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Bidirectional Eye Contact for Human-Robot Communication

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SUMMARY Eye contact is an effective means of controlling human communication, such as in starting communication. It seems that we can make eye contact if we simply look at each other. However, this alone does not establish eye contact. Both parties also need to be aware of being watched by the other. We propose a method of bidirectional eye contact satisfying these conditions for human-robot communication. When a human wants to start communication with a robot, he/she watches the robot. If it finds a human looking at it, the robot turns to him/her, changing its facial expressions to let him/her know its awareness of his/her gaze. When the robot wants to initiate communication with a particular person, it moves its body and face toward him/her and changes its facial expressions to make the person notice its gaze. We show several experimental results to prove the effectiveness of this method. Moreover, we present a robot that can recognize hand gestures after making eye contact with the human to show the usefulness of eye contact as a means of controlling communication.

key words: *eye contact, gaze, human-robot interface, nonverbal behavior, gesture recognition, embodied agent*

1. Introduction

Gaze plays an important role in human communication. Thus, there has been a great deal of research on using gaze or eye movements for human interfaces, which can be considered as communication between man and machine. Most human interfaces use eye movements for pointing instead of a mouse or a joystick, such as in choosing an icon [1]–[3]. However, unlike arms and hands, eyes are not appropriate for precise pointing. We move our eyes toward the direction that objects we would like to see, exist in. However, we do not use our eyes to point something. The main role of gaze in actual human communication is to control the flow of communication. This function can be called meta-communication. Recently, several robots have been proposed that utilize gaze for meta-communication. ROBITA [4] turns to the specific person speaking at the moment in a group conversation. Robovie [5] and Cog [6] are similar examples.

Eye contact is a phenomenon that occurs when two people cross their gaze. Since we perceive eye contact clearly, eye contact has stronger meta-communication capability than a simple gaze. Suppose we would like to make an order to a waiter in a restaurant. We search for a waiter, then waiting until he turns toward our direction. When he turns, our eyes meet his eyes. We make eye contact. Then, we beckon slightly. This small gesture is enough to let the waiter know that we want him to come over.

The robots mentioned above such as ROBITA are supposed to make eye contact with humans by turning their eyes (cameras) toward human faces. Psychological studies show, however, that this turning action alone may not be enough to make eye contact. In addition, each party must be aware of being looked at by the other [7]. Thus, we have proposed a method of eye contact between human and robot considering the above through the observations of the human face and the actions of the robot head and face [8]. Since the robot's actions including changes in its facial expression play an important role, we call our method active eye contact.

In our previous work [8], we considered only the eye contact from a human to a robot. The robot searches for a human who would like to start communication with itself by establishing eye contact. If the human fixes his/her gaze on the robot, it turns its gaze on him/her, establishing eye contact. However, there should also be eye contact initiated by a robot to a human. When a robot needs to initiate communication with a particular person, it should try to make eye contact with the person. In this paper, we consider this reversal case as well, proposing bidirectional eye contact between a human and a robot. In such a case, the robot needs to make the person notice clearly that the robot is looking at none other than him/her. We show that the body action of the robot is effective for this through experiments.

In addition, we show the usefulness of eye contact as a means of meta-communication by using a robot that accepts simple hand-gesture commands after making eye contact with the human, like the waiter in the restaurant mentioned before. Hand gestures are good means of nonverbal communication. However, it is difficult to reduce false detection if we use simple hand movements for gesture commands, because such simple movements are frequently observed in human activities other than making orders. Combining eye contact and gestures can solve this problem. We demonstrate this through experiments.

