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Assistant Devices for Presentation of Distinctive Viewers' POV in 360-degree Internet Live Broadcasting

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Abstract –360-degree Internet live broadcasting has been widespread in Internet live broadcasting services such as YouTube. However, there is an issue in the 360-degree Internet live broadcasting. The broadcaster cannot be aware of viewers' point of view (POV) because the 360-degree Internet live broadcasting uses an omnidirectional camera and the camera lens do not show the viewers' POV unlike conventional web cameras. The role of gaze information in remote communication is very important, as it shows the focus of the conversation and the object of interest. If the broadcaster cannot be aware of the viewers' POV, it is difficult to perform smooth communication between the broadcaster and the viewers. To solve this issue, we have studied an analysis algorithm of viewers' POV in 360-degree Internet live broadcasting. The algorithm used characteristics about the viewers' viewing behavior and could detect distinctive POV which represented viewers' interests. In the previous research, the distinctive viewers' POV were simply presented as red circles on the equirectangular video using a laptop PC for the broadcaster. The presentation method was not easy to comprehend and the use of a laptop PC would increase the risk of accidents. In this paper, we propose three assistant devices for presentation of the distinctive viewers' POV in 360-degree Internet live broadcasting. The first one is a belt-type device which presents directions of the POV using vibration motors. The second one is a LED-type device which presents directions of the POV using LED light sources cylindrically. The third one is a robot-type device which presents directions of the POV using movement of the robot's head. We developed the three assistant devices and conducted an evaluation experiment. From the experiment, we found the broadcasters did not prefer assistant devices in visual form and they had a positive impression of the robot-type device.

Keywords: 360-degree Internet live broadcasting, Viewers' POV, Assistant devices

1 INTRODUCTION

In recent years, many people use Internet live broadcasting services. In the Internet live broadcasting services, the viewers can enjoy real-time communication with the broadcaster. Besides, YouTube started a 360-degree Internet live broadcasting service which supports omnidirectional cameras from 2016. It enables anyone to easily use the 360-degree Internet live broadcasting service now.

In the 360-degree Internet live broadcasting, a broadcaster takes a 360-degree video using an omnidirectional camera and distributes it to viewers in real-time via the Internet. The broadcaster does not need to care about the view angle of the camera. The viewers can change their point of view (POV) while watching the 360-degree live video and they can watch the video from POV which they are interested in.

The 360-degree Internet live broadcasting, however, has an issue that the broadcaster cannot check the viewers' POV. In the conventional Internet live broadcasting, it uses a web camera which has a single lens and the single lens definitely shows the rectangular photographing range. The broadcaster can be aware of the viewers' viewing range and what they are watching by direction of the lens. On the other hand, in the 360-degree Internet live broadcasting, it uses an omnidirectional camera which has a wide-angle lens or multiple lens and the broadcaster cannot know what the viewers are watching by direction of the lens.

There are many studies about the role of gaze information in the remote communication [1][2]. In the studies, it is turned out that the communicatee's gaze information indicates the target of interest or center of the topic. The gaze information in the remote communication is similar to the viewers' POV in the 360-degree Internet live broadcasting. Therefore, the viewers' POV are not only information which indicates where the viewers are watching but also information which indicates what the viewers are interested in. Because of that, the broadcaster sometimes cannot understand the context of the viewers' comments and it can be a factor which causes communication errors between the broadcaster and the viewers.

To solve this issue, we have studied about an algorithm which detects distinctive viewers' POV to grasp viewers' interests [3]. In this research, the algorithm could detect useful viewers' POV for the broadcaster. We have also studied the effect of presentation of the distinctive viewers' POV to the broadcaster [4]. In this research, we found the presentation of the distinctive viewers' POV could be effective for the broadcaster and it gave positive effects to the communication between the broadcaster and the viewers. It enabled the broadcaster to know what the viewers were interested in. The broadcaster also had a chance to communicate with passive viewers who sent few comments to the broadcaster by the presentation of the distinctive viewers' POV. Even if the distinctive viewers' POV which were not useful to know the viewers' interests were displayed, it did not have a significant negative impact on communication and broadcasting.

