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YOUPLAY: DESIGNING PARTICIPATORY THEATRICAL PERFORMANCE USING WEARABLE TECHNOLOGIES

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This paper describes a participatory theatrical performance named YOUPLAY. In YOUPLAY, a general person who is usually treated as an audience member becomes an actor and plays a character role in the performance. He/she wears several types of equipments such as sensors and a microphone, and experiences an interactive story. While our system presents various interactive stage effects using wearable sensors, these devices raise hardware/software troubles. We found during the development and actual use of the system that such interactive systems need robust activity recognition techniques. We explain the details of the system for YOUPLAY and present the knowledge gathered from 80 actual stages. Additionally, we discuss the general design for interactive system with the results of questionnaires that are gathered from participants of our system, the occurrence of the troubles, and the way to deal with them.

Keywords: Interactive, Performance, Sensing Technology, Theater Arts

1 Introduction

There are various interactive systems using wearable sensors or image processing technologies in the fields of stage performance and media arts. There are several merits for making the system interactive. For example, interactive systems can adapt to the sudden/unexpected movements of the performers by capturing their movements using sensors or cameras. Moreover, the performers can control the timing for changing scenes or triggering an effect. Such interactivities are usually used for stage performances who wear sensors and actuators. In addition, recently there are cases where audience members wear sensors to participate in staged effects. We propose a novel entertainment field in this paper that combines interactive

Fig. 1. Handbill of YOUPLAY Vol.1

Fig. 2. Snapshots from YOUPLAY performance

technology with theater arts.

Theater arts have been a familiar form of entertainment for many people through the ages. It is a basic entertainment in which the actors and actresses play roles on a stage and the audience enjoys watching them from their seats. Although the most audience are general people, they sometimes impersonate other people or speak through body language in daily life. Everyone usually plays some form of a theatrical performance. Therefore, we think that playing a theatrical performance is not necessarily something special, and we were led to the idea that we can provide an opportunity in which the audience plays a part in the entertainment.

In a field of music, people who play instruments can enjoy performing a session, and people who do not play instruments can also join a session by singing or making sounds using their eating utensils. On the other hand, since theater arts are not as simple as music, it is hard for people to play a theatrical part by just being given a role. We believe that people can enjoy a *theatrical session* with complex rules by participating in a stage in which the projected images and sounds interactively change in accordance with the process of the story and the movements of the people. From this idea, we propose a participatory theatrical performance named YOUPLAY. In YOUPLAY, an audience member becomes an actor and actually plays a character role in the performance. Each participant is given a role with a character setting, a hand prop, and a costume equipped with sensors and a microphone. He/she basically experiences an interactive story with by ad-libbing. The surrounding environments including images projected onto a floor or a wall changes in accordance with his/her ad-libbing by interactive technologies. The purpose of YOUPLAY is to help the audience member understand the enjoyment of participating in a theatrical performance. YOUPLAY is neither a participatory game nor an interactive art.

We explain the details of the system used for YOUPLAY, and present our knowledge gathered from 80 actual stages over a two week period. The actual stages are separated into two terms: YOUPLAY Vol.0 and YOUPLAY Vol.1. Figure 1 shows a handbill of Vol.1, and Figure 2 shows snapshots from a performance.

2 Related Works

There are various interactive systems using sensors and image processing, which are used for media art works and stage performances [1, 2, 3, 4, 5, 6, 7]. In experience-based performances/artworks, the effectiveness of the interactivity is quite obvious since it is the core of the user experience.

For example, PingPongPlus [8] can detect the location where the ball has hit the table by using multiple microphones, and changes the projection images in accordance with its hit position. Jellyfish Party [9] is a mixed reality installation using a head-mounted display to create virtual soap bubbles and jellyfish in real space in response to the breath input. livePic [10] and Thermo-Tablet [11] detect both the touch and breath of a user by using a thermoinfrared camera located behind the surface. Takegawa has proposed painted musical instruments that output sounds by using the conductivity of a pencil when a person in the audience fingers the pictures that are drawn on the paper [12]. Mixed Reality Lab in University of Nottingham has provided the systems for participatory outdoor events [13, 14, 15]. 34°_41.38'N 135°_30.7'E is a media art work using an interactive screen that simultaneously recognizes the point and the intensity when a person in the audience breathes into it [16]. Since the users of these systems are everyday people, the system should suppose unexpected behaviors. Therefore, the interactivity is the core of the user experiences. This is also applied to interactive game machines such as the Wii, Xbox + Kinect, and PlayStation + PS Move.

There are also several systems in the field of stage performances that interactively control the stage effects in order to adapt to the sudden/unexpected movements of the performers. When the performers use such systems, they wear some sensors or set up a camera to capture their movements. Sparacino adds effects to the projection images and sounds using the movements of the performers that are captured using a camera [17]. Messa di voce is an audiovisual performance that creates effective images by detecting the performer's voice volume and position [18]. Fujimoto has proposed a dance shoes system in which the performer can select the sound effects and songs by himself/herself while he/she interactively controls the system by installing sensors onto their shoes [19]. Kanke has proposed a drum stick system in which the performer can play drums by integration of real and virtual drums by using drum sticks with embedded sensors [20].

On the other hand, there are also systems that are for the audience to get involved by creating their own stage effects. Hirasawa has performed "Interactive Live [21]" since 1994. At the event, the audience can be involved in projected images via special interfaces that are set up throughout the hall. There are also several systems in which the audience can join via a smartphone. SYNK [22] is an iPhone application that was released for Plastikman's live tour. The audience can control the sounds and LEDs on the stage via this application. DROW [23] is an iPhone application in which the audience can project images that are drawn on the iPhone display. Rhizomatiks [24] provided a system in which the audience can join in on some of the effects for a live production. Hirabayashi has held music events through an activity named NxPC.Lab [25]. The audience can interact with the performer at these events [26]. Maynes-Aminzade [27] has enabled hundreds of audience to control onscreen activity by (1) leaning left and right on their seats, (2) batting a beach ball whose shadow is used as a pointing device, and (3) pointing at the screen using laser pointers. Aphex Twin projects images of the performer's own face that are mapped onto the audiences' faces that are captured with cameras during the performance [28]. Cerratto-Pargman has displayed text messages from the audience on a display behind the actors [29]. StarLight allows the audience to control the directions of the LED projectors by body movement in front of the disk-jockey stage [30]. In Parcival XX-XI [31], the member of audience can interact in a theatrical play by using Nintendo Wiimote controllers. The members are confronted with the effects of their own actions on the digital visuals, the behavior of the real dancer, and the surroundings (other participating members and their avatars, and the dancers in front of it). Xylobands [32] and Pixmob [33] are wrist bands that are equipped with LEDs, and the audience wears them. The operator can wirelessly control the blinking timing of the LEDs and their color. In addition to the performances that have a set stage, the audience can also join by posting comments about the performance via niconico Live [34] and Showroom [35], which are on-line programs and show the received comment on the display. Yonezawa's system enables the audience not only to post comments but also to control the live cameras [36].