2. Robot System

This section briefly describes our robot system used for eye-contact experiments before explaining our method of making eye contact between humans and robots. Figure 1 shows

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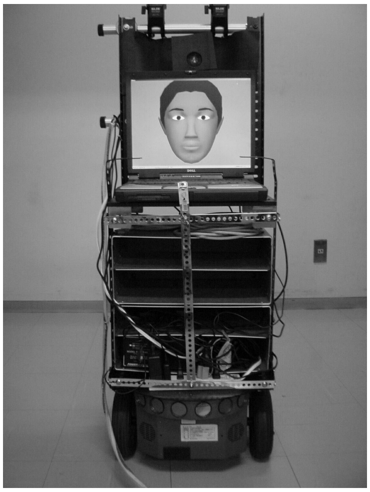


Fig. 1 Eye-contact robot.

our robot. We use a mobile robot Pioneer 2 by ActivMedia. A laptop PC is placed on it so that a 3D CG human head is shown at an appropriate height. We believe that robots like ours with flat displays for their heads will be widely used. We can easily change facial expressions of CG faces. In addition, the robots can show various information on them to humans when necessary. A pan-tilt-zoom controllable camera (EVI-D100 by Sony) is set above the PC with a black screen behind it so that it will not attract attention and people can concentrate on looking at the face on the computer display.

3. Basic Eye Contact Method

As mentioned in the Introduction, two conditions — gaze-crossing and gaze-awareness — are necessary for humans to feel that they have made eye contact.

It is relatively easy to satisfy the first condition since this is a sort of physical condition. The robot observes the human's gaze. If the human is looking in the direction of the robot, it turns its eyes toward the human. This observation-and-action sequence can fulfill the first condition.

The second condition is more difficult to satisfy. Even if the robot has noticed that the human is looking at it, the person may not be aware of this fact. We solve this problem by making the robot show this fact explicitly by changing its facial expressions. If the robot finds a human looking at it, it turns its face toward him/her. If the person is still looking at it after this action, the robot assumes that the human is really looking at it. Then, it changes facial expressions, such as by smiling, to let the person know that it is aware of his/her gaze. We again use this observation-and-action sequence to fulfill the second condition.

We have found from preliminary experiments that we need one more thing to realize eye contact between humans and robots. The robot should not make humans feel that it is looking at them when it is actually not. There is, however, the so-called Mona Lisa effect [9]. We humans tend to perceive that a face in a still image is looking at us when we look at it. To avoid this effect, the robot should keep moving its head when any human is not looking at it. This head motion should be independent of the existence of humans around the robot. Hereafter, we use the phrase 'moving the head' to mean that the head moves in the way mentioned above except when it is clear to mean others.

Based on these considerations, we have designed an eye contact method as follows.

1. While rotating its camera, the robot detects face candidates. The CG head on the display turns in the same direction as the camera.
2. If it detects a face candidate, the robot examines the existence of the eyes and the nostrils to confirm whether or not it is a human face. (If not a face, return to 1.)
3. The robot computes the face direction. If the direction is toward the CG head on its display, the robot turns in the direction of the human. It also turns the CG head to the frontal face position. If the robot observes that the human is still facing toward it after this action, the robot changes its facial expressions on the CG head, completing eye contact with the human. (If the face direction is not toward the robot, return to 1.)

4. Facial Image Processing and Facial Actions

This section describes techniques used in the robot system.

4.1 Facial Image Processing

Psychological studies show that humans may avoid eye contact when they are too close to each other. The frequency of eye contact increases as the distance between the humans increases [10]. This means that the robot should be able to make eye contact even when humans are a little far from the robot. Thus, our robot first searches for face candidates with the zoomed-out camera. When a candidate is detected, the camera zooms in on it. Then, the robot examines detailed face features.

Face candidate regions are detected in the images with a wide field of view (Fig. 2). First, skin color regions are extracted (Fig. 3). Then, small regions and too elongated regions are removed. Inside the remaining regions, subtraction between consecutive frames is computed. The largest region among those where the sum of absolute values of the subtraction exceeds a given threshold is considered as a face candidate (Fig. 4). Then, the pan, tilt, and zoom of the camera are adjusted so that the candidate region can be taken large enough to examine facial features. Experiments show that it can detect human faces indoors at a distance of 6 m.

The system detects the eyes (pupils) and the nostrils in the zoomed-in image. We use the feature extraction module in the face recognition software library by Toshiba [11] for this process. Then, the system measures the horizontal distance between the left pupil and the left nostril dl and that for the right side dr as shown in Fig. 5. From these two values

Fig. 2 Input image.