The use case which we envisioned for the previous researches were that a single broadcaster delivered the situation of walking through a tourist spot. The broadcaster would visit a tourist spot and report about the spot to the viewers. The equipment used for the broadcasting were a laptop computer and an omnidirectional camera. The broadcaster carried a backpack with a camera mounter to fix the omnidirectional camera and handed the laptop PC. The distinctive viewers' POV were simply presented as red circles on the equirectangular video using a laptop PC for the broadcaster. The presentation method was not easy to comprehend and the use of a laptop PC would increase the risk of accidents.

To solve these issues, we study several assistant devices to present the distinctive viewers' POV to the broadcaster in an effective manner. In this research, we propose three assistant devices for presentation of the distinctive viewers' POV in 360-degree Internet live broadcasting. The first one is a belt-type device which presents directions of the POV using vibration motors. The second one is a LED-type cylindrical device which presents directions of the POV using LED light sources. The third one is a robot-type device which presents directions of the POV using movement of the robot's head.

The contributions of this paper are summarized as follows:

- We developed three assistant devices for presentation of distinctive viewers' POV.
- We clarified the effects of each assistant device in experiments and which device the broadcaster preferred.

The rest of this paper is organized as follows. Section 2 describes our previous work about viewers' POV introducing related work. Section 3 describes three assistant devices for presentation of the distinctive viewers' POV in 360-degree Internet live broadcasting. Section 4 describes implementation of the assistant devices. Section 5 describes evaluation experiments to clarify the effects of each assistant device and discussion about the experimental results. Section 6 summarizes this study.

2 PREVIOUS WORK

2.1 Importance of Gaze Information and POV Analysis

There have been many studies on the role of non-verbal information in communication. In particular, gaze information has been shown to play an important role in communicating mutual intentions. The GAZE Groupware is a study of gaze information in communication [1]. In this study, the non-verbal information of the remote communication in a teleconference system is analyzed. He verified whether natural communication can be performed by conducting a meeting with nonverbal information in a virtual conference room. In addition, he discovered a problem that it is difficult to present gaze information because the space in which the conference participants reside is different in the remote meeting systems. He concludes that it is possible to analyze who talks about what by talking about the gaze directions of the communicatees.

Another study on mutual gaze in remote communication using videoconferencing systems [2] has revealed some interesting findings. The authors argue that the eye contact information of the communicatee is an important factor in the outcome of collaborative work with remote communication. Furthermore, the study also examined the method of presenting gaze information and concluded that the presentation of images including the eyes of the communicatee requires a certain size of images. In 360-degree Internet live broadcasting, the POV is the information that indicates the viewing direction and viewing range of the viewers, and it plays the same role as the gaze in remote communication.

On the analysis of viewers' POV in 360-degree video, a study of Yen-Chen Lin et al. examined on the correction of viewing direction in 360-degree video [5]. In this study, they examined a method of correcting the viewer's direction to the direction of the main story of a 360-degree video. They have implemented and evaluated two patterns of corrections: an automatic correction function and a correction with annotations. The results showed that there were multiple purposes and patterns in the viewer's viewing behavior and emphasize the need to analyze the viewer's viewing direction to provide a higher quality viewing experience.

YouTube provides a heat map analysis function for posted 360-degree videos, and the results of the analysis of the entire 360-degree videos are also available [6]. An analysis of the viewer's POV during viewing revealed the characteristics of watching a 360-degree video. The viewer's POV was directed most toward the 90-degree horizontal range centered on the front of the video, where 75% of the playback time was spent. It was also shown that only 20% of the users watched the full 360-degree range, even for the most popular videos.

2.2 Proposed Algorithm

We have built the following three hypotheses concerning the characteristics about the viewers' POV in a 360-degree Internet live broadcasting [3].

(1) The viewers' POV is concentrated on the direction of the broadcaster's way in mobile environment.
(2) If the viewers' POV directs at other direction except the direction of the broadcaster's way, the viewing behaviors have meanings and there are some interesting objects for the viewers in the direction.
(3) The viewers' POV returns to the direction of the broadcaster's way after the viewers' interests are satisfied

Summarizing the above hypotheses, in a 360-degree Internet live broadcasting, the viewer's POV is directed in the direction where the broadcaster is going. It changes from the frontal direction to the other direction when a target of interest is found. Thereafter, when the interest is satisfied or the target is no longer visible, the viewer's POV is expected to return to the direction where the broadcaster is going.

