Researching Nonverbal Communication Strategies in Human-Robot Interaction

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Abstract. We propose an alternative approach to find each robot's unique communication strategies. In this approach, the human manipulator behaves as if she/he becomes the robot and finds the optimal communication strategies using attachable and detachable robot's shapes and modalities. We implement the system including a reconfigurable body robot, an easier manipulation system, and a recording system to evaluate the validity of our method. We evaluate a block-assembling task by the system by turning on and off the modality of the robot's head. Subsequently, the robot's motion during player's motion significantly increases whereas the ratio of confirmatory behavior significantly decreases in the head-fixed design. In this case, the robot leads the users and the user follows the robot as in the turn-taking communication style of the Head-free condition.

Keywords: Design Methodology, Human Robot Interaction, Human Interface.

1 Introduction

Nowadays, robots having various kinds of shapes and modalities can support our lives in many ways. In this paper, we define shape as the appearance of the robot and modality as the possible observation and behavior of the robot. There are still questions about what kind of interaction is required for each robot shape and modality [1]; [2].

Previous studies have designed and implemented the shape and modalities of robots according to human-human interaction. There are many studies that referred to humanlike modalities in robots, such as gesture [3], manner [4], timing [5], and bipedal walking [6]. This process is conducted as shown in the two figures on the left side of Fig. 2. First, the researchers extract a psychological finding from human-human interaction and create an interaction model from it. Second, they implement the model to a humanlike robot. Third, they conduct an interaction between a human and a humanlike robot and confirm that the robot can interact as the proposed model. Such a design method is widely used in human-robot interaction (HRI) studies because of the following reasons. First, the researchers can base the study on psychological findings that have been already investigated. Next, it is easy to compare the results and the goals. The above-mentioned reasons and method allow the researchers to incorporate the contributions of previous studies.

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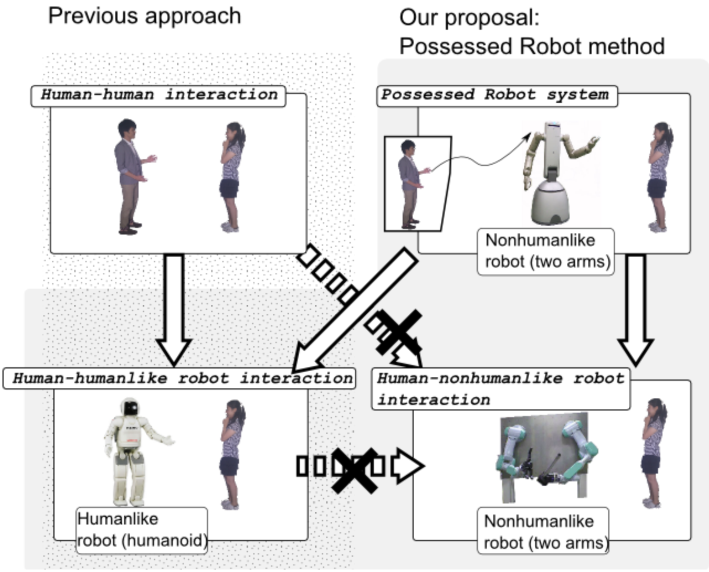

Fig. 1. Difference between the previous HRI approach and our proposal

However, we cannot find the specific behaviors of a robot that are not related to human shape and modalities by referring to existing findings in human-human interaction. With the above process, we may miss the most appropriate communication strategies for the robot if the robot and the human modalities are not the same. We call this kind of robot a "nonhumanlike" robot. In this paper, we use the word "nonhumanlikeness" to describe the lack of humanlike social appearance, such as humanlike head and arms. Detailed examples are shown in Fig. 2 [3]; [6]; [7]; [8]. Several HRI studies about less humanlike robots suggest that imitating humans is not the only approach to designing a robot. Sometimes, we use different communication strategies for nonhumanlike agents. One of the best examples is the human-pet interaction. Our interaction style with pets is different from our style in human-human interaction and human-tool interaction. Robots have both aspect of tools and pets. They generate different types of interaction to users using different shapes and modalities from that of humans, even if the shapes and modalities are nonhumanlike. For example, Mu, eMuu, and Social Trash Box extracted the essence of human interaction and created an abstracted relationship to humans different from human-human interaction [9]; [10]; [11]. Animal robots like Paro and AIBO result in specific interaction experiences by merging animal-like features with the original robot's modalities [12]; [13]. Training with additional humanlike features of an object allows us to use a communication strategy by merging the original features of the object and humanlike features [14]; [15]. However, there is no design method to find original communication strategies for robots except the analogical method (i.e., deriving metaphors and abstractions from existing design). This shortcoming of the previous approaches prevents us from building a robot design on human-nonhumanlike robot interaction (right bottom area on Fig. 1) because we cannot directly apply human-human interaction findings to nonhumanlike robots.