Fig. 3 Skin-color regions.

Fig. 4 Detected face.

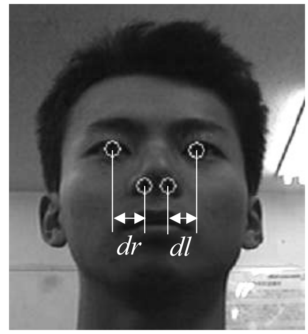
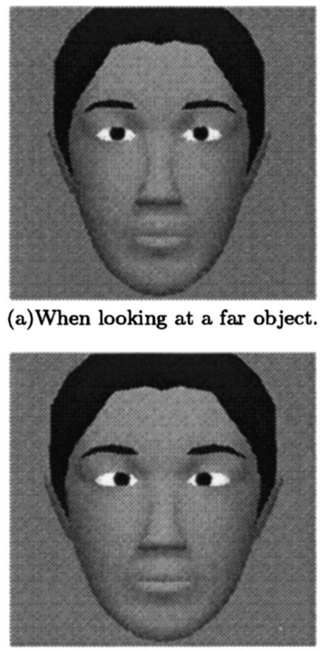


Fig. 5 Face direction computation.



(a)When looking at a far object.

(b)When looking at a near object.

Fig. 6 The pupil distance.

it determines the direction of the gaze (face). In actuality, the robot does not need to compute the accurate direction. It only needs to determine whether or not the person is looking at the robot. Since the camera has turned in the human's direction, the frontal face must be observed if the human is looking at the robot face. If the ratio between dl and dr is close to 1, the human face can be considered to be facing toward the robot.

4.2 Facial Actions of the Robot

We use the embodied agent developed by Hasegawa et al. [12] as our robot's head and face.

The CG head on the display turns in the same way as the camera. Thus, the head keeps moving while the robot is trying to detect human faces. This solves the so-called Mona Lisa effect. In addition to the face direction, the distance between the two pupils of the robot face changes using the focused distance data of the camera as shown in Fig. 6. The auto-focus module of the camera outputs the distance where the focus is adjusted. If the distance is large, the pupil distance is increased (Fig. 6 (a)). If small, it is decreased (Fig. 6 (b)). The face direction and the pupil distance show humans where the robot is looking. Such expressions by the robot are useful for humans to know when they can start communicating with the robot.

When the robot detects a human face, it turns its body in the human's direction. The CG head also turns back to the frontal position. The first condition necessary for eye contact is satisfied by this action. If the human still maintains his/her face directed toward the robot, the robot considers that the human is looking at it. The robot notices the human's gaze upon it. Since the movement of the robot's eyes stops, the human may in turn feel the robot's gaze on him/her. To make this feeling much clearer, the robot changes its facial expressions.

5. Eye Contact Experiments in Human Initiative Cases

We performed experiments to examine whether or not our method would make humans feel that they had made eye contact with the robot.

First, we checked the effect of moving the head (Experiment 1). We prepared two display cases: a moving head and a still image of the head with the frontal face. We used ten subjects; all were graduate students in our department. We asked them to give a value ranging from 0 (they do not perceive the gaze of the robot at all) to 6 (they do definitely) for each case.

Figure 7 shows the result. Comparing the ten resultant pairs with the Wilcoxon signed rank test gives a *p-value* of 0.0039. The two conditions are significantly different at the $p < 0.05$ level. Therefore, moving the head was proven to be effective in making humans not perceive any eye contact from the robot.

Next, we performed an eye-contact experiment (Experiment 2). We asked the same ten subjects to turn their head to look at the CG face and make eye contact with the robot, and then to give a subjective value from 0 (they do not perceive eye contact with the robot at all) to 6 (they definitely do) for each of the following three methods.

Method 1 (proposed method): The CG head is moving. When it notices that the human is looking at it, it stops in the frontal face position, then smiles.
Method 2: The CG head does not move and remains in the frontal face position. When it notices that the human is looking at it, it smiles.
Method 3: The CG head is moving. When it notices that the human is looking at it, it stops in the frontal face position without any changes in facial expressions.