As the attempt for adoption of interactive system, Human Media Interaction Group in University of Twente has researched on "Play is an important factor in the life of children" principle [37, 38] (*play* is not only theatrical play in this topic). They have observed children's cognitive, social, and physical development by providing interactive playgrounds that combine the benefits of traditional playgrounds with advances in technology. In contrast, our aim is making adults enjoy performing theatrical play.

As stated above, a lot of attention has been paid to the type of entertainment that an audience can join in on and experience. Our purpose in creating YOUPLAY is to help audiences join in on and enjoy theatrical stage performances that involve interactive stage effects.

3 Participatory Theatrical Performance YOUPLAY

3.1 Summary of YOUPLAY Story

One stage of YOUPLAY has basically ten participants, and each participant is assigned one of 10 kinds of character as shown in Figure 3. They interactively advance the story while they solve several events. If a people wants to join in as a performer, he/she can make a reservation on YOUPLAY's website. They decide the character that they want to act out and the date & time of their participation. On that day, he/she pays participation fees and joins the performance at the hall after changing into the theatrical costume with the appropriate hand prop. Each performance is approximately 30 minutes. There are some crossroads, and multiple endings. There are also some directional guides to smoothly advance the story. The system projects an animation character as shown in Figure 4 as a facilitator to control the directional guides. A professional actor plays the role of the animation character using a microphone and speakers, and talks with the participants in real time. An operator changes the direction and the position of the animation character. The basic setting portrays the participants as young space ranger cadets and the facilitator is their instructor. Since the facilitator appears only in its initial and middle phases, the participants do not necessarily can talk with the facilitator all the time. In addition, the system plays the sounds of narration (that have been recorded in advance) in accordance with the scenes in order to advance the story, explain the scenes, and support the participants. The stage includes the images projected onto the floor and the wall as shown in Figure 5. The participants can immerse

Fig. 3. Characters settings

Fig. 4. Animation character is played by professional actor

Fig. 5. Projected images onto floor and wall

themselves into the story because the projected images interactively change and the sound effects are then output. There are also viewers who do not perform but only watch. They may have just enjoyed watching, or they have enjoyed comparing the performance with their past performance.

YOUPLAY Vol.0 was held from March 20 to 24, 2013, and Vol.1 was held from November 16 to 24, 2013. They were 80 stages and held at HEP HALL in Japan. Although there was a little difference between Vol.0 and Vol.1, we will mainly describe the details of Vol.1 in this paper.

3.2 Story of YOUPLAY

The following is the story that the participants can watch on the website [39].

> **In the future.**
> **You are a young space ranger cadet who resolves various problems that occur in space.**
> **Today is the last day of training.**

You receive a distress signal while training, and as was expected you dive into space.
So, what will happen...!?

The settings about the character features shown in Figure 3 are also on the same website. The followings are two examples of character settings. Although the participants play a role according to each setting, they can play freely basically even if they depart from their character settings.

01 George
George had always wanted to be a hero from childhood. When he watched a documentary program on the success of space rangers, he has had the dream of being a space ranger. He had improved his unsociable personality by his efforts. As a result, he has been a gregarious person. Then, he has had attraction for girls, and has gone into raptures over. Now, he has wrong thinking, which the space ranger is more attractive for girls.

02 Catherine
Catherine was a servicewoman, a crack shot, and too rough personality. One day she lost her friend by an accident caused by her mistake during a mission. From that time on, she always loads a gun with only one bullet per one mission. Her principle is "Do not prodigally pull the trigger." She hates bugs and rats.

The following is the brief story after the opening.

1. On the spaceship, you encounter an instructor/self-introduction.
2. You take off into space after receiving a signal from a mysterious planet.
3. You perform training on the spaceship, and an accident occurs.
4. You float through the universe if you fail the mission.
5. You search for the origin of the signal after arrival on the targeted planet.
6. Mysterious living things appear at night.
7. You encounter the living thing that sent the signal.
8. You conduct a rescue operation after one participant's oxygen tank fails.
9. A rescue ship arrives.
10. You take off after catching a signal from Mars.
11. Ending

4 Theatrical Design

This section describes some of the important points related to the theatrical production and the preparation.

Staff composition on the performance: The staff members are composed of an assistant (who help the participants put on the costumes), a stage manager, a sounds operator, the facilitator, a system operator, and system assistants (who assist the system operator). The stage manager speaks with the participants as an icebreaker before entering the hall, guides them into the hall, and simply explains YOUPLAY. The icebreaker is a method that relaxes the participants' tension. In YOUPLAY, we first make the participants introduce themselves to the facilitator (as shown in Figure 4), and they make them move in accordance with the instructions through narrations and the advancement of the story. We help the participants recognize the way to play is by ad-libbing through such activities.

There is an operator room above the hall so that the operators can look out over the inside of the hall. The system operator, the system assistants, the facilitator who plays the role of the character shown in Figure 4, and the sounds operator are in this room. The system operator is the first author of this paper, and the system assistants include the third author and two students from our laboratory.

Number of participants: You can be played with less than ten participants. However, since we recommend performing with as many as possible, we have held all of the performances with more than four participants. Although each participant can freely select the character that he/she wants to portray, YOUPLAY's story needs a robot character and made sure that the robot is always included.

