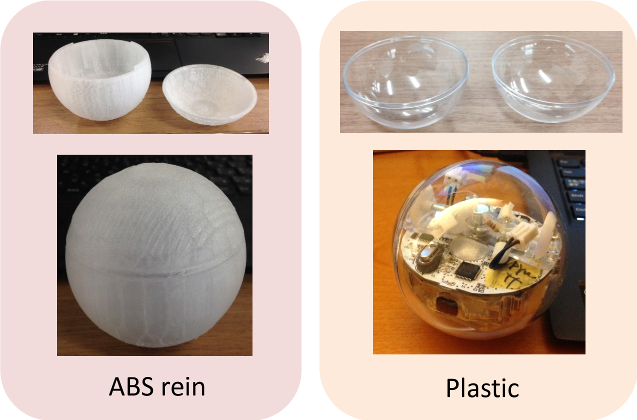


Figure 1: The two types of external shell.

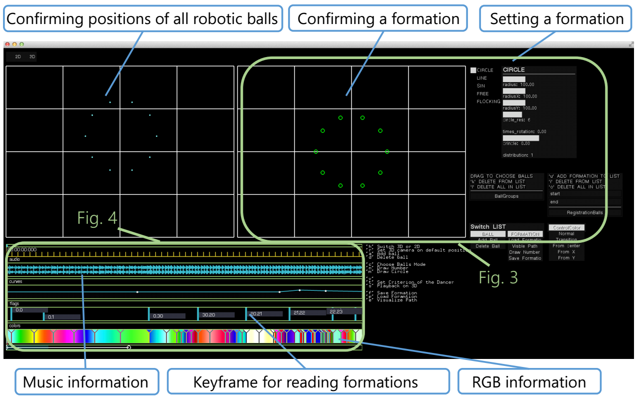


Figure 2: UI of developed application.

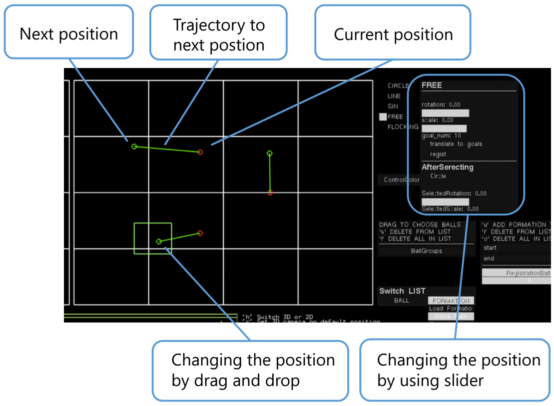


Figure 3: Display for creating formations.

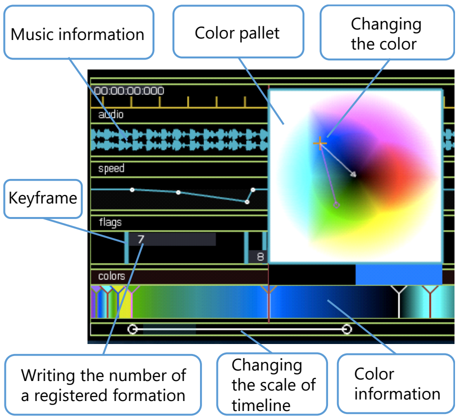


Figure 4: Timeline function.

fitting a parameter with a slider or dragging and dropping the point indicated by the position of a robotic ball.

Regarding the formation created by adding Keyframe (Fig. 4) to the timeline on which music information is mounted, the formation movement that is synced to music is made possible. Added keyframes can be stored with reffrence to the color information obtained by clicking a palette of the CMYK color representation.

Furthermore, the confirmation of the movement and light can be displayed in 3D. The overall performance can be confirmed while actually choreographing on the simulator by using Kinect. The screen when confirming performance is shown in Fig. 5. A performer is represented by the skeleton created from the joint information acquired by Kinect. When the confirmation of the performance is done, a file in which the patterns of the movement and light of the robotic balls are contained is automatically created in CSV format.

3.2.2 *Control System for Robotic Balls*

The configuration of the robotic ball control system is given in Fig. 6. An infrared camera detects the position of robotic balls mounted on an infrared LED from the difference between the current image and the previous image. This is then transformed into the location information of the robotic ball that is same as the environment attached to the ceiling by using projective transformation. Thus, the infrared camera can be placed at a free angle and position.