By conducting an experiment about these three hypotheses, we found they were true. The viewers changed their POV according to their own interests when the POV was directed to the other range in the experiment. Therefore, we developed an algorithm to detect POV viewing within other ranges as the distinctive viewers' POV. We determined the classification of the viewer's state. The viewer's state was classified into the following four categories. The state in which the viewer was viewing the front range was called the "normal viewing". The state in which the POV changed from the front range to other range was called "start of other range viewing". The state in which the viewer was continuously viewing the other range is called "other range viewing". The state that returns to the front range was "end of other range viewing". The "normal viewing" was the state which the viewer's POV changed only within the front range, and we were expected to remain in this state for the longest period of time during the broadcast. The algorithm detected the POV in the state of "other range viewing" by checking the start of other range viewing and end of other range viewing.

Figure 1 shows a flowchart of the algorithm which we created and Fig. 2 shows the variables and conditional expressions used in the flowchart. In the algorithm, the front range is defined as horizontal polar coordinates of broadcaster's way $\varphi_f \pm 60$. It monitors horizontal polar coordinates of viewers' POV every 100 milliseconds. φ_{i_n} gives the horizontal polar coordinates of i-th viewer's POV in n-th monitoring by the algorithm. If one of the viewers' POV goes beyond the front range by satisfying the conditional expression 1 and 4, the algorithm sets the state to "start of other range viewing" and considers it is the distinctive viewers' POV until the state goes to "end of other range viewing" by satisfying the conditional expression 2 and 3. From an experiment, we found the algorithm could detect the distinctive viewers' POV which could be utilized for broadcasting with 89.76% accuracy.

We conducted an experiment for evaluation of presentation of distinctive viewers' POV [4]. As shown in Fig. 3, The distinctive viewers' POV were simply presented as red circles on the equirectangular video using a laptop PC for the broadcaster in the previous work. As a result of the experiment, we found that the presentation of the distinctive viewers' POV made it easy for the broadcaster to understand interests of the viewers. On the other hands, the presentation method was not easy to comprehend and the use of a laptop PC would increase the risk of accidents. We have to study some methods to present the distinctive viewers' POV to the broadcaster in an effective manner.

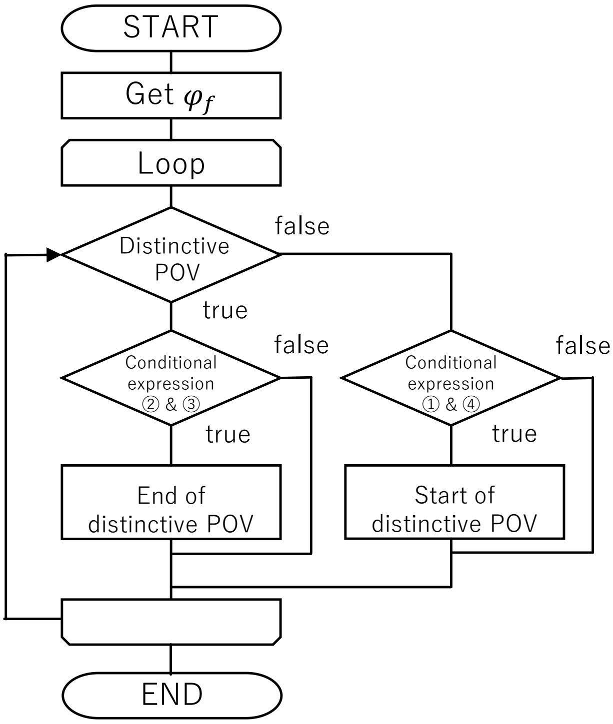


Figure 1: Flowchart of the algorithm

Variables:
Horizontal polar coordinates of viewers' POV
$$\varphi_i = \{\varphi_{i_1}, \varphi_{i_2}, \dots, \varphi_{i_n}\}$$
Horizontal polar coordinates of broadcaster's way
$$\varphi_f$$

Conditional expression ① :
$$\varphi_f - 60 < \varphi_{i_{n-9}} < \varphi_f + 60$$