Figure 8 shows the result. The Friedman test gives a *p-value* of 0.0016, showing that there are significant differences among the methods ($p < 0.05$). The Scheffé test shows that Methods 1 and 3 give significantly different results ($p < 0.05$). These results indicate that the proposed method (Method 1) is effective to make humans perceive eye contact with the robot.

Furthermore, we performed an experiment to examine what facial expression is most effective (Experiment 3). We used Method 1 in the above experiment but tried changing the facial expression part. We examined the following three expressions: smiling (the same as in Method 1), nodding, and surprised (opening the eyes wide and raising the eyebrows). We used 11 subjects; all were graduate students in our department. We asked them to arrange these three expressions in order of making them perceive eye contact. We allowed them to give the same ranking to multiple expressions.

Figure 9 shows the result. (Note that the value 1 means the most effective expression for eye contact.) The Friedman test gives a *p-value* of 0.0057, showing that there are significant differences among these three ($p < 0.05$). The Scheffé test shows that significant differences exist between the smiling and surprised expressions, and between the nodding and surprised expressions ($p < 0.05$). We cannot say what is the best expression since there are various possible facial expressions. From these experiments, however, it can be seen that simple natural expressions such as smiling and nodding are good enough to tell humans that the robot is aware of their gaze.

Our eye contact method includes two actions: moving the head without any relation to the surroundings and turning it to the person when the robot finds him/her; and changing facial expressions. In Experiment 2, we examined three methods: both actions were included and either one is included. (The method without any action is to display a static face image. The result of Experiment 1 shows that this is not usable because of the Mona Lisa effect.) We adopted the facial expression change into smiling. In Experiment 3, we examined three facial expressions while we use the same head motion for all the cases. In theory, we need to con-

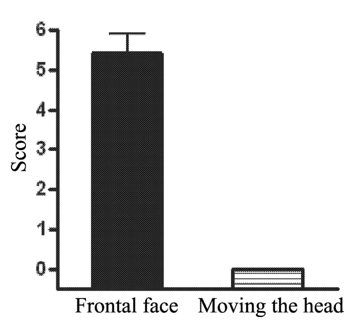


Fig. 7 Effect of moving the head (Experiment 1).

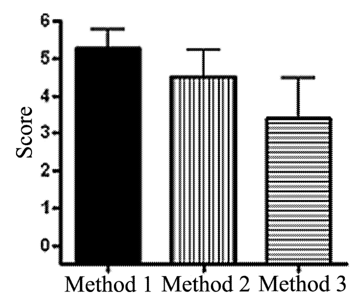


Fig. 8 Eye-contact experiment (Experiment 2).

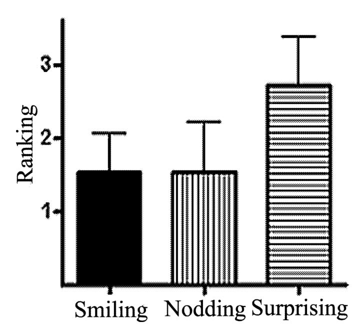


Fig. 9 Expression experiment (Experiment 3).

sider the dependency of the two actions. However, the robot should move the head to avoid the Mona Lisa effect. And the result of Experiment 3 shows no difference between smiling and nodding. These facts show that Experiment 2 was good enough to prove the effectiveness of the proposed method.

6. Eye Contact Experiments in Robot Initiative Cases

So far, we have considered the cases where a human has some request for a robot and would like to start communication with it by initiating eye contact. On the other hand, there are occasions that a robot would like to start communication with a particular human. For example, it might be better for clerk robots to start helping customers after making eye contact with them. If they do not need any help, they will avert their eyes. Guide robots might also be preferred to make eye contact with people who seem to need help before starting actual actions. We must consider such cases as well. Since the proposed method satisfies the two conditions necessary for eye contact, the basic procedure for establishing eye contact can be the same. In the human-initiative case, the robot first tries to find a human who is watching it. In the robot-initiative case, however, the robot should first find the person whom it wishes to start communicating with and fix its gaze on him/her. If the person casts his/her gaze on the robot and maintains it a while, he/she must have noticed the robot's gaze. Then, the changes of the robot's facial expression can complete eye contact.

