Title:	Robot Mediated Round Table: Analysis of the Effect of Robot's Gaze
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Keywords:	Human-Robot interaction, Robot's gaze, Communication Robot, psychological experiment, gaze awareness, Robovie

Robot Mediated Round Table: Analysis of the Effect of Robot's Gaze

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Abstract

This paper investigates the relations between the direction of a robot's face and a gaze which a person notices. Non-verbal information such as gaze movement or gesture is crucial to conversation between people. In particular, the effect of a gaze is most important in the non-verbal communication because the gaze movements convey various information such as timing of taking turns or a target which a person mentions. This paper argues that the important role of the gaze is also the same in interaction between a human and a robot. In spite of the importance of the gaze, there is not a study of the relations between a robot's head orientation and a robot's gaze. This paper has conducted an experiment to investigate the relations with an experimental environment named RM-RT where the robot's head orientation was fixed to a particular person in a conversation. The result indicated that people noticed the robot's gaze depending on the robot's head orientation.

1 Introduction

According to the development of Honda's P-3/ASIMO [4] or Sony's AIVO [3], the dreams of a communication-robot have appeared to come true. To improve communication skills of the robot, this paper deals with the eye-contact between a person and a robot. In other words, it concentrates on a robot's gaze toward a person.

There are several difficulties for a robot to achieve eye-contact with a person. That is, the robot must obtain person's information from a vision sensor; where is the location of the person, where is the position of his/her face, and where does he/she gaze?

Several studies handled the difficulties to achieve the eye-contact. For example, a social robot named Kismet [2] has the ability to find out a person's face location to achieve a social interaction with him/her. In a humanoid named SIG [8], audio and visual data streams are integrated in search of a exact location of a speaker person because the location only detected form one of the data streams is less accurate. In addition, a humanoid named Infanoid [6] attempts to recognize the exact face position and the direction where the person pays attention.

However, even if the development of the above technologies are completed, an important issue remains to be dealt with. That is the effective zone of the robot's gaze toward a person. In short, where should the robot's head turn to make the person notice its gaze? This issue is significant to succeed in achieving eye-contact. However, the effective gaze zone of the robot to the person has not been investigated yet.

This paper conducts a psychological experiment to investigate the effective gaze zone. Strictly speaking, it investigates the orientation of the robot's head, which makes the person notice its gaze. The effective gaze zone is examined from viewpoints of both the person to whom the robot's head turn and him/her to whom it does not.

In addition, this paper develops an experimental environment named RM-RT (Robot-Mediated Round-Table) for the psychological experiment. RM-RT is a communication environment where eight subjects sit down surrounding a communication robot named Robovie. In RM-RT, while they communicate with each other (except for Robovie), Robovie tries to communicate with one of the subjects turning its head to face him/her depending on a experimental condition. In short, the subjects are gazed at by Robovie in a actual conversation. Since they does not concentrate on the robot's gaze intentionally, RM-RT can examine the unconscious effective gaze zone.

The remainder of the paper is organized as follows. Section 2 explains the robot's gaze and proposes a hypothesis. Section 3 explains RM-RT environment, and Section 4 describes a psychological experiment under RM-RT to confirms the hypothesis. Section 5 discusses the robot's effective gaze zone in terms of the

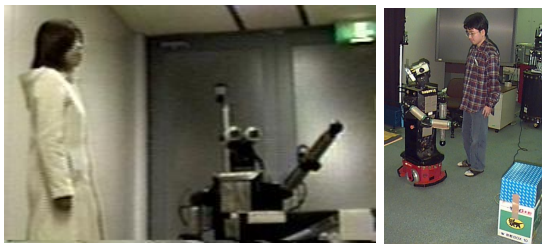

Figure 1: Left: the robot refers to a poster on a wall with gaze movements and hand gestures. Right: the robot achieves eye-contact with the person.

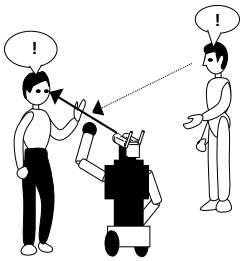

Figure 2: The robot turns its head to face one person. The other person observes the behavior.

experimental result. Section 6 concludes the paper with a summary.