Conditional expression ② :
$$\varphi_{i_{n-9}} < \varphi_f - 60 \,||\, \varphi_f + 60 < \varphi_{i_{n-9}}$$

Conditional expression ③ :
$$\varphi_f - 60 < \varphi_{i_n} < \varphi_f + 60$$

Conditional expression ④ :
$$\varphi_{i_n} < \varphi_f - 60 \,||\, \varphi_f + 60 < \varphi_{i_n}$$

Figure 2: The variables and conditional of flowchart

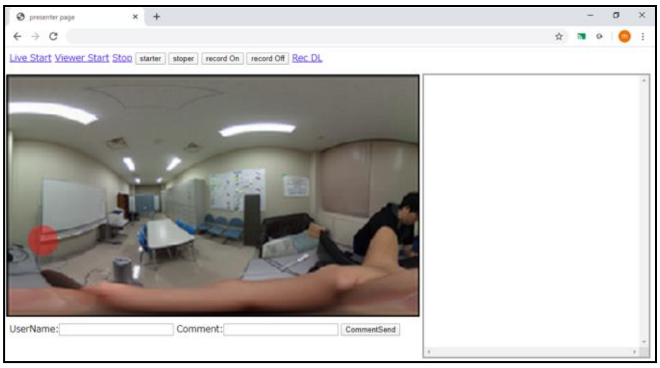


Figure 3: Presentation of distinctive viewers' POV in the previous work

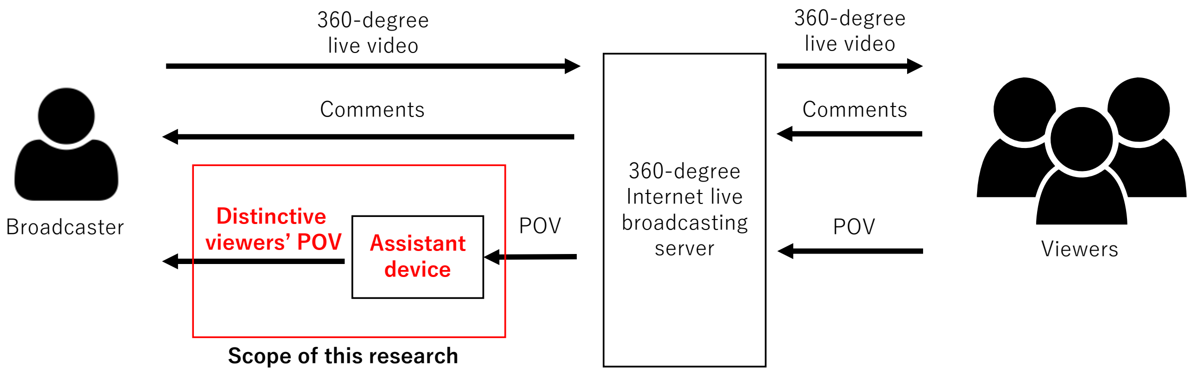


Figure 4: A model of the assistant devices in the 360-degree Internet live broadcasting

3 ASSISTANT DEVICES

3.1 A Model of the Assistant Devices

We propose assistant devices for presentation of distinctive viewers' POV in 360-degree Internet live broadcasting. Figure 4 shows a model of the assistant devices. In the model, a broadcaster sends 360-degree live video to the broadcasting server and viewers can watch the broadcasting and send comments to the broadcaster accessing the broadcasting server as same as typical 360-degree Internet live broadcasting services. The viewers can watch the video changing their POV. The coordinates of the POV are also sent to the broadcasting server in real time as same as our previous work. In this research, the broadcasting server sends the POV to an assistant device. The assistant device uses the algorithm of the previous work to detect distinctive viewers' POV. The assistant device presents the distinctive viewers' POV to the broadcaster by using a presentation means. The broadcaster can communicate with the viewers smoothly estimating their interests from the presentation of the distinctive viewers' POV.

3.2 Requirements of the Assistant Devices

The broadcaster's motivation to use the assistant devices is to make the walk in the tourist spot better. The idea is that the broadcaster can gain a companion from the viewers, even if the broadcaster is traveling alone. In this environment, there are the following three requirements.