We propose the alternative method to find a specific communication strategy for a robot that can consider its own shape and modalities. In this approach, one person "possesses a robot," and behaves as if she/he is the robot while interacting with another person. This trial-and-error interaction process between two persons reveals original communication strategies that are reasonable and specific to each robot's shape and modalities. Our approach is applicable to both humanlike and nonhumanlike robots, shown in Fig. 2. If the method is applied to a two-arm and headless robot, the results are also applicable to another robot that has the same design (shown in the right side of Fig. 2).

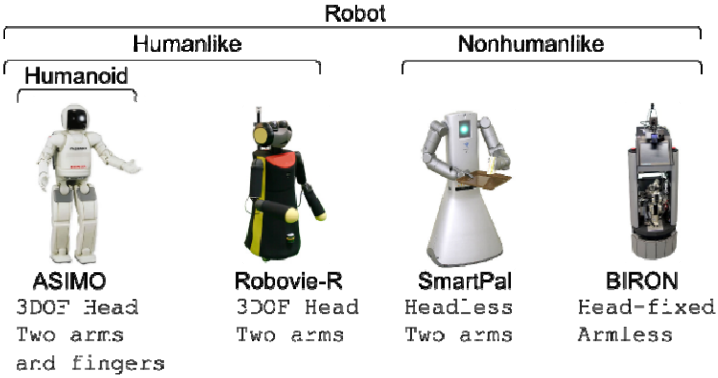

Fig. 2. Different styles of robots: their shapes and modalities

In this paper, we implemented the Possessed Robot demonstrative System (PoRoS) to validate our approach. PoRoS allows the user to possess the robot by converting the user's behavior to the robot's output and by converting the robot's input to the user's input. We evaluated our proposal with demonstrative tasks to instruct a user on how to assemble a building from wooden blocks using a robot by changing the robot head modality. A humanlike robot with head modality resembles human modalities and allows us to use conventional communication strategies, such as nodding and shaking motions. However, a humanlike robot without head modality requires different communication strategies that cannot be achieved with the existing human communication theory. Headless or head-fixed robots, such as BIRON and SmartPal, are also popular [7]; [8]. The demonstrative task also answers what kind of communication strategies are more appropriate to the commonly used headless robots.

The following sections are organized as follows. Section 2 explains the differences between related methods and studies (Wizard of Oz, teleoperation robot, and marionette system) and the Possessed Robot method. Section 3 explains the design process of the Possessed Robot method, and section 4 explains in detail the implementation of PoRoS (Possessed Robot System) for realizing the Possessed Robot method. In section 5, we explain the evaluation of PoRoS and the results are presented in section 6. In sections 7 and 8, we discuss the results and the conclusions, respectively.

2 Related Studies

In spite of differences in policy, there are several similarities between previous approaches and ours. In this section, we compare our work to related studies and clarify our contribution.

2.1 Wizard of Oz

The Wizard of Oz (WoZ) method is used mainly in evaluating computer interfaces [16]. This method uses human manipulator as sensors to avoid unessential errors from the evaluation. The WoZ experiment method is also widely used in the field of HRI. Steinfeld et al. inferred several consequential evaluation methods (called Oz of Wizard) from WoZ for evaluating robots behavior [17].

WoZ uses a human manipulator as part of the experimental interface system instead of being autonomous. The manipulator behaves as the decision maker in the system and selects the system behavior from a determined list. The role of the human manipulator in WoZ is restricted to replace sensor actions. We extend the notion of WoZ in the field of robotics using attachable and detachable robotic devices and sensors. The entire robot input and output are directly connected to the manipulator, and the manipulator behaves as an intelligent computer in finding the most optimal communication strategies for each task using the specific robot shape and modalities.