Expected playing time: We supposed that the play time for one stage is approximately 30 minutes. Due to prevent from too long play time, we set the time limits for some scenes. For example, the participants need to escape from the spaceship within the limited time. As another time adjustment method, we provided some scenes that the facilitator can control the finish time of them. Additionally, in the scenes where participants advance the story with free imagination, the system outputs several narrations according to the situations to give hints.

Character cards: The participants can perform with/without following each character setting. We put a card, which the features for character is written on, into the chest pocket for each costume, and participants can check their character setting as they want. In addition to this, we supported the participants by presenting some narrations such as "Space rangers remember that a self-introduce card is in the chest pocket" from the stage speakers.

Robot character: There are scenes in which the participants receive a signal from a mysterious planet and they talk with a living thing in that planet. The signal and voice sounds come from speakers that are set around the stage, and the sounds are incomprehensible language. Since the robot character has the setting for being good at translation, only the participant who plays the role of robot can listen to the strange language in Japanese from his/her headphone. The conversation among the participants is thus activated because the robot should present the translation.

Hand prop: There are eight kinds of hand props that are assigned to each participant based on their character's features. The props support the participants in advancing the story as

Fig. 6. Participant explaining content of hand prop (book) to others.

Fig. 7. Oxygen gauge follows performer.

shown in Figure 6 or activating the participants' imagination.

The hand props include a gun and a butterfly net, which have specific systems. If the participant pulls the trigger of the gun, the sound of gunfire is output from the speakers. The sound is output only once during one performance. If the participant swings the net, wind noise is output from the speakers. We have the participants understand that the wind noise is output when they introduce themselves by trying to catch an insect.

Images following the participants: Some images are projected around the participants and follow their movements as shown in Figure 7. Such effects have the participants immerse themselves into the performance.

Effect sounds: Sounds are output from the speakers that are set around the stage and each headphone that the participants are wearing. When the system outputs the sounds only from the headphone, the participants appear to play under their own volition despite the movements that are played in accordance with the cues fro m the headphones. The sound effects are interactively output in accordance with the movements of the participants.

Recorded narrations: We provide the narrations to help advance the story using the speakers or headphones in accordance with the situation. For example, we use recorded narrations such as *the space rangers motivate themselves by regular calls* and *the space rangers hurrying to go to the cockpits whose colors are assigned to each character*. We also explain the situation using the narrations such as *the space rangers are hurled off into space since they failed in escaping*.

Facilitator: In addition to the narrations, a professional actor joins in using his voice and the designated animation as the facilitator, and often talks with the participants in real time. He supports in the advancement of the story. Additionally, the participants enjoy playing together with the professional.

Conversation among the participants: We facilitate the conversation and cooperation among the participants using some narrations that accelerate the conversation and cooperation. Even if each participant meets the others for the first time, he/she can naturally play the performance.

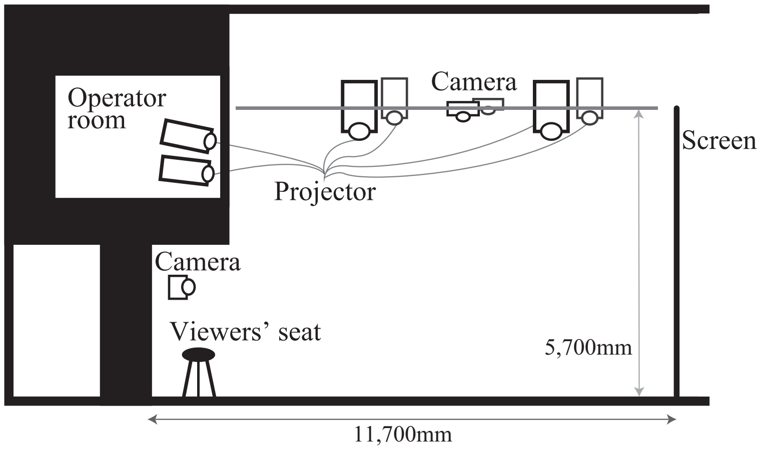

Fig. 8. System arrangement around stage

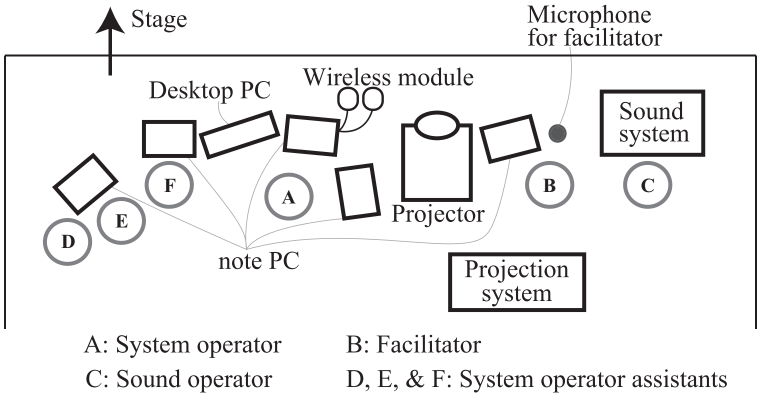

Fig. 9. System arrangement in operator room

5 System Design

5.1 System Structure

The systems for the system operator consisted of a desktop PC, five note PCs, two wireless modules (XBee: XBee-PRO Series 1), and three wide-angle web cameras (iBUFFALO BSW20KM11BK, whose viewing angles are 120 degrees). The system arrangements are shown in Figure 8 (viewed from the side of the stage) and Figure 9 (viewed from the ceiling in the operator room).

The sound system is set in the operator room, and the speakers are set around the stage. The sounds operator can output sound effects and narrations by selecting them on the system. The projection system has six projectors. Four projectors are set on the celling of the hall to project images onto the floor, and two projectors are set in the operator room to project images onto the screen that is on the front of the wall.

There are seven kinds of software that are used by the system operator as the followings. OSC (OpenSound Control Protocol) is used for communication among the softwares.