2 Robot's Gaze

2.1 Gazing at real world objects

In a conversation between people, a real world object (except for a speaker and hearer) becomes frequently a main topic. If the object is in sight, they point at it to refer to with gaze movements and hand gestures. These ordinary behaviors are also essential for natural interaction between a person and a robot.

We conducted an experiment to confirm the importance of the gaze movements when a robot pointed at an object [5] (the left picture of Figure 1). In the experiment, the robot generated a utterance "please look at this" pointing at a poster on a wall with gaze movements and hand gestures.

The result indicated the effect of the gaze movements on the pointing hand gesture. For instance, subjects realized that the robot referred to the poster by the utterance when the robot turned its head to them and carried out eye-contact with them. On the other hand, they did not become aware of the reference when it did not carried out eye-contact.

The experimental result suggests that eye-contact is also important in the interaction between a person and a robot. To achieve obvious eye-contact between them, this paper examines a condition where the person notice the robot's gaze.

2.2 Robot's gaze in eye-contact

The right picture of Figure 1 shows the eye-contact between the person and the robot. The following sequence of the robot behaviors will achieve distinct eye-contact.

1. The robot finds out the location of a person via a vision sensor, and turns its head to the direction.
2. The robot recognizes the direction of the person's gaze, and meets his/her gaze.

However, does the robot need to achieve such distinct eye-contact in usual interaction?

It is relatively easy for the robot to obtain the location of the person. For example, if it detects a skin color at the position where there is a difference between two flames from an omni-directional camera, there is a distinct possibility that the person will be there. The advantages of this method are low computational costs and simplicity to develop it. The disadvantages is low precision of an angle where the robot's head turns.

On the other hand, a technique for capturing a person's gaze direction already exists [7]. With the technique, it is possible for the robot to meet person's gaze and to achieve distinct eye-contact. However, since cameras on the robot moves frequently, it is difficult to use the technique on an actual robot.

In comparison with the first method, the second one is superior in terms of precision. However, the first method is appropriate for the robot in view of a robot vision system. To determine which one is appropriate, this paper investigates a required precision on a robot's gaze.

2.3 Power of gaze

This paper concentrates on the relations between a robot's head orientation and a robot's gaze to investigate the required precision on the robot's gaze. This paper calls the range of robot's head angles where the person can notice the robot's gaze by the effective gaze zone.

Figure 2 shows the relations between the robot's head orientation and the robot's gaze. The figure demonstrates two possibilities when the person notices the robot's gaze; one is a gaze noticed by the person to whom the robot's head turns (the left person in Fig.

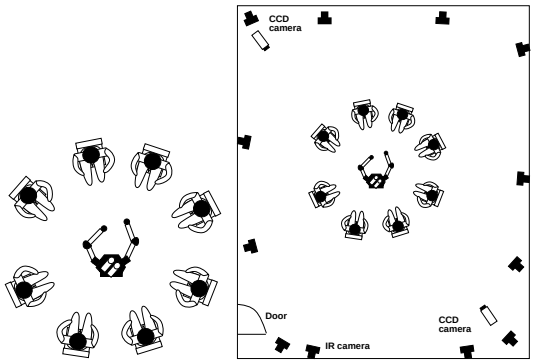

Figure 3: Experimental environment RM-RT

2), and the other is a gaze noticed by the person to whom robot's head dose not turns (the right person in Fig. 2).

It is essential in human-robot interaction that the person faced by the robot's head notices the robot's gaze. To achieve the essential gaze, this paper finds out what angle of the robot's head can make the person notice its gaze.

In addition, it is also vital that the person who is not gazed notices the robot's gaze toward another person because information about who is a speaker and who is a hearer is crucial to the interpretation of a generated utterance [1]. Therefore regardless of gazed person or not, he/she must notice the robot's gaze to interact with the robot. This paper also investigates whether the person notices the robot's gaze when it turns its head to face another person.