In the eye contact from a robot to a human, the robot should have the human notice that it is looking at him/her. Especially when there are multiple people, the robot must have only the target person perceive its gaze. We have studied this issue.

We used a CG display as a robot head instead of an actual mechanical head since we can easily generate various facial expressions through CG. However, flat images like CG images are known to cause the Mona Lisa effect [9]. We tend to think that the eyes in the images are watching us when we are in front of them. As mentioned before, we move the head image when it does not try to establish eye contact to avoid the Mona Lisa effect. However, when the robot tries to make eye contact and stops its head movement, the Mona Lisa effect may cause a problem. For example, if multiple people are in front of the robot and the robot wants to make eye contact with one of them, all of the people may feel that the robot is looking at them. Through the experience in human-initiative cases, we expected that the fact that the robot has a body and moves it might help to solve this problem. We performed experiments to examine this.

We examined whether or not the existence of the robot's body would affect humans in establishing eye contact. We projected the same CG image on the screen and examined whether or not human's perception of the gaze could change between the image projected on the screen, and the image mounted on top of the robot body.

We used 9 subjects; all were graduate students in our department. We asked them to sit on the chairs at A, B, and C, seeing in the frontal direction (parallel to line DB), as shown in Fig. 10. All the seats were occupied by subjects during the sessions. We performed experiments in the following two conditions.

Experiment 4: We placed a large screen at D. We projected the CG image on the screen with an LCD projector.

Experiment 5: We placed the robot at D whose body and CG display were directed toward B. The robot did not move in this experiment.

The images shown in both cases were the same in size and position. At first, the gaze in the images was directed 60 degrees from the direction of B as shown in Fig. 10 so that no one could perceive the robot's gaze. From this situation, we asked the subjects to turn and look in the direction of D. Next, the CG face turned to its frontal position toward B and changed its facial expression to smiling. All subjects experienced and evaluated all positions (A, B, C) under both conditions.

Then, we examined the effect of turning the robot's body as follows. The experimental set-up was the same as in Experiment 5 except the robot's action.

Experiment 6: We placed the robot at D whose body was directed 60 degrees away from position B. From this situation, we asked the subjects to turn to see the robot. When they did, the robot turned right in the direction of B. Then, the CG face turned to the frontal position and changed its facial expression to smiling. All subjects experienced sitting in all chairs (A, B, C).

In each experiment, we asked the subjects to give a value ranging from 1 (they do not perceive the gaze of the robot at all) to 5 (they definitely do).

Figure 11 shows the results. In Experiment 4, the Friedman test gives a *p-value* of 0.0153, showing that there are significant differences among the three positions ($p < 0.05$). In Experiment 5, it gives a *p-value* of 0.0017, also showing significant differences among them ($p < 0.05$). We used the Scheffé test to examine the existence of significant differences between each position pair: A and B, B and C, and C and A. Significant differences are found between A

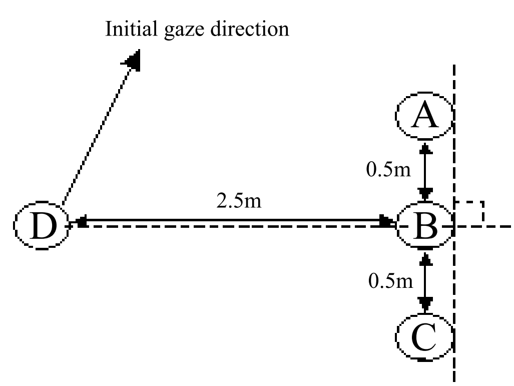
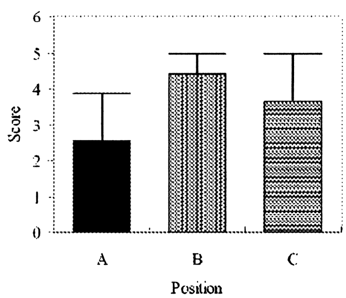


Fig. 10 Experimental set-up to examine the effect of body and action.