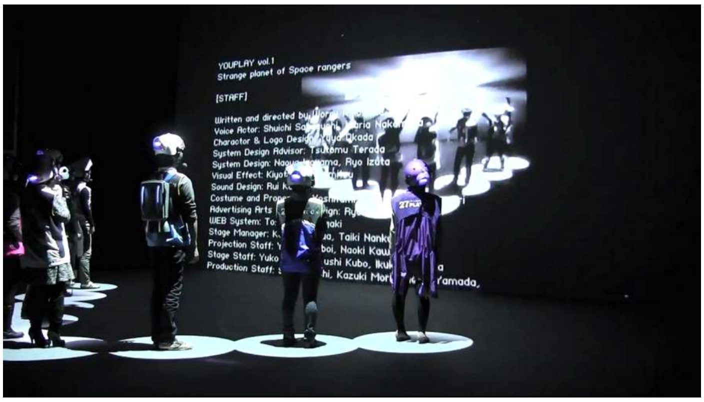

Fig. 10. Participants' posing image onto background of staff roll call

1. **Video output:** It outputs videos in accordance with the story. This software also overlays interactive images onto the videos by receiving the participants' positions.

2. **Backup of video output:** It is used for backing up the video output on another PC. This software can be controlled manually while the main video system is controlled automatically by OSC signals.

3. **Sounds operation:** A part of the sounds that are output from the headphones are manually controlled with this software. The detailed functions are described in the explanation on the helmets.

4. **Output videos operation:** Some of the projected images move by hand operations. The system operator control them by mouse operation. The system operator also changes the output videos with keyboard operations.

5. **Communication with the participants:** It communicates with the systems of the helmets and the hand props. The detail is explained in the section concerning the hand props.

6. **Position detection of the participants:** It tracks the positions of the participants in real time with the web cameras that are set up on the ceiling. The detail is explained in the section concerning position detection.

7. **Taking image of participants' posing:** It takes an image of the participants' posing. The system projects the participants' image onto the background of staff roll call as shown in Figure 10.

5.2 Helmet system

Figure 11 shows a helmet that participants are equipped with. The main circuit board is set on the back of the head, and it consists of a micro computer (Arduino Nano), an add-on module to play MP3 files (MP3-4NANO), an XBee, and an accelerometer (#KXM52-1050

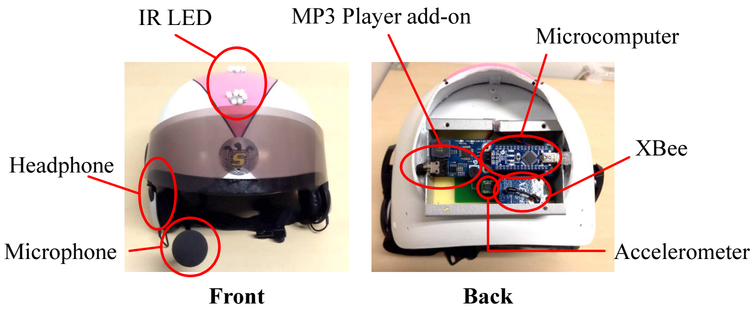

Fig. 11. System structure for helmets

(XYZ ±2G)). The circuit board is connected with multiple IR-LEDs that are set on the top of the head, a microphone (BOB-09868) that is set near the mouth, and a headphone. Since there is a little space between the headphone and the participant's ear, the participants can listen to both the surrounding sounds and the sounds coming from the headphone. We used a litium ion polymer battery (3.7V, 850mAh, 18.5g) in Vol.0, and used a mobile battery charger (5V, 1800mAh, 60g) in Vol.1 as a battery for the helmet system. We changed the battery in Vol.1 because we could not turn on the IR-LEDs with enough bright due to an error that occurred on the circuit. We confirmed that the batteries could work for 90 minutes (that are three times longer than the expected playing time) or more with the state that the system uses the energy at the maximum in advance. During the performance, we saved the electricity as much as possible by such as turning off IR-LEDs diligently.

The IR-LEDs are used for position tracking. LEDs blink by receiving a signal from the PC that is set in the operator room via XBee. For achieving interactive effects, the system recognizes the movements of the participants using accelerometer, and recognizes vocalizing of the participants using the microphone. The helmet outputs pre-recorded sounds from the headphone in accordance with the signals via XBee and the recognition results using the accelerometer on the helmet.

5.3 System for hand props

The gun is a part of the hand props, which have own system consisting of a microcomputer (Arduino Fio), a Lithium ion battery, an XBee, and a tact button on the inside of the gun. When a participant pushes the button, the system sends a signal to PC via XBee. Then, the PC outputs the necessary sounds from the speakers that are set around the stage. The participant can use the gun only once. We aim to have the participants think when to use it and to facilitate a conversation for consultation.

Figure 12 shows the system structure for butterfly net. The system consists of a microcomputer (Arduino Fio), a Lithium ion battery, an XBee, a Serial SRAM Chip, and an accelerometer. The system recognizes the action in which the participant swings the net by using the accelerometer, and it sends a signal to the PC via XBee if it recognizes the action.

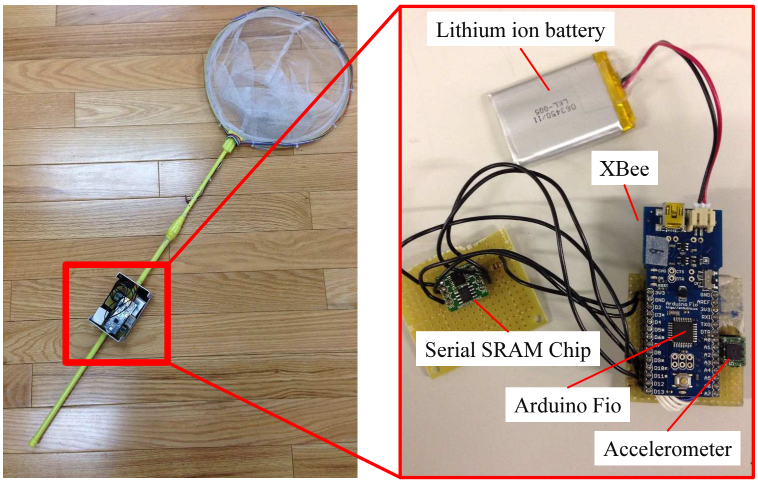

Fig. 12. System structure for butterfly net

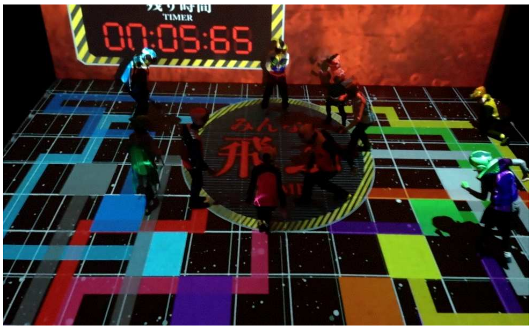

Fig. 13. Alert is output if participant runs out of load.