This paper puts forward the following hypothesis in terms of the relations between the robot's head orientation and the robot's gaze.

Hypothesis 1 *When two persons are near each other, a person to whom the robot turns its head notices the robot's gaze toward him/her and the other person to whom it dose not turn its head dose not notice the gaze toward him/her. Also, if the robot turns its head between them, they notice the gaze toward them simultaneously.*

This paper confirms the hypothesis with interaction between the persons and the actual robot.

3 Robot Mediated Round Table

3.1 RM-RT

This paper has developed an experimental environment named RM-RT to investigate the relations between the robot's head orientation and its gaze (left figure in Fig. 3). In the figure, a communication robot named Robovie is in the center of RM-RT. The eight subjects sit down surrounding Robovie.

In RM-RT, the subjects must have discussion about two topics. Within the discussion, Robovie tries to communicate with one of them turning its head to face him/her. The head orientation is determined according to the experimental condition. In addition, Robovie's body dose not turn during the discussion. Also, the subjects must not swap their chairs. Therefore, the combination of each head orientation and each position of the subjects is fixed in RM-RT.

RM-RT is also designed to examine the effect of the Robovie's gaze when the subjects do not focus on its gaze intentionally. Strictly speaking, the contents of the interaction with Robovie have no connection with the current discussion topics.

3.2 Robovie

The Robot in the right picture of Fig. 1 is Robovie in itself. Robovie has two 4 DOF hands and a 3 DOF head to generate hand gestures or gaze with head motions. It also has a movable base and several types of sensors: touch sensors to notice being touched by persons, ultrasonic distance sensors to detect obstacles, and two types of vision sensors. One of the vision sensors is an omni-directional vision sensor able to capture panoramic scenes around Robovie. Robovie obtains the direction of a person's location by detecting skin color movements in an image captured by the omni-directional vision sensor. The other vision sensor includes two CCD cameras on Robovie's head for stereo vision. Robovie is also equipped with speech recognition and generation software.

In RM-RT, Robovie turns its head to only a few subjects to communicate with them. The duration of the interaction with one subject is from 5 to 10 minutes. The interaction consists of vocal and gesture communication.

4 Experiment

[Subjects]

There were 36 subjects (men and women), and their average age was 19.8 years old. They were divided into five groups. Three groups consisted of eight subjects and remaining two groups consisted of six subjects. In the two groups, the two seat behind Robovie was vacant.

[Experimental environment]

Right figure in Fig. 3 shows an experimental environment with RM-RT. This environment is a experimental room in our labs. RM-RT was set in the center of

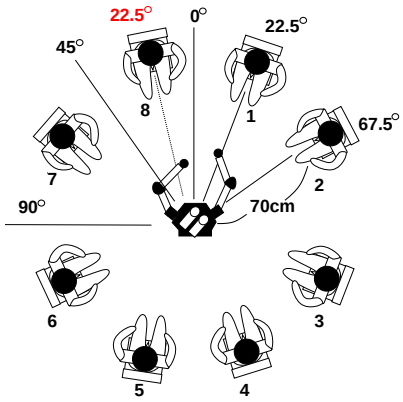

Figure 4: The position of each subject and Robovie

the room. Also, there were twelve IR cameras around RM-RT to capture the head orientations of the subjects and Robovie. The subjects wore caps attached markers tracked by the IR cameras to. In addition, there were two CCD cameras to record the experimental scenes.

[Experimental condition]

Figure 4 shows the position of each subject and Robovie, and the direction where it turns its head. In Fig. 4, each seat of the subjects was numbered from 1 to 8 to explain the experiment. The subjects was sitting 70 cm from Robovie. The distance from Robovie made it available for them to touch Robovie.

Robovie turns its head to the several directions: 45 degrees in the left side, 90 degrees in the left side, 22.5 degrees in the right side, and 67.5 degrees in the right side. In short, Robovie turned its head to face two subjects sitting at number 1 and 2 seats. Also, it turned its head between number 1 and 8, between number 7 and 8, and between number 6 and 7. However, there was one experimental session where Robovie turned its head to the subject sitting at number 8. As a result, there were four experimental conditions. The subjects was also divided four types according to the conditions; the subjects to whom Robovie turned its head (11 persons), the subjects near whom it turned its head (15 persons), the subjects to whose next it turned its head (5 persons), and the subjects to whom it had never turned its head (5 persons).