2.2 Teleoperation Robot

Teleoperation robot studies also use manipulated robots. The robot design is sometimes verified and analyzed by recorded results. Kuzuoka et al. discussed the optimal instructions in teleoperation [18]. However, teleoperation studies themselves are not designed to find the optimal communication strategies in autonomous robotic systems. If the system behaves autonomously, it is not teleoperation anymore.

Several research groups proposed to use teleoperation to complement an autonomous robot. Glas et al. proposed to use a human manipulator to guide the robot [19]. In their approach, the robot behavior is replaced by the human manipulator if the task is hard for the robot to solve. Thus, a human manipulator can temporarily possess the robot. However, their study only focused on improving the task performance in a real world human-robot interaction. This approach did not focus on feedback to optimize communication strategies. They also hypothesized that the robot might use humanlike modalities in the future. Other robot possibilities are also not well discussed in their paper.

2.3 Marionette and Digital Puppetry

Marionette is a well-known art for making puppets behave lifelike (they are sometimes humanlike and sometimes nonhumanlike). Currently, the possibility of interactive marionettes is accelerated by technology. They are called Digital Puppetries. This kind of system allows us to control humanlike and nonhumanlike robots [20]. Turtle Talk with Crush is the most successful marionette in the commercial field [21]. It is a screen agent that interactively changes its face and behavior according to people's responses.

However, these studies are specialized to each robot's shape and modalities. Manipulation requires not a small amount of training time although interface is supported by today's technologies. This marionette system is not appropriate for the trial-and-error approach that required in our method.

3 Designing the Possessed Robot Method

Possessed Robot method is a design method conducted by two participants. One participant possesses a robot and behaves as if she/he is the robot. Another participant interacting with robot.

Based on the differences to previous studies mentioned in above section, we estimate that the following three sub goals are required to perform the Possessed Robot method. First, the Possessed Robot method requires a reconfigurable robot body to examine all kinds of robot shapes and modalities. Second, the manipulation method must be easy for the human manipulator to allow frequent trial-and-error efforts. Third, the system requires recording the interaction between the robot and the human for later analysis.

The entire design process is described below:

- Select the robot input and output, and configure the robot shape and modalities.
- Assign two persons as the manipulator (who possesses the robot) and the player (who follows the robot).
- Connect the robot input and output to the manipulator. All connections are required to be understood and controlled by humans.
- Two persons interact via the robot and conduct a task cooperatively. They repeatedly try to interact and gradually find the most optimal communication strategies for the task. The system records the entire interaction.
- The evaluators analyze the result of the interaction and the kind of modalities, which are the most and least required. We also compare the results with the human-human interaction findings, which is the original interaction setup for the robot.

This process brushes up the robot design. If we require a more detailed analysis, we can also select more optimal shapes and modalities with the results from process 5, and repeat the entire process.

4 System

We implemented PoRoS (Possessed Robot demonstrative System) to estimate the validity of our process. We used a reconfigurable robot, a monitoring device to capture movement, and a recording system to solve the sub goals mentioned in the previous section.

4.1 A Reconfigurable Robot That Allows Us to Use Variable Shape and Modalities

In the Possessed Robot method, we can evaluate not only the humanlike robot shape and modalities but also any kind of shapes and modalities. For evaluating the Possessed Robot method clearly and rapidly, we created a robot kit that has separate body parts and allows variable shapes and modalities. The kit includes three axis heads and two four-axis arms. Each head has three motors. Each arm has two motors on the root of the device to achieve movements toward the pitch and yaw directions of the arm. It has also two motors on the tip to achieve movement toward the pitch and roll directions of the hand.

These devices are attachable and detachable by Velcro tapes. Each head and arm are wired and connected to a microcomputer, and can be separately turned on and off. The total axes of the kit are sufficient to reproduce normal humanlike robots. If you want to turn off the modality of the head of the robot, just turn off the switch and the robot stops controlling the head. If you want a different humanlike robot shape, you can detach each part and attach it on a different position. In the experiment, we assigned each part as in Fig. 3 left and compared the communication strategies of the humanlike robot by turning on and off the head of the robot.