Fig. 14. Images change and sound output by entering the cockpit

5.4 Position detection

The system tracks the positions of all the participants using two web cameras that are set on the ceiling and the IR-LEDs equipped on the helmet. The cameras are modified to capture only IR-images. Some of the stage effects occur based on the tracking results. For example, oxygen gauge images appear around each participant as shown in Figure 7. Participants can turn on their spot light by shouting "Light on". The alert sounds from the headphone if the participant runs out of a given pathway as shown in Figure 13. The volume of sound changes in accordance with the distance from a specific position. When a participant enters the point of the cockpit, the color of the point brightens and a specific sound outputs from the headphone as shown in Figure 14.

The system makes the IR-LEDs equipped on each helmet blink one by one to individually detect the positions of all the participants. The system assigns the ID of each character at the position that is captured by the cameras while blinking. If all the IDs for tracking have been assigned once, all the IR-LEDs turn on. The system tracks the IDs by renewing their positions to the positions that are the shortest distance between the points captured for the current

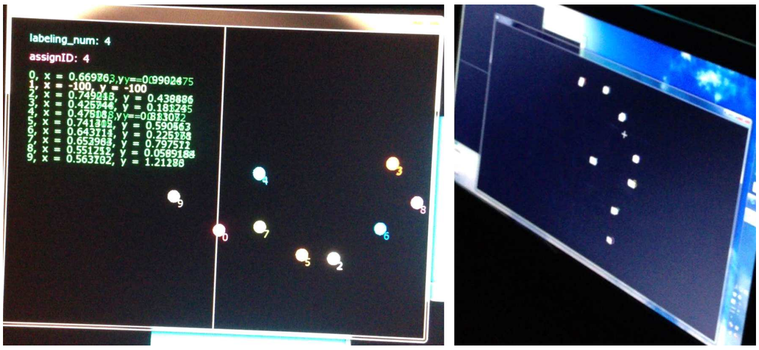

Fig. 15. Assigning IDs by hand

frame and that of the previous one. If an error occurs while assigning the IDs, the system initiates the re-assigning process. However, when we conducted testing using the developed software, the frame rate of the camera was approximately nine fps since the image processing calculation was slow. We were not able to use this function. Therefore, we used a method in which the system assistants in assigning IDs by hand using a keyboard and a mouse while watching a display showing the images captured by the cameras during a performance. The display shows a binarized image of the image captured by the cameras, as shown on the right in Figure 15, and the ID that is specified by using the keyboard is assigned if the assistants click on a white point. The assistants can confirm the IDs and their positions by using image, as shown on the left in Figure 15.

We use two cameras because only one camera cannot capture the entire stage area.

5.5 Action recognition

The systems recognize several actions by using the accelerometers that are set in the helmets and the butterfly net. The systems recognize these actions by using Arduino, which is connected to the accelerometer, and sends the results to the PC via XBee.

Helmet: The system recognizes the actions (jumping, walking as if in a low-gravity state, and rough amounts of movement) by using the accelerometer that is in the helmet. Although the system can correctly recognize if the accelerometer is set on a belt or in a shoe, we placed the accelerometer in the helmet together with the other circuits so that it was easily wearable with the costume and to reduce the amount of wires or wireless modules.

When the participants jump or walk as if in a low-gravity state, the sound effects that have been assigned in accordance with each action are output from the headphone (as shown in Figure 16). The system collects the data from the accelerometer at 30 Hz. The system calculates the variance value of the acceleration in the vertical direction of the participant's body within a window width of ten to recognize jumping. If the value is over the threshold during this definite time, the system recognizes the action as jumping. The system uses the raw value of the acceleration of the participant's body from the front to the back to recognize walking. If the value is over the threshold during a definite time after the value is below the same threshold, the system recognizes the action as walking.

The system projects the images of the oxygen gauge to improve the reality for the performance in which the participants are on a planet that has no oxygen. The more the participants

Fig. 16. Sounds is output if the participant walks like being in the low-gravity state.

Fig. 17. Oxygen lost.

move, the less the gauges become. The system calculates the variance value of the norm value of a three axis acceleration within the window width of ten to recognize the amount of movement. The system decides that the participant has moved at a constant amount if the variance value is between two thresholds during a definite time after the value has been over the bigger threshold once, and sends a signal to the PC via XBee. Once the system has recognized this, it restarts the process for another recognition. The system that is on the PC adds the number of receiving signals for each participant, and reflects them onto the images of the oxygen gauges. When the story has advanced to a specific scene, the oxygen gauge of the participant that has been decided by the system as being the most moved person is shown as having the smallest gauge. After that, the gauge reads zero, and the event in which the other participants have to rescue him/her occurs through their ad-libbing (as shown in Figure 17).

Butterfly net: The system recognizes the two actions *swing downward* and *swing in a horizontal direction* by using the accelerometer that is set in the butterfly net, and the recognition result is sent to the PC via XBee. When the PC receives the result signal, the system outputs a different sound in accordance with each action from the speakers that are set around the stage. The system use pattern matching, which uses the learning data to recognize the actions. If the system outputs the sound due to the recognition after the participant has finished swinging, the sound is output at a timing that is later than the timing that the participant intended. In such cases, the sound gives a strange feeling to the participants and viewers. Therefore, we use our early gesture recognition method [40], and it is possible to output the sound while the participant is swinging.

5.6 Vocalizing recognition

The system projects the images like lights onto the positions where the participants are if the participants shout “Light on” (as shown in Figure 18). Figure 18 shows the state in which all the participants shouted. Since each participant freely shouts at their own timing, it is hard to handle every timing by hand. The system uses the raw data from the microphone that is connected to each participant's helmet for the recognition. The system recognizes the vocalizing of the participants if the raw data value is over the threshold during a definite time.