1. It should be short time to check the assistant device.
2. It should not restrain the broadcaster's physical activity.
3. It should improve the broadcaster's experience.

The first and second requirements are needed not to increase the risk of accidents, for example, in case of using a laptop PC. The third requirement means the assistant device has great potential to become a companion for the broadcaster in order to improve his/her experience.

3.3 Ideas of the Assistant Devices

Based on the requirements, we present three ideas of the assistant devices. The first one is a belt-type device which presents directions of the POV using vibration motors. The second one is a LED-type cylindrical device which presents directions of the POV using LED light sources. The third one is a robot-type device which presents directions of the POV using movement of the robot's head.

The belt-type device has an advantage that the broadcaster does not need to look the assistant device and can pay attention with his/her surroundings. It would highly satisfy requirement 1 and 2. We use a single line belt and the belt is bound around broadcaster's waist so that it can keep fashionability. Although the belt-type device can present the distinctive viewers' POV in the horizontal direction, it is difficult to present the distinctive viewers' POV in the vertical direction.

The LED-type cylindrical device has an advantage that it can present the distinctive POV both in the horizontal and vertical direction. However, the degree of achievement of the requirement 1 and 2 would be lower than the belt-type device because the LED-type device makes the broadcaster look the assistant device in order to check the distinctive viewers' POV.

The robot-type device specializes in requirement 3. It has an advantage that the robot can be a companion as if the broadcaster walked with a friend together and it would improve the broadcaster's experience. On the other hand, it has a disadvantage in terms of requirement 1 and 2 because it makes the broadcaster look and carry the device.

4 IMPLEMENTATION

We implemented prototypes of the assistant devices evaluate their effectiveness in an experiment. We used a 360-degree Internet live broadcasting system which was developed in our previous work [4] and added some functions to the broadcasting system so that it can handle the assistant devices. In this section, we describe the system architecture and prototypes of the assistant devices.