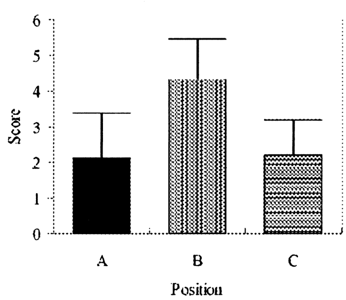
and B in Experiment 4; A and B, and B and C in Experiment 5.

The fact of no significant differences between B and C in Experiment 4 means that the subjects were not able to perceive the robot's gaze correctly at position C. The Mona Lisa effect can be considered to cause this result. At position A, the subjects felt the robot's gaze less than at B. This can be explained as follows. Since the robot's face passed position A when turning toward B, the subjects at position A felt that the robot's gaze passed over them. At position C, we cannot expect this effect. The Mona Lisa effect may cause a problem. Still, in Experiment 5, the subjects did not perceive the robot's gaze much at position C where they did in Experiment 4.

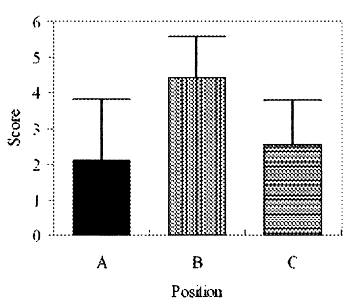
The difference in set-up between Experiments 4 and 5 is the existence of the robot's body. From the experimental results we can conclude that humans look at the body in addition to the head to determine the intention of the robot. The direction of the body can be used as an important means to convey to humans where the robot is looking.



Display only (Experiment 4).



With body (Experiment 5).



With body and action (Experiment 6).

Fig. 11 Effect of body and action (Experiments 4–6).

In Experiment 6, the Friedman test gives a *p-value* of 0.0051, showing that there are significant differences among the three positions ($p < 0.05$). The Scheffé test shows that there are significant differences between A and B, and B and C, the same as in Experiment 5.

These experimental results confirm that the body's existence and its action are effective in making the target person selectively feel the robot's gaze. We now compare the effect of body and that of action. We had expected that the body action could give better selectivity. The results at positions A and B in Experiment 6 show slightly better performance than those in Experiment 5. However, the differences are small and the statistical test cannot give significant differences. The result at position C in Experiment 6 is rather worse than that in Experiment 5, although no siginificant differences are observed. We consider that this can be explained by the mental inertia of the robot's motion. Although the turning action actually stopped in the direction of B, the subjects at C might feel that the robot kept turning a little toward them. Thus, they felt the robot's gaze more in Experiment 6 than that in Experiment 5. We investigate this hypothesis further in the next section.

7. Actions to Reduce the Mental Inertia

We have devised and tested two methods to solve the mental inertia issue. One is that the robot turns a little over in the direction of the target person and turns back toward him/her (Method 2). (We call it Method 1 just to turn toward the target person as in Experiment 6.) The other is that, after turning its body toward the target person, the robot turns its CG face left and right, and then looks in the direction of the person (Method 3).

We performed experiments to examine the effectiveness of these methods (Experiment 7). We used 12 subjects; all were students in our department. We asked them to sit in the chairs at A, B, C and D as shown in Fig. 12. All the seats were occupied by subjects during the sessions. At first, the robot was directed 90 degrees from the direction of A.