Fig. 18. Projected images of light around participants

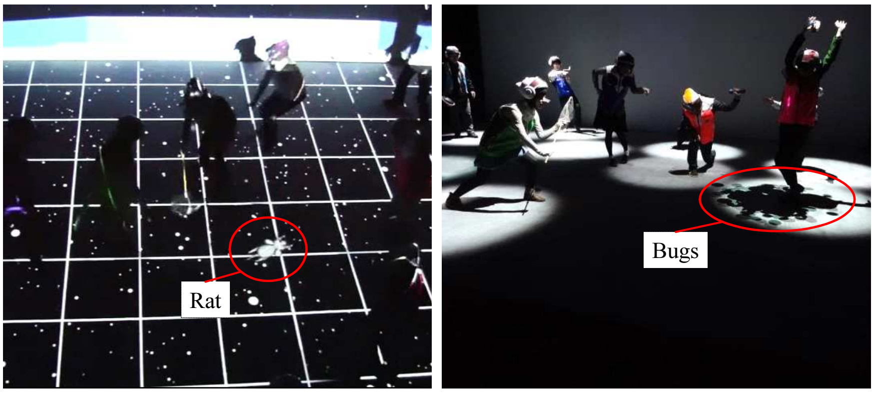

Fig. 19. Appearance of a rat and bugs

5.7 Operation by hand

The operator initiates some functions to ensure better effects are used when he does it by hand. We describe some of the functions below that are operated by hand.

Rat and bug motions: A rat and bugs appear during the story (as shown in Figure 19). The rat runs away from the participants and gets caught if the participant who has the butterfly net swings the net at the good timing that the operator intended. The bugs chase a specific participant. They run away if the participant pulls the trigger of the gun or shouts with a loud voice. The system operator handles their motions by using the mouse, and handles events such as catching the rat using the keyboard. Since the system tracks each participant's position, the system can also handle their motion by using the tracking information. However, we handled their motions by hand in order to change them in accordance with the participants' reactions and enhanced the reality. The timing when the bugs run away is also handled by hand after the system operator has consulted with the professional actor and the director in order to judge the timing when the participants liven up better.

Entrance scene: After the participants come into the hall, the participants go to their assigned spots as indicated from the stage manager. They also confirm their own assigned character names and colors. When the participant enters the proper spot, the appropriated

Fig. 20. The participants come into the spots

sound effect is output from the speaker (as shown in Figure 20). The system can judge whether or not the participant enters their spot from their position information. However, this scene is important for helping the participants understand that the projected images and the sounds interactively change. Therefore, we handle this process by hand in order to reduce errors.

Facial expression, direction, and position of animation character: The facial direction and position of the animation character that represents the facilitator (as shown in 4) are operated using the mouse, and the facial expressions are assigned by using the ten-key pad. The facilitator talks with the participants in real time during turning his head to the participant who talks with him. Since the participants freely talk to him, it is difficult to automatically turn his head. The system operator handles the functions by hand in order to make adjustment like during natural talking. The animation character has seven facial expressions such as *laughing*, *angry*, and *surprising*. The expressions are changed by the professional actor using the ten-key pad.

6 Problems and solutions

There were many problems on the systems in Vol.0. Therefore, we took some solutions for them in Vol.1. In this section, we describe the happened problems and their solutions in the revised version.

6.1 Wireless communications for sensor data

Our system recognizes the participants' activity using accelerometers and microphones to realize the interactivity on stage effects. When we held Vol.0, our system calculated the sensor data on PC (that is set in the operator room) by sending raw data from the sensor to PC via wireless communication (XBee). However, the PC could not recognize the participants' actions well because it could not sufficiently receive the data due to wireless communication errors. When we performed the wireless test in the hall in advance, the PC could receive the data completely. After finishing setting all systems that include the projectors and the sound systems, we confirmed that the quality of wireless environment became worse. Although it was not serious problem for the advancement of the story without the recognition of the actions using accelerometers because we had supposed such trouble, the participants could not enjoy some effects according to their actions. The vocalizing recognition, which our system recognizes the participants' shouting "Light on", was indispensable for the advancement of the story. Therefore, we prepared the dependability that we pushed keys (that corresponds to each participant) of the keyboard for the trigger of the image output. If the system had wireless communication errors, we pushed the keys as soon as we checked that each participant shouted with our eyes. We often used the dependability because there were the errors frequently. However, it took a long time to confirm the key that corresponds to each participant. In Vol.1, the microcomputer on the helmet recognized the participants' actions, and it sends only the result of recognition to reduce the amount of data transmission. In addition to this, the device transmits the recognition results repeatedly until it receives the confirmation signal from the PC.

6.2 Sounds from headphone

We used a headphone that can receive and output the sounds that includes the voice sounds of the facilitator in the real time and the recorded sounds by using wireless in Vol.0. The function of the headphone could not work well as with the wireless communications for sensor data. Here, some sounds that are output for the robot character were indispensable for the advancement of the story. Therefore, we used the wireless headphone only for the robot character and did not use it to others in Vol.0. Although we could send some sounds for the robot character well as a consequence, the other participants could not listen to some sounds from headphone. In Vol.1, since we set some recorded sounds into a SD card that is connect to the circuit set on helmet in advance, the system could output the sound that is specified by the signal sent from the PC. In spite of this solution, there were some troubles regarding wireless that are described in Section 6.3, and some sounds could not be sometimes output. In addition, because we could not output the voice sounds in real time form the headphone, we need to prepared several narrations in advance. We could not change the sounds according to the situations.

6.3 Wireless communications

There are still some outstanding issues for the wireless communications after Vol.1. We used XBee for communication between the PC and the Arduino. During the performance, it caused a problem that the communications of the XBee stopped due to a collision of the data. Although some participants could hear the sounds from the headphone, others could not sometimes hear them. Hence, the others could understand that the system had an error, and they felt uncomfortable. We do not resolve this trouble still, and it is the future work. The wireless communications is very important for YOUPLAY. If we can stably control them, effects that we can use for the stage will increase. Since it can apply to other stage performances, we will continue to improve the wireless communications technique.