[Experimental sequence]

In the experiment, all subjects played with Robovie for 10 minutes to become familiar with Robovie before beginning RM-RT. After the playing session, the subjects sat down at RM-RT seats at random and wore the caps with IR markers. After preparing RM-RT, the subjects discussed two topics; the one is current problems of Japan, and the other is something like a game. After each topics was finished, the subjects answer questionnaires about the topics. Also, at the end of the two topics, the subjects was asked about the robot's gaze.

The relations between the orientations of Robovie's head and Robovie's gaze was investigated with questionnaires. The quetions were the following items.

- Did you realize a gaze from Robovie?
- did you realize the Robovie's gaze to the other subjects? If any, who were them?

[Predictions]

This subsection predicts the experimental outcomes from the hypothesis and the experimental conditions. The following three items are predictions.

1. The subjects (sitting at the seats of the number 1 ,2, and 8 if Robovie turns to 8) where Robovie turns its head will notice Robovie's gaze.
2. The subjects (sitting at the seat of the number 3) to whose next Robovie turns its head will not notice Robovie's gaze.
3. The subjects (sitting at the seats of the number 6, 7, and 8) between whom Robovie turns its head will notice Robovie's gaze.

[Outcome]

Figure 5 and 6 show the outcome where each graph represents the percentage of the persons who realized the gaze (the left bar) and who did not (the right bar).

Figure 5 show the answer to the question "did you realize a gaze from Robovie?" In other words, the number of subjects notices Robovie's gaze to him/her. Each graph (a., b., and c.) represents a comparison between each experimental conditions. In the outcome at the graph b., there is the significance between the subjects to whom Robovie turned its head and the subjects to whose next it turned its head.

Figure 6 show the answer to the question "did you realize the Robovie's gaze to the other subjects?" In

other words, the number of subjects notices Robovie's gaze to the other subjects. Each graph (a., b., and c.) also represents a comparison between each experimental conditions. In the outcome at the graph c., there is the significance between the subjects to whom Robovie turned its head and the subjects to whom it had never turned its head.

[Verification of prediction 1.]

Figure 5 a. indicates that almost subjects noticed Robovie's gaze when Robovie turned its gaze to them. Also, Figure 6 a. indicates the same outcome. These evidence suggests that the prediction 1 is true.

[Verification of prediction 2.]

Figure 5 b. indicates that the subjects to whom Robovie turned its head noticed Robovie's gaze but that the subjects to whose next Robovie turned its head did not notice Robovie's gaze. The evidence suggests that the prediction 2 is true. However, even though Figure 6 b. shows the same tendency as Figure 5 b., a few subjects noticed Robovie's gaze to the subjects to whose next Robovie turned its head.

[Verification of prediction 3.]

Figure 5 a. and 6a. do not show the significance. The fact indicates that two subjects between whom Robovie turned its head noticed Robovie's gaze together. The evidence suggests that the prediction 3 is true.

From prediction 1 to 3, the proposed hypothesis is verified.

5 Discussion

This section discusses the robot's head motion in a conversation from the experimental outcome point of view. Figure 5 a. and b. suggests the robot's head motion when the robot does not determine who communicates with it. According to the outcome, the robot should turn its head between persons in such a situation. Also, if the robot intends to communicate with a specific person, it turns its heads to him/her exactly. According to the exact gaze, the people near the specific person does not notice its gaze.

Moreover, the experimental outcome suggests that the robot can make the person notice its gaze even thought the robot can not obtain an exact location of the person or their gaze direction. In particular, the robot can select a person to communicate with even using such a easy gaze control. In short, the communication robot does not always recognize a person's gaze direction. The location information of the person is sufficient when interacting with people.