The location the robotic ball moves to and the light have been determined by reading CSV formatted files created by the application for the movement and light creation. The lighting pattern is saved on the mobile phone in advance, so the information sent from the main PC to the mobile phone can be limited to the movement of the robotic balls.

The velocity and direction of a robotic ball are calculated from the distance and the angle toward the next destination of the ball by using PID control. Moreover, to avoid collision, a repulsion is put in place in accordance with distance, and the velocity and direction of the robotic ball are corrected by the value. The system sends the information of the velocity and direction of the robotic ball decided by the controlling PC to the mobile phone via Wi-Fi and sends commands from the mobile phone to the robotic ball connected via Bluetooth. A robotic ball corresponds to a mobile phone to make the Bluetooth connection stable. To avoid radio wave interference, the Wi-Fi uses the 5 GHz frequency band.

One weak point of the current system is that it is difficult to track the robotic ball when the dancer is between the camera and the robotic ball for more than a certain period. Hence, a performance configuration that is not between the

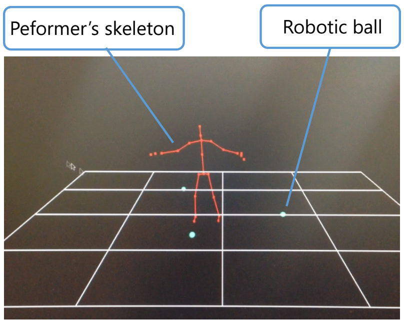


Figure 5: 3D image.

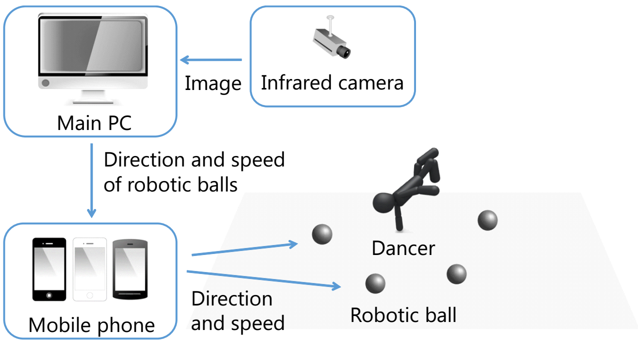


Figure 6: System configuration.

camera and the robotic ball is required.

4. EVALUATION EXPERIMENT

4.1 Experiment Procedure

In our evaluation experiment, participants created performances with robotic balls by using the proposed system. We investigated how participants used the system and how much time was needed for completion of a performance. In terms of the performance accompanying the movement robot, we investigated how participants took both their own body expression and that of the robot into consideration to create the performance. Participants were three males with an average age of 22.3 who had been dancing for more than four years. This group included a system developer aged 25 had been dancing for more than four years and had some experience in performance creation using robotic balls. The procedure for the experiment is as follows.

(1) The participant receives a 20-minute explanation about how to use the application.

(2) The participant uses the application to create choreography based on a song about 1 minutes, 10 seconds long at 120 BPM.

(3) The participant confirms the choreography on the application.

(4) The participant carries out a performance using robotic balls.

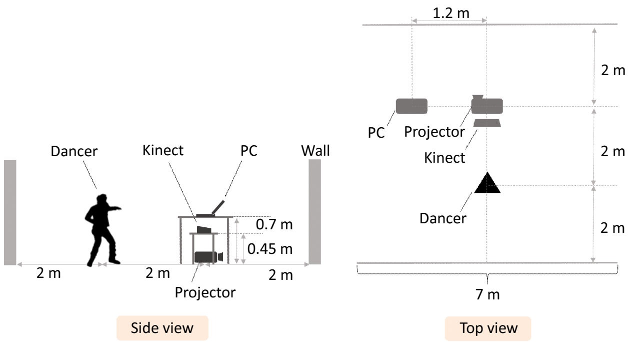


Figure 7: Layout for procedure 3.

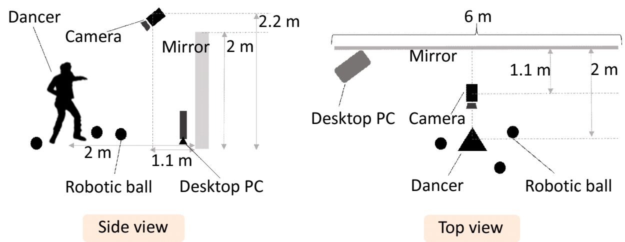


Figure 8: Layout for procedure 4.