7 Reactions of participants

We describe the participants' characteristic reactions, which we have been able to observe through 80 performances. Additionally, we requested the participants and viewers to fill out a questionnaire, and we also described part of the questionnaire results. The participants

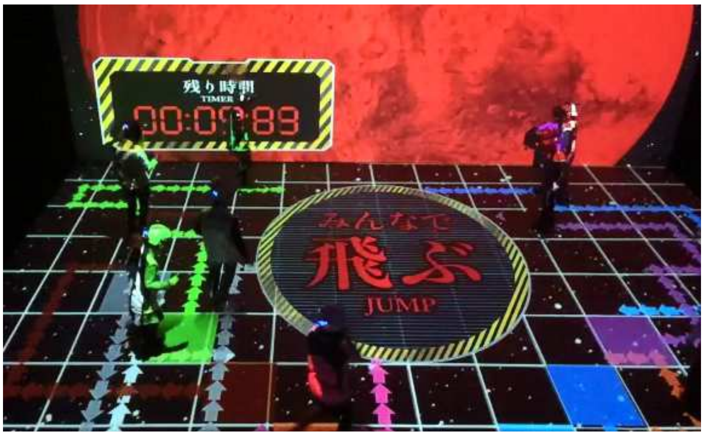

Fig. 21. Route is steadily shown by arrow images.

were men and women ranging in age from teenagers to those in their 50s, and there were approximately 1000 participants and viewers.

Following of image effects: Many of the participants enjoyed that the effect images followed them at first, and they soon became natural movements. It seems that they could immerse themselves into the story world after confirming that the images followed them.

However, the system sometimes lost sight of the participants, and ID information crossing errors sometimes occurred among the participants. The method that the assistants used to reassign the tracking IDs by hand did not save time since they needed to confirm what kind of error was happening. Many of the participants pointed out the errors by word of mouth if the images did not follow them. We had to make them leave the story world as a result. Since the effect in which the image follows a human is easy to understand, it is a stranger feeling if it does not work well. It is important for the system to sufficiently handle errors and that it has robustness when it must deal with such stage effects. If we use the current method in YOUPLAY, we can improve on it by making the IR- LEDs brighter and making the frame rate of the cameras faster. In addition, we came up with some methods in which the system can track the participants by capturing the light reflections between an IR-light projector that is set on the ceiling and the retroreflective material that is used on the top of the helmet. Another method is that we added laser range sensors to the sides of the stage and detect the participants' positions.

Way to output images: For the scene in Figure 13, each participant goes to specified position (where a circular image is projected) using each load whose color is assigned in accordance with the character. In Vol.0, we simultaneously showed the route that is expressed by rectangles (as shown in Figure 13) from the start to the goal point, but there were participants who ignore this route. Therefore, in Vol.1, we modified it to steadily show the route that is expressed using arrow images (as shown in Figure 21), and found that none of the participants ignore the route.

Interactive effect sounds: The system recognizes two actions, which are jumping and walking, using the accelerometer set inside the helmet, and outputs the sounds in accordance with the recognitions. The function was used just for a short period of time and the sounds were output from only the headphones. We were not able to understand the concrete reaction of the participants for this function. However, we could confirm that some of the staff enjoyed the fact that the sounds were output in accordance with their movements when we tested the sound output. The staff have little experience in using interactive systems with sensors. In addition, while testing walking slowly, we could observe that they practiced in a way to ensure there was a good output.

In regards to the sound of the butterfly net, we could understand that the participants could grasp the link between the swinging and resultant sound since they were surprised by the output of the sound in accordance with their swinging. The movement became larger in Vol.1 than in Vol.0 since we did not include the sound effect system in the first volume.

Recorded narrations: We guided the story by outputting the narrations in accordance with the situations. There were few participants who ignore pointed out instructions. Although we left the performance up to the participants by basically ad-libbing, they were confused about what to do in some scenes. In such cases, we supported them through narration. Accordingly, the narrations were important for advancing the story.

In the scene where the participants were outside the spaceship, the sounds of the facilitator were output not from the speakers but from only the headphones to enhance the reality. Since the viewers who were not performers could not listen to these sounds, there were answers from the questionnaire that read, "please output sounds from the speaker because I cannot always understand what is going on". In order to improve this problem with maintaining a good level of reality, we come up with some methods for setting up a directional speaker array whose sounds are transmitted to only the viewers or had the viewers also wear headphones.

For example, we used narrations whose contents were concrete, such as, "Catherine who does not like a rat gives a yelp" to aim at adding more fun. Another one was, "He was reminded of his self-introduction". We aim to have the participants expand their imagination. Actually, we found that some of the participants that listened to the narrations made an effort to liven up.

Judging whether or not to output the narrations and what timing to use is necessary because the narrations influence the stage atmosphere and help to advance the story along. Therefore, the operators need to be familiar with the theatrical direction to a certain extent. If we prepare many narrations in advance, we can more easily deal with several situations. However, we need to decide how many we need to prepare in consideration of how difficult it is to decide which narration to output on the spot.

Talking with facilitator: The participants introduce themselves to the facilitator (instructor) in the first scene to start the performance. In this scene, we could have the participants move like they are playing in the performance and could prompt them to use their imagination, and thus, they can understand the point of YOUPLAY. In addition, the participants can loosen their tension by talking together. In the questionnaire, some of the answers stated that the participants could act smoothly by following the live narrations from the facilitator although the consciousness among the participants started off as only rambling at first. Since YOUPLAY was an unknown event for everyone, the facilitator was important in order to have the participants understand the way to advance.

Talking among participants: We provided some opportunities for the participants to talk with each other. The opportunities involved instructions from the facilitator, providing information that only one participant knows, and catching the rat by all the participants. The conversation among the participants became more active as the story advanced. In most of the performances, the participants exchanged their ideas collectively without any ceremony near the end of the story. After the performance, many of the participants took a group picture.

Degree of difficulty: We used many narrations in the initial phase. We gradually made a more important and more open for ad-libbing performance and a more imagination use by friendly opportunity increasing the opportunities the participants needed to use their imagination as the story advanced. In the theatrical workshops, the instructor did not have the participants play in a performance by totally becoming a certain character from the beginning. He/she gradually makes the difficulty in playing harder, such as by starting from uttering their voice. YOUPLAY has worked more effectively since we adopted the method in which the degree of difficulty increasing step by step.