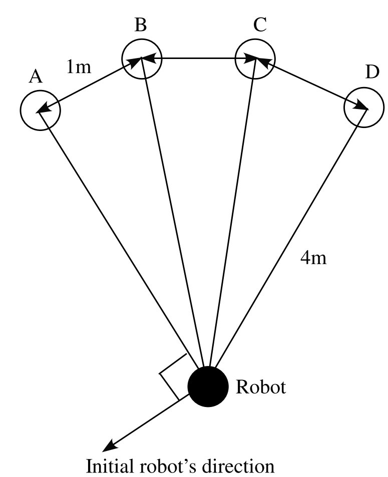
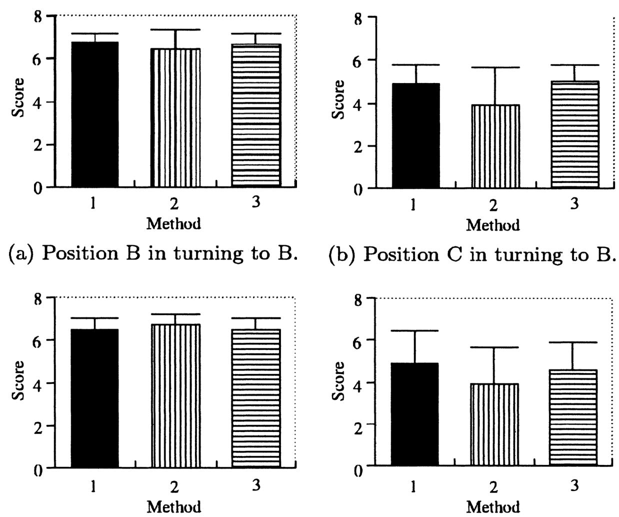


Fig. 12 Experimental set-up to examine the mental inertia reduction.



(a) Position B in turning to B. (b) Position C in turning to B.

(c) Position C in turning to C. (d) Position D in turning to C.

Fig. 13 Reducing the mental inertia effect (Experiment 7).

Then, it turned in the direction of one of the four chairs using one of the three methods. The direction and the method were chosen randomly, but in total, all subjects experienced all the combinations of the three methods and the four positions. In each robot action, we asked the subjects to give a value ranging from 1 (they do not perceive the gaze of the robot at all) to 7 (they definitely do).

Figure 13 (a) shows the average scores by the subjects at position B when the robot turns in the direction of B, whereas Fig. 13 (b) shows those by the subjects at position C on the same occasion. Figures 13 (c) and (d) show the same kind of results for positions C and D. All methods can make target persons aware of the robot's gaze. The results shown in Figs. 13 (b) and (d) suggest that Method 2 might reduce the mental inertia effect and that turning the CG head alone (Method 3) might not be effective. However, since the difference is small and the variance is large in the experimental results, we cannot obtain significant differences by statistical tests. The current robot motion is not so smooth and quick that some subjects felt the robot action clumsy when the robot tried to make sudden movements. Although the current experimental results might show a promising result, we cannot give a definite conclusion at this stage. We should investigate this further after improving the robot's mechanism and cotrol method.

8. Gesture Interface with Eye Contact

8.1 Gesture Recognition Method

We have adopted hand gestures as a communication means to examine the usefulness of eye contact. It seems to be easy to recognize simple hand gestures, such as the one that we use to express the meaning of "Come here." However, it is not so easy in actual complex scenes because such simple hand movements can occur unintentionally. Eye contact can be an effective means to avoid misunderstanding and set up an effective communication channel between a human and a robot in such cases. The robot accepts the hand movements as a meaningful gesture only after making eye contact with the human. This can reduce false detection cases (false alarm errors).

We use the spotting recognition method based on continuous dynamic programming for gesture recognition [13]. We track a moving skin-color region and use the motion vector as the feature for recognition.

Table 1 Number of false detection times (Experiment 8).

	With eye contact	With face detection	None
False detection times	0	5	7

8.2 Experiments

We registered the hand gesture that we usually use to ask a person to come. First, we performed experiments to examine whether or not the robot was able to recognize the gesture. We did 20 experiments. The robot was able to recognize the gesture after making eye contact with the human in all cases. Then, we performed experiments to examine the effectiveness of eye contact in terms of avoiding false detection errors (Experiment 8). We asked a subject to repeat the following action five times: walking from left to right (or vice versa) in the robot's camera field of view and returning to the start position. We consider this as one session and asked the subject to do 20 sessions in each of the following three cases.

(a) With eye contact: The robot starts gesture recognition only after making eye contact with the human.
(b) With face detection: The robot starts gesture recognition after detecting the face.
(c) None: The robot is ready for gesture recognition all the time.