In this experiment, the number of robotic balls was three. The participants created the movement and light of the mobile robot and choreographed while simultaneously creating performance. Moreover, the participants proceeded to create and modify the choreography while they confirmed the movement and light of the mobile robot on the application. One B5 paper and a pen were also used when creating the choreography. The experimenter received the question about how to operate the application during the experiment. The time taken for the experimental procedures 2 and 3 was noted and a 10-minute break was scheduled every hour. At the end of the experiment, participants provided feedback on the application and commented on how they considered the movement and the light of the robot each eight beats. We defined a quarter note as one beat. The layout of procedures 3 and 4 is shown in Fig. 7 and 8, respectively. In this experiment, we used a laptop PC (Apple, Macbook Air 13-inch, mid-2011), a desktop PC (Apple, iMac 27-inch, late 2013), projector (BenQ, MP522ST), Web camera (iBUFFALO, BSW20KM11BK), and depth camera (Microsoft, Kinect v2). The experiment took place in a studio measuring 6 m×7 m, located inside a laboratory where the experiment took place. The doors were all closed to minimize outside sounds. All lights were turned off when using the projector.

4.2 Results and Discussion

The time in took for participants to create a performance is given in Table 2, how to show the expression of each eight is shown in Table 3, and the memos written by participants 1, 2 are shown in Fig. 9. It took an average of 2 hours 22 minutes for participants to create a performance with three robotic balls.

Table 2: Time taken by participants for performance creation.

Participant	Performance creation time
1	2 hour, 38 minutes
2	3 hour, 29 minutes
3	2 hour, 17 minutes
4	1 hour, 4 minutes

One favorable response about the application was that its movements were immediately clear at a glance. However, on the negative side, one participant said it was hard to determine the sense of distance with the robotic balls while confirming the choreography via simulator display. Therefore, the participant would prefer to confirm the choreography by actually using the robotic ball. Regarding this problem, our future work will be to construct the system such that it can give the sense of dancing with the robotic ball. Another negative piece of feedback was that the setting to take color gradient between keyframes made it hard to operate when participant was deciding on the lighting. One participant suggested that it would be more convenient if the location of the robotic balls moves instantly when the participant moves the sequence bar on the timeline. We intend to modify these points in the future.

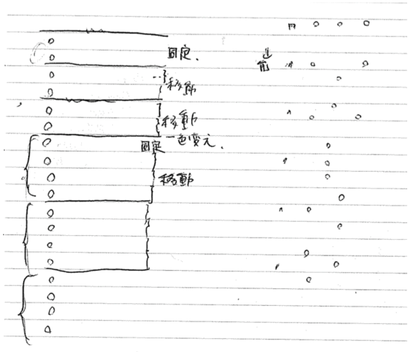
Of all participants, participant 4 that has the experience using the system created the performance most quickly. It seems one reason for this was his familiarity with the system operation. However, the other three participants said it was easy to operate as far as the operability of a system goes. Therefore, it was difficult to consider that there was much difference in the actual operating time. We considered the important factor, as it follows more than the differences in familiarity with operating. Participant 4 had experience using the system and accumulated experience with how the robotic balls were combined and the sense of dancing with the robotic balls. It is then easier to imagine the expression one wants to convey, and the ease of coming up with ways to achieve the expression contributed greatly to reducing the time. Thus, we provided the performers with various examples of what they wants to express on the basis of the response regarding how the expression was shown. For example, when the performer wants to express the robotic balls connecting with him/her, we prepared various examples of making it appear like they were connecting. If the prepared expression can be easily previewed for confirmation, we feel it will not only reduce the creation time but also widen the range of expression the performer creates. Here, each eight beats, we confirmed from the memos in Fig. 9 that all participants created the choreography. We extract and list the ways to show what the performer wants to express on the basis of responses to how the expression was shown.

- The extracted expression

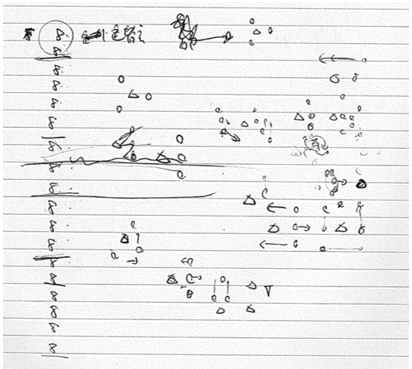
  Enclose, Link a dancer, Emphasize, Gather, Enter a space, Spread, Make a space, Rotate the entire formation, Work a force, Move a border, Intersection, Create a shape (such as a triangle).