Play time: The play time was approximately 40 minutes for all stage. The time that was set for self-introduce was long in Vol.0. Therefore, we contrived to make the self-introduce time shorter by employing the ice-break time before entering the hall in Vol.1. Here, a whole time for one stage did not change because we added the new scenes that are such as "You float through the universe if you fail the mission." (that is described in Section 3.2) to Vol.1.

Special performance: In Vol.1, two performances were particularly special. Professional performers who are belonged to sunday [41] and Patch [42] performed as the participants. The viewers were excited that professional performers challenged YOUPLAY without having a specific script, and they were full of laughter. In addition, some of the viewers joined the performance on that day after watching the special performance.

Questionnaire: There were mostly positive impressions in the questionnaires such as "I enjoyed it", "I want to play more", "I look forward to the next event", and "I'm glad to play even if I am a novice".

For the question, "Please tell me the scene that you enjoyed the most", many answered "All". Since the scenes that were written as other answers varied and there were no scenes that were specially popular, it seems that various people could enjoy their experiences.

For the question, "How do you feel about the playing time?", many answered it was "short" and "just good". In addition, there were many impressions like, "I wanted to play longer" in the free comment field. There were a few impressions stating it was "long". Therefore, we are thinking about adjusting the content of the story and increasing the stage effects by providing interactivities within the images and sounds to improve of the system, but we will not shorten the playing time.

In the free comment field, there were many comments expressing that the participants' motivation will increase, such as "I should have played without hesitation", "I should have been able to play better", and "I want to play better next time". There are some comments such as "I understood that professional actors are very great". It seems that they changed their interests and concerns about the performance. In fact, there were many repeaters who participated in both Vol.0 and 1 or repeatedly participated in Vol.1. From these questionnaires and the high repeater's rate, we believe that we helped the participants enjoy playing in a theatrical performance, and that is the aim of YOUPLAY.

There were many participants that enjoyed the difference between their own performance and another's performance by viewing them after playing. There are comments such as "It was fun because their performance was very different from mine", "Their performance were better than mine", and "my performance was better". Since there was the comment "I enjoyed only viewing", we could confirm that the theatrical performance has a high level of entertainment even if novices play.

There were a few comments about the system errors such as the images did not follow the action and the sounds were not output from the headphone. For the duration of YOUPLAY, we have added a PC in which the system assistants can track the participants' positions for the image following and have added the visual check for the sound outputting when we conduct the sound testing before every performance. The system errors have decreased with repetition. It is important that the system easily handles errors and has robustness in order not to alleviate any feelings of mistrust in the system.

There were several comments concerning the degree of freedom. Those comments included, "I can play freely because of ad-libbing", "I want to play more freely", and "I was confused because play was too free". If we hold the event again, we will prepare multiple classes such as upper, middle, and beginner in order to separate the degree of freedom. For example, the participant who plays for the first time can select the middle or beginners class, and a repeater can also select an upper class. The participants can also select the level of difficulty.

Twitter: Using Twitter, we have prepared *#hep_youplay*, and have recommended people to write their impression and so on. Most tweets were positive like in the questionnaires. Many of the participants tweeted with the picture that they took after the performance. Besides their impressions, some tweets gave written advices. In addition, we provided the videos that we took during the performances via YouTube, and some of the participants tweeted about it. There were comments such as "I enjoy a quiet laugh", "YOUPLAY was too fun...", and "My performance was funny". We can confirm that the video distribution service pleased the participants.

8 Consideration

We observed the participants' reactions through 80 performances and are surprised that they are not opposed to playing in a theatrical performance. At beginning of the story, although some participants were confused, they gradually got used to playing. Near the end, most of the participants sufficiently played a role. We thought that many people would feel difficulty in *playing*. However, *playing* may actually be a primitive expression like singing and drawing. Our participatory theatrical performance YOUPLAY was the event that helped us understand that.

Every performance was different from another, and all the performances had nothing to fail. We took care that it did not become a game, and attached great importance to using your imagination and that you communicate with the other participants. Accordingly, the story is always different even if the participant join many times in accordance with the others, and the participants can also enjoy the diversity. YOUPLAY is different from the escape the room and participatory games in that there is no answer. It is just like a novel sport because the participants move their own bodies and communicate with one another. YOUPLAY is content in which the aim is to have the participants actively imagine the story. Since the participants need to start moving on their own, those that get the hang of playing in the beginning could enjoy the experience more. It is believed that many people can enjoy it from the beginning if the participatory theatrical performance expands since the participants can understand the necessary points in advance. It was important for us to use many videos and sounds and interactively to change things since the participants can enjoy moving and immersing themselves into the story world. However, the interactivities this time were for the individuals, and we have not been able to connect these interactivities in relation with others. Our future challenges focus on the interactivities prompting the participants to act with the other and we are developing an interactivity that is coordinated by multiple participants. As described above, we could have the participants effectively immerse themselves into the story world based on the staged effects using information technology. However, it is believed that system errors will kill the immersion. In an event that uses staged effects for the immersion, it is very important to measure possible errors in advance and to ensure there is a high level of robustness against them.

We could confirm that many people enjoyed *playing*. We want to repeatedly propose different types of entertainment that can be enjoyed through playing.

9 Conclusion

We explained the details of the system for the participatory theatrical performance *YOUPLAY* in this paper, and presented our knowledge gained from 80 actual stage performances over a two week period. Based on all the performances, we could confirm that YOUPLAY, in which the participants play as performers, is enjoyed by many people, and all the performances could finish without any significant trouble. We observed that the narrations were important for advancing the story and the interactivities with the images and sounds helped the participants to immerse themselves into the story world. Both YOUPLAY Vol.0 and Vol.1 used large-scaled systems. We will examine the mechanism needed for holding these events by using different technology such as bone conduction speakers and head-mounted displays. In YOUPLAY, the costume was easily wearable, and did not have a system. Honauer [43] has researched staging interactive costumes in the theatre. There is room for improvement of the costume for YOUPLAY. We will consider the improvement for increasing immersion.

We can expect an increasing the participatory events that an audience member can join. Error measure methods and a high level of robustness are very important since the systems are used and treated by many people. We need to join such events as engineers or creators while also being careful not to decrease the quality of the performance through the use of information technology. We want to advance our collaboration with several fields and activate more entertainment opportunities based on the knowledge that we have gathered using YOUPLAY here forward.

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