Table 1 shows the experimental results. As shown in the table, the combination of eye contact and gesture proves to be effective to avoid false detection. The gesture recognition method used here is based on the movements of a skin-color region. Since the hand movement in the come-here gesture is simple, the robot erroneously considered the face movement when the subject turned left or right as the gesture.

9. Conclusion

In this paper, we have proposed a bidirectional eye contact method to facilitate better communication between humans and robots. Establishing eye contact needs that both parties should be aware of being watched by the other in addition that both look at each other. We have shown that we can satisfy these conditions by using actions of the robot's face and body. Moreover, we have presented a robot that can recognize hand gestures after making eye contact with the human, and shown how that reduces miscommunication. This can be a good example to show the effectiveness of eye contact as a means of meta-communication.

Eye contact can be useful in various occasions other than in the gesture recognition case presented in this paper. We are now working on this further.

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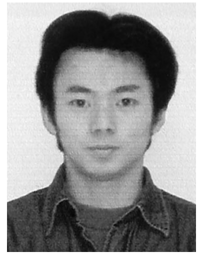
References

[1] R.J.K. Jacob, "The use of eye movements in human-computer interaction techniques: What you look at is what you get," ACM Trans. Inf. Syst., vol.9, no.3, pp.152–169, 1991.
[2] J.P. Hansen, A.W. Anderson, and P. Roed, "Eye-gaze control of multimedia systems," in Handbook of Symbiosis of Human and Artifact, vol.20A, ed. Y. Anzai, K. Ogawa, and H. Mori, pp.37–42, Elsevier Science, 1995.
[3] T. Ohno and N. Mukawa, "Gaze-based interaction for anyone, anytime," Proc. HCI International 2003, vol.4, pp.1452–1456, 2003.
[4] Y. Matsusaka, S. Kubota, T. Tojo, K. Furukawa, and T. Kobayashi, "Multi-person conversation robot using multi-modal interface," Proc. SCI/ISAS 1999, vol.7, pp.450–455, 1999.
[5] T. Kanda, H. Ishiguro, T. Ono, M. Imai, and R. Nakatsu, "Development and evaluation of an interactive humanoid robot 'Robovie'," Proc. IEEE ICRA 2002, pp.1848–1855, 2002.
[6] R.A. Brooks, C. Breazeal, M. Marjanovic, B. Scassellati, and M.M. Williamson, "The Cog project: Building a humanoid robot," in Handbook of Computation for Metaphors, Analogy and Agents, Lecture Notes in Artificial Intelligence, vol.1562, ed. C. Nehaniv, pp.52–87, Springer-Verlag, 1998.
[7] M. Cranach, "The role of orienting behavior in human interaction," in Handbook of Behavior and Environment, ed. A.H. Esser, pp.217–237, Plenum Press, 1971.
[8] D. Miyauchi, A. Sakurai, A. Nakamura, and Y. Kuno, "Active eye contact for human-robot communication," CHI 2004 Extended Abstracts, pp.1099–1102, 2004.
[9] A. Kendon, "Some functions of gaze direction in social interaction," Acta Psychologica, vol.26, pp.22–63, 1967.
[10] M. Argyle and R. Ingham, "Mutual gaze and proximity," Semiotica, vol.6, pp.32–49, 1972.
[11] K. Fukui and O. Yamaguchi, "Facial feature point extraction method based on combination of shape extraction and pattern matching," Systems and Computers in Japan, vol.29, no.6, pp.49–58, 1998.
[12] O. Hasegawa, K. Sakaue, K. Itou, T. Kurita, S. Hayamizu, K. Tanaka, and N. Otsu, "Agent oriented multimodal image learning system," Proc. IJCAI-WS IMS 1997, pp.29–34, 1997.
[13] T. Nishimura, T. Mukai, and R. Oka, "Spotting recognition of gestures performed by people from a single time-varying image," Proc. IEEE/RSJ IROS 1997, vol.2, pp.967–972, 1997.



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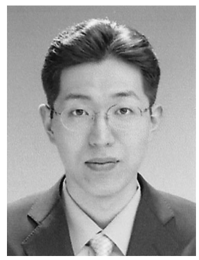

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