Also, RM-RT employs IR cameras to capture head orientations of the subjects and Robovie. In the future work, we will try to analyze the data and investigate the relations between the head motions and Robovie's gaze much more exactly.

6 Conclusion

This paper investigated the relations between a robot's head orientation and a robot's gaze. For the investigation, this paper developed an experimental environment named RM-RT where the subjects discussed some topics with each other, and conducted a psychological experiment with RM-RT.

The outcomes indicated that the subjects to whom the robot turned noticed the robot's gaze. On the other hand, the subjects next him/her did not notice the robot's gaze. If the robot turned its head between two subjects, they noticed the robot's gaze together.

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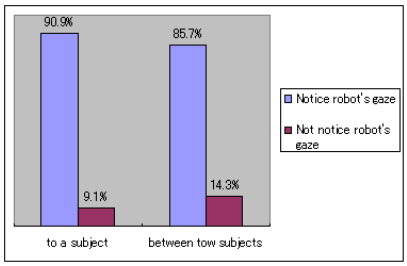
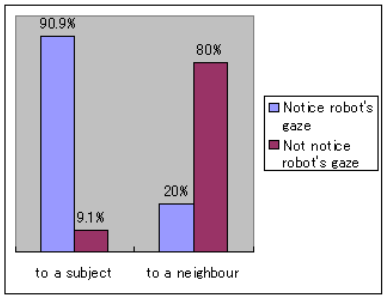
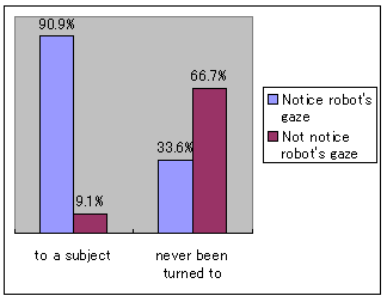


a) a comparison between the subjects to whom Robovie turned its head and the subjects near whom it turned its head. ($P > .1, U = 73$)

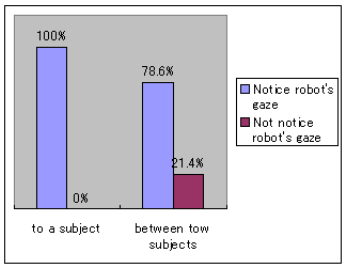


b) a comparison between the subjects to whom Robovie turned its head and the subjects to whose next it turned its head. ($*P < .05, U = 8$)

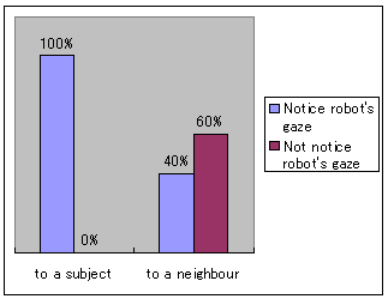


c) a comparison between the subjects to whom Robovie turned its head and the subjects to whom it had never turned its head . ($P < .1, U = 14$)

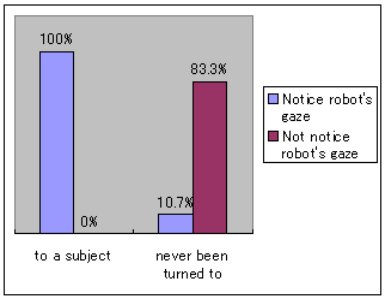
Figure 5: The answer to the question "did you realize a gaze from Robovie?" Each graph represents the percentage of the persons who realized the gaze (the left bar) and who did not (the right bar).



a) a comparison between the subjects to whom Robovie turned its head and the subjects near whom it turned its head. ($P > .1, U = 60.5$)



b) a comparison between the subjects to whom Robovie turned its head and the subjects to whose next it turned its head. ($P < .1, U = 11$)



c) a comparison between the subjects to whom Robovie turned its head and the subjects to whom it had never turned its head. ($*P < .01, U = 5.5$)

Figure 6: The answer to the question "did you realize the Robovie's gaze to the other subjects?" Each graph represents the percentage of the persons who realized the gaze (the left bar) and who did not (the right bar).