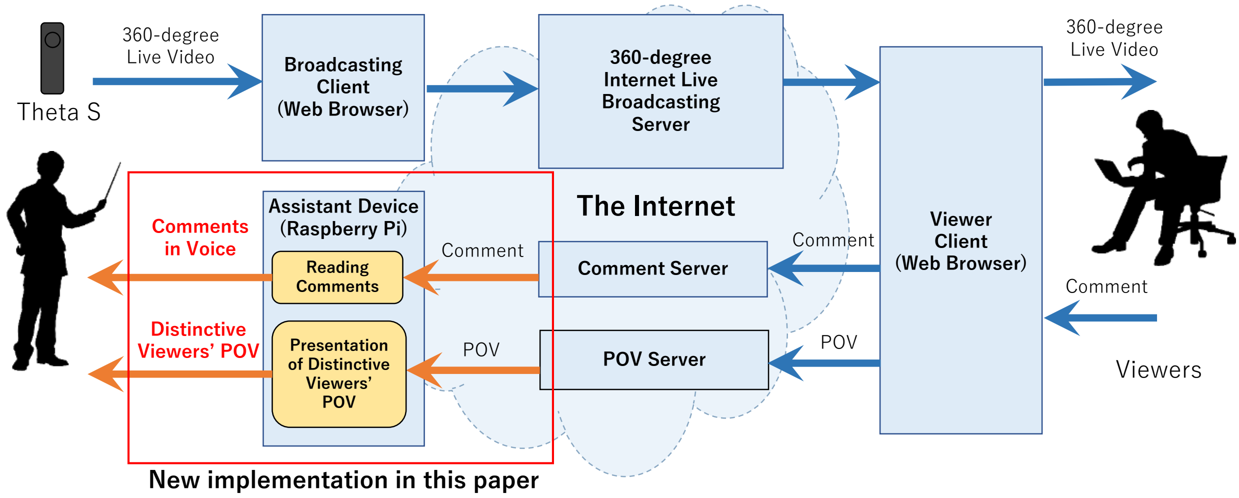


Figure 5: System architecture

4.1 System Architecture

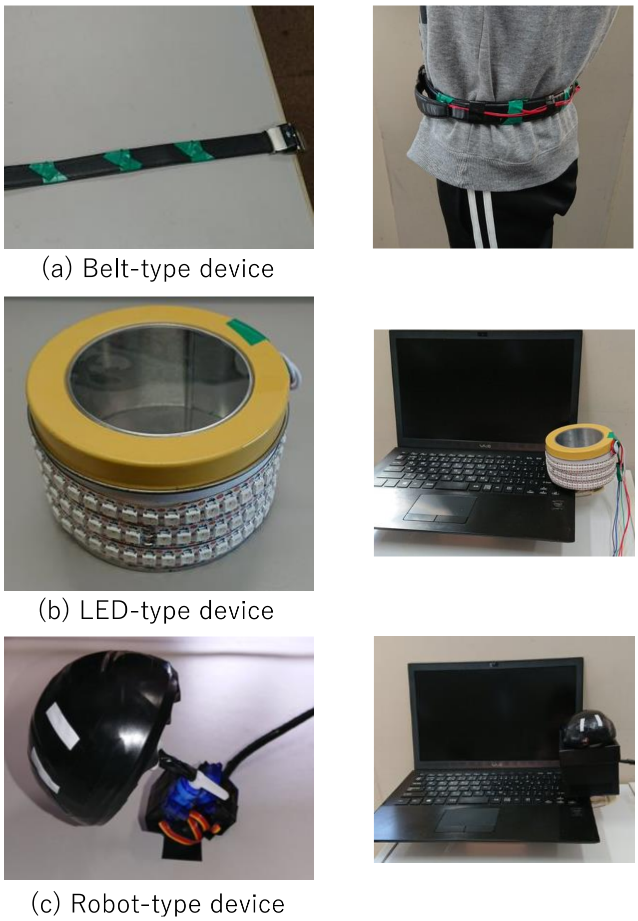
The basic features of the 360-degree Internet live broadcasting system was similar to that in our previous work. In the broadcasting system, it consists of two components which are a 360-degree Internet live broadcast system and a POV server which collects the viewers' POV to deliver it to an assistant device of the broadcaster. Figure 5 shows the architecture of the system. We use the Ricoh Theta S as an omnidirectional camera for the system.

The broadcaster accesses a broadcasting system and starts broadcasting by a web browser. Viewers access the broadcasting system and watch the live broadcasting. The viewers' POV information is sent to the POV server periodically.

We implement the 360-degree Internet live broadcast system by adopting WebRTC that realizes the video streaming on HTML5. We use the Kurento Media Server [7] for the video streaming server. The WebRTC is an API to provide real-time communication functions such as voice communication and video distribution without requiring any plug-in and installation of special software. We use a javascript library called Three.js [8] for processing images. The image acquired from the omnidirectional camera is mapped to a spherical object by using the library. The viewers' POV are managed by the angular coordinates of the two axes which are acquired every 100 ms and the data is sent to the POV server. In this system, the POV is represented by the polar coordinate (ϕ, θ, r) of the spherical surface. The POV sever receives the POV from the viewers and saves the collected data in the database. The Web server and the POV server are implemented using node.js [9]. The algorithm which detects the viewers' distinctive POV is implemented in the POV server.

4.2 Prototypes of the Assistant Devices

Described below are the new functions in this paper. The POV server analyzes the collected POV with the algorithm and send the distinctive viewers' POV to the assistant device.


(a) Belt-type device

(b) LED-type device

(c) Robot-type device

Figure 6: Prototypes of assistant devices

The assistant device has functions of presentation of the distinctive viewers' POV and reading comments in voice. The prototypes of the assistant devices are controlled by software on Raspberry Pi.

Figure 6 shows the prototypes of the assistant devices. The belt-type device has several vibration motors inside the belt at regular intervals. The broadcaster binds a belt around his/her waist and grasp the distinctive viewers' POV in a horizontal direction by the vibration. The LED-type device has several LED tapes which can light individually. The LED tapes are wound around a cylindrical can. The bottom of the can has a clip to fix it on something such as a laptop PC. The broadcaster can grasp the distinctive viewers' POV both in horizontal and vertical direction by the light. The robot-type device has a robot head and it can be turned up, down, right or left using two servo motors. The bottom of the robot head also has a clip to fix it on something. The broadcaster can grasp the distinctive viewers' POV both in horizontal and vertical horizontal direction by the direction of the robot head.