- The extracted movement

  Slide, Line up in sequence, Change alternately, Fix a point, One by one action.



Memo of participant 1



Memo of participant 2

Figure 9: Memos of participants 1, 2.

If the movement corresponded with the expression that multiple people who had answered had equaled in each movement, the movement could be said to be frequently used by performers. Therefore, those who frequently used the movement should be in the library programme. Here, we picked up each movement that corresponded to the expression seen within the expression extracted. We confirmed and summarized the characteristics of each movement.

All participants were found to have the expression of "entering the space (a triangle, etc.)". Regarding participant 1, the robotic ball lined up in a row moved to a triangle formation and the dancer slid into the space the robotic ball made after the movement in eight beats. As for participant 2, the dancer had already slid into the triangular space the robotic ball drew in two beats. Simultaneously, the dancer kept the spot of the space in accordance with the robotic ball's movement. With participant 3, the robotic ball lined up in a row spread right and left into a triangle formation and the dancer slid into the space the robotic ball made in eight beats. Compared to participant 1, the dancer was placed slightly behind the space made. Regarding participant 4, the robotic ball had drawn a small triangle formation in advance and spread it in four beats for the dancer to slide into the space made in four beats. In consequence, in the expression entering the space, there are two movements of expression: the movement of the dancer sliding into the space made by the robotic balls and the dancer sliding into the space that the robotic ball formed in advance.

Table 3: Ways to show what the performer wants to express: participant 1.

Beats	How to show a movement	How to show a light
8	Standing.	Showing the color change.
8		
8	Posing. The audience's attention is on the dancer.	Changing the line of color every four counts.
8		
8		
8		
8	The dancer intersects robotic balls and changes a formation.	Red line.
8	Stopping robotic balls. The audience's attention is on the dancer.	Blue and green lines.
8	The audience's attention is on the dancer.	From yellow to red.
8	The dancer intersects robotic ball and enters created triangle.	Changing the color finely.
8	Synchronizing the dancer and the robotic ball. Creating a square by the dancer and the robotic ball.	
8	Like controlling a robotic ball.	
8	Line up robotic balls in a row in front of the dancer.	
8	Sliding with robotic balls	
8	Robotic balls move in conjunction after the dancer moves.	
8		
8		
8	Gathering the dancer and robotic balls.	

All participants were found to have the expression of "Emphasize". For all participants, the dancers were dancing while the robotic balls were stopped. Regarding participant 1, the answer was turning the audience's attention to the dancer. This could be replaced as emphasizing. With participant 2, the position of the dancer was almost fixed. Moreover, the movement of robotic balls was changed in eight beats. Regarding participant 4, the state of a corresponding movement of the dancer and a robotic ball being emphasized, was expressed. Regarding participant 1, the movement of controlling a robotic ball was confirmed. It could be also considered as an expression of emphasizing: namely, the expression emphasizing movement. There are two movements of expression about the dancer dancing freely while the robotic balls were stopped and the dancer moving simultaneously with a robotic ball.

All participants were found to have the expression of "Link a dancer". With participant 1, robotic balls lined up in tandem and the dancer is moving toward the same direction in eight beats. Further, when the dancer comes near to the robotic balls in tandem, the robotic balls move away from the dancer. Regarding participant 2, the dancer stands in the center of the triangle drawn by robotic balls and repeats moving at the same time the direction is changed every eight beats. For participant 3, the dancer stands behind robotic balls that line up in a row and simultaneously move sideways in eight beats. Regarding participant 4, the dancer stands behind robotic balls that line up in a row and simultaneously move back and forth in eight beats. Furthermore, body parts such as feet are moving toward the same direction at the same time as a robotic ball. In consequence, in the expression linking the dancer with the robotic balls, there are two movements, one in which the dancer and robotic balls move in the same direction simultaneously and one where the dancer and robotic balls move in the same direction alternatively.

Three of the participants 1, 3, and 4 were found to have the expression of "Gather". Regarding participant 1, the dancer and the greatly expanding robotic balls are coming together in the center in four beats. For participant 3, the robotic balls expanding in a column move to the center in four beats and make the formation in tandem with the dancer. With participant 4, in accordance with the movement of the dancer turning, the expanding robotic balls move to the center in eight beats. In consequence, in the expression about gathering, there are two movements about the robotic ball and the dancer: one where they are moving to the center and one where the robotic balls move to the center in coordination with the dancer's motion.