The reading comments in voice is a function which enables the broadcaster to confirm the viewers' comments in voice without looking a display device such as a smartphone and a laptop PC. In the previous work, the viewers' comments were displayed on a laptop PC. Since the prototypes of the assistant devices do not need the laptop PC, the broadcaster does not need to look the laptop PC. This function makes the broadcaster free from looking the laptop PC. In the outdoor environment, the broadcaster must to be able to hear the surrounding sound for safety. We use a bone conduction headphone for hear the viewers' comments.

5 EVALUATION

5.1 Experimental Procedure

We conducted two sets of experiments to evaluate the prototypes of the assistant devices. In each set of the experiments, there were one broadcaster and five viewers and the total experimental participants were 12 people. The location of the broadcasting was Takamatsu Pond in Morioka City, Iwate Prefecture, which was famous as a place where swans flied. Each broadcaster performed broadcasting for approximately 15 minutes and it was performed three times changing the assistant devices. The broadcaster walked around the pond and communicated with the viewers talking about the situation of the circumference. The viewers sent comments about the situation of the circumference of the broadcaster. We asked the broadcaster to stop at a safe place when checking the assistant device for his/her safety and to reply the comments from the viewers as many times as possible.

After three times of the experiments changing the assistant devices, we interviewed to the broadcaster about the presentation of the distinctive viewers' POV. In the interview, we asked about "Awareness of the presentation of the distinctive viewers' POV", "Awareness of the POV direction" and "Usefulness of the POV". Moreover, we asked the broadcaster to evaluate about "understandability of the POV direction", "Easiness of the POV check", "Utilization degree of the POV" and "Do you want to use it again?" on a scale of one to five. After that, we asked the broadcaster to give his/her impression about the assistant device through the whole experiment.

Table 1: Result of the interview after the experiment

Presentation Method	Experiment	Presentation Times	Awareness of the POV	Awareness of the POV direction	Usefulness of the POV
Belt-type	1st	24	24 (100%)	19 (79.2%)	14 (58.3%)
	2nd	23	23 (100%)	20 (87.0%)	11 (47.8%)
LED-type	1st	18	17 (94.4%)	**8 (44.4%)**	9 (50%)
	2nd	21	19 (90.5%)	**12 (57.1%)**	10 (47.6%)
Robot-type	1st	21	21 (100%)	18 (85.7%)	16 (76.2%)
	2nd	28	28 (100%)	24 (85.7%)	18 (64.3%)

Table 2: Result of the comparison

Presentation Method	Understandability of the POV direction	Easiness of the POV check	Utilization degree of the POV	Do you want to use it again?
Belt-type	3.5	5	3.5	4
LED-type	2	2.5	3	2
Robot-type	4	4	3	4

Table 3: Comments about the assistant devices

Presentation Method	Experiment	Comments from the Broadcaster
Belt-type	1st	The vibration reduced labor and time for checking the POV. Since the space between the vibration motors was long, it was difficult to understand what the viewers were looking at. I could use the belt-type device without worrying about what surrounding people thought of my equipment comparing with the other devices.
	2nd	I was easy to understand the vibration. The direction of the POV was a little vague.
LED-type	1st	It was difficult to check which LED were glowing because of the sunlight reflected by the pond. The vertical direction of the POV was vague and it was not useful in this experiment.
	2nd	It was difficult to understand which LED were glowing because the time of light was short. It took time and effort to check the glowing LED because I needed to make a shadow portion for the device.
Robot-type	1st	Although I was worried about what surrounding people thought of my equipment comparing the other devices, it was easy to understand the direction of the POV. I felt friendship for the robot because the voice of reading comments sounded to me as if the robot had spoken.
	2nd	The head movement was cute. It took time to wait until the head movement was completed. The direction of the POV was best understandable.
Impression about all methods	1st	Since the device read the comments, it was easy to perform the broadcasting. The assistant devices did not impose a burden to me.
	2nd	I could not check the assistant device on several occasions because it was slippery.