Three of the participants 1, 2, and 3 were found to have the expression of "Create a shape". For participant 1, the dancer who is in the center moves quickly in two beats and the quadrangle is made by the dancer and three robotic balls. Regarding participant 2, in the free comments of the questionnaire, he created the performance with how it can be expressed using a triangle drawn by three robotic balls and the dancer in mind. Therefore, the ratio of a side and the rotation were changed while the shape of a triangle was maintained. With participant 3, a robotic ball that was positioned far away from the rest moves in front of the dancer in four beats and draws a triangle. In consequence, in the expression of creating shapes, there are two instances about the movement of shapes: one drawn by the dancer and the robotic balls, and one drawn by the robotic balls only.

Two of the participants 1 and 4 were found to have the expression of "Intersection". Regarding participant 4, he moves toward the same direction with a robotic ball and the other two robotic balls move toward the opposite direction simultaneously. As for participant 1, he made the same movement as participant 4. Moreover, when the formation of robotic balls changes from in tandem to a triangular shape, a robotic ball and the dancer move as they pass each other and their positions are exchanged. In consequence, in the expression of intersecting, there are two movements about a robotic ball and a human: one moving as they pass each other and one in which the position of the

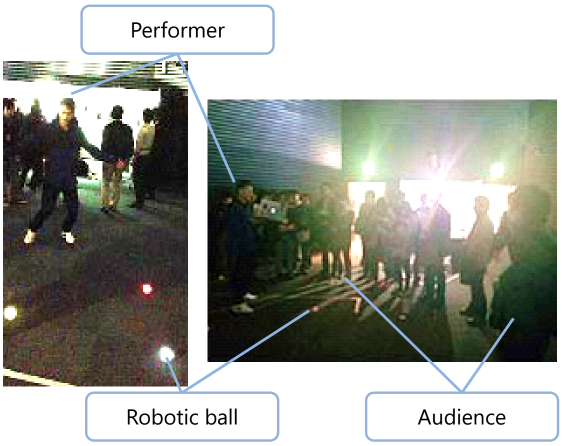


Figure 10: Demonstration at a domestic academic conference.

dancer and the position of a robotic ball switch.

On the basis of the above, our challenge for the future is to create a list of what we wish to express and turn the corresponding robot movement and lighting into a library that can be implemented in such a way that the movements can be previewed on the application. We also intend to have more performers use our system and enrich the expression library. Moreover, we will investigate cases of more than four robotic balls. We will also create a correspondence table of body expression and moving robots, and if we can investigate and clarify how the combination of these can give a certain expression, we may be able to formulate an expression that combines robot movements.

5. DEMONSTRATION

We confirmed that our proposed system could be used for performance in a real environment by staging a demonstration with it at a domestic academic conference (Fig. 10) held at the National Museum of Emerging Science and Innovation in Japan from March 6–8, 2015. We were able to reliably repeat the one-minute performance over a two-hour demonstration. This academic conference boasts over 600 participants, many of whom had the opportunity to view the performance. Viewers offered feedback such as, “It looked as if the performer were controlling the robots in real time”, “The wobbly robotic balls were irresistibly cute”, and “If the moving robots are not bigger then the viewers who are near the back will not be able to tell that they are spherical”. As a result, we won the award for an interactive presentation in the 2nd division.

We staged another demonstration using this system and submitted a short paper[29] as performance session at ACE 2015 (Fig. 11), which was held at the White Box and Black Box arts complex Medini Mall in MALAYSIA from Nov. 16–19, 2015. We used our system with stage lighting and succeeded in giving a one-minute performance in which no mistakes are allowed and only one performance is permitted. We received requests for an encore from the audience.

As demonstrated by, we were able to prove that the system is reliable for use in real environments.

Figure 11: Demonstration at ACE2015.

6. CONCLUSION

In this paper, we constructed a system by which a performer can interactively create patterns of the movement and light of robotic balls while he/she considers the correspondence between his/her motion and the mobile robot’s movement and light. To evaluate the effectiveness of the system, we had four performers use the system to create and demonstrate performances. We extracted and listed the ways to show what the performer wants to express on the basis of responses to the expression and confirmed that the movement corresponded with the expression by multiple people whose answers matched each movement. Moreover, we confirmed that the system performed reliably in real environment.

In the future, we will improve our system and to create more performances. We will perform investigations into the effect on body expression that comes from designing robots that are non-spherical.

7. ACKNOWLEDGMENT

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