5.2 Experimental Results

Table 1 shows the experimental result of the interview after the experiment. The presentation of the distinctive viewers' POV by the belt-type device was 24 times in 1st experiment and 23 times in 2nd experiment. The presentation by the LED-type device was 18 times in 1st experiment and 21 times in 2nd experiment. The presentation by the robot-type device was 21 times in 1st experiment and 28 times in 2nd experiment. There was no significant difference among the assistant devices and it could be fair comparison. In terms of the awareness of the POV, they were aware of almost all of the POV presentations. In terms of the awareness of the POV direction, the POV presentations by the belt-type and robot-type devices could be understandable about 80%. However, that of the LED-type device was remarkably low, that is, around 50%.

Table 2 shows the experimental result of the comparison of the assistant devices. The belt-type and robot-type devices achieved scores above average in all comparison items. This result showed these devices were useful to the broadcaster. However, the LED-type device was low score in most comparison items without "utilization degree of the POV". The LED-type device especially would have problems of the usability.

Table 3 shows the comments from the broadcaster written by a free format about the assistant devices. In terms of positive comments about the belt-type device, "it reduced labor and time for checking the POV" and "it can be equipped inconspicuously". In terms of negative comments about the belt-type device, "it was difficult to understand what the viewers were looking at" and "the direction of the POV was a little vague". These results showed the belt-type device was usable but there was an issue with understandability of the POV direction. The LED-type device got only negative comments. They were "difficult to check which LED were glowing", "it was difficult to understand which LED were growing" and "it took time and effort to check the glowing LED". These results showed the LED-type device was not suitable outdoors in the daytime. In terms of positive comments about the robot-type device, "it was easy to understand the direction of the POV", "I felt friendship for the robot", "it was cute" and "The direction of the POV was best understandable". In terms of negative comments about the robot-type device, "I was worried about what surrounding people thought of my equipment" and "it took time to wait for the robot movement" These results showed the robot-type device gave friendship feeling to the broadcaster and it had an advantage in understandability of the POV direction though it stood out outside and the delay time was existed to present the POV.

5.3 Discussion

In the experiment, the belt-type device was highly evaluated by the broadcaster because the device could be used without attention to the device disturbing the broadcasting. The robot-device was also highly evaluated by the broadcaster because it gave friendship feeling to the broadcaster in addition to good understandability of the presentation of the distinctive viewers' POV. We found a new possibility that it became a companion for the broadcaster in order to improve his/her experience. On the other hand, the LED-device got significant low evaluation because it disturbed the broadcasting to check the device and was difficult to see the light outside. To summarize the experimental results, we found the broadcasters did not prefer assistant devices in visual form and they had a positive impression of the robot-type device.

The prototypes of the assistant device in this paper can present one presentation of the distinctive viewers’ POV at a time. However, in some cases, there are several distinctive viewers’ POV at the same time. In such cases, the several distinctive viewers’ POV should be weighted by using the importance because multiple presentations of the distinctive viewers’ POV may confuse the broadcaster. The weighting function should be studied and implemented into the assistant devices.

The other point to be discussed is whether a voice assistant is effective for the presentation of the distinctive viewers' POV. In the experiment, the voice function was only utilized for reading out the comments from the viewers. It could be utilized for the recognition of the distinctive viewers' POV by reading out the position by voice such as "the distinctive viewers' POV is right-upper direction". It is necessary to evaluate the voice assistant comparing these assistant devices. We consider there is a possibility of combination of the robot-type device with the voice assistant in order to improve its understandability and friendship feeling.

6 CONCLUSION

In this paper, we proposed assistant devices for presentation of the distinctive viewers’ POV in 360-degree Internet live broadcasting. we study and developed three prototypes of the assistant devices; a belt-type device which presented directions of the POV using vibration motors, a LED-type device which presented directions of the POV using LED light sources cylindrically and a robot-type device which presented directions of the POV using movement of the robot’s head. We conducted an evaluation experiment. From the experiment, we found the broadcasters did not prefer assistant devices in visual form and they had a positive impression of the robot-type device.

For the future work, we will improve the robot-type device to make it more understandable and friendlier. We also study other methods to present the distinctive viewers' POV to the broadcaster using mixed reality (MR) technologies without disturbing the broadcasting.

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