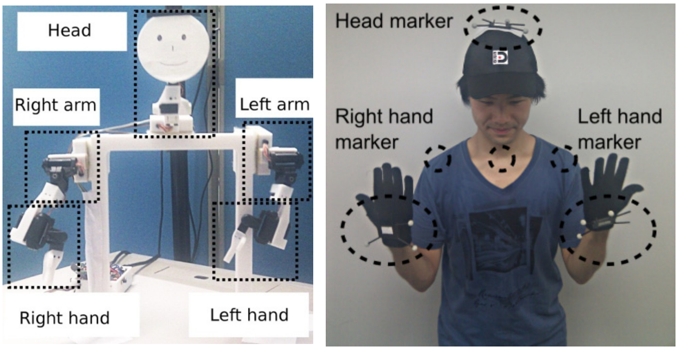

Fig. 3. Implemented reconfigurable robot on PoRoS system and motion capture markers on a participant

4.2 Monitoring Device Using the Motion Capture System

To use a human as the controller of the robot, we need to monitor the behavior of the human manipulator and feedback the robot with it. We used a motion-capturing system for feedback from the human manipulator because it is easy to understand how to move a robot. In this system, we used seven motion-capturing cameras (OptiTrack s250e [22]) for tracing the human head and hands. Each human body part is captured and converted to robot body movement as described below:

- Head: The system extracts three angles (yaw, pitch, and roll) of the head and assigns them to the robot's head movement.
- Arm: The system calculated the robot's arm angles (yaw and pitch) by a vector from the head position to the hand position.

- Hand: The system calculates the robot's hand angles (pitch and roll) by directions of the user's head.

Each marker is attached to the human body as in Fig. 3 right. Head markers are attached on the top of the manipulator's head. Hand markers are attached on the back of the manipulator's hands.

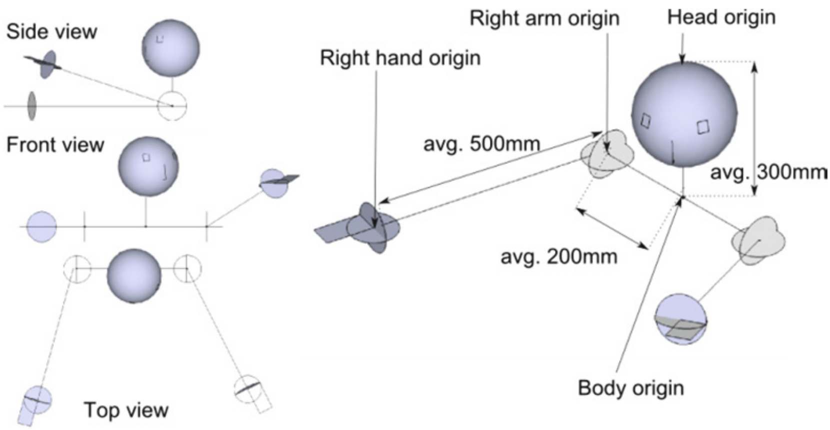

Fig. 4. Calculation method for the position of each part

All origins are calculated as in Fig. 4. First, the system calculates the centre of the human body using the top of the head. The average position of the centre of the body is 300 mm below the head top. Second, the system calculates the origins of the right and left arm from the centre of the body. Each origin is on average 200 mm from the centre of the body. We can estimate that the origins of the arms are stable because the manipulator stands in front of the video and does not change her/his shoulder angle. Third, we calculate the arms' vectors from each angle and arm's length (average 500 mm). Last, we assign the hands' directions toward the pitch and roll axis of the robot's hands.

4.3 System Connections

All modules are connected as in Fig. 5. In PoRoS, the input data to the human manipulator is the video image and the output data from the human manipulator are the motion-capturing data and angles of each motor. The latency from the robot to the user is below 200 ms and this delay does not cause any critical communication problems. All input (video) and output (motor angles) data are stored to the data server for later analysis.

Note that this PoRoS system is just one example of realizing the Possessed Robot method and we can select other inputs (motion-captured data by the player) and output method (joystick) for other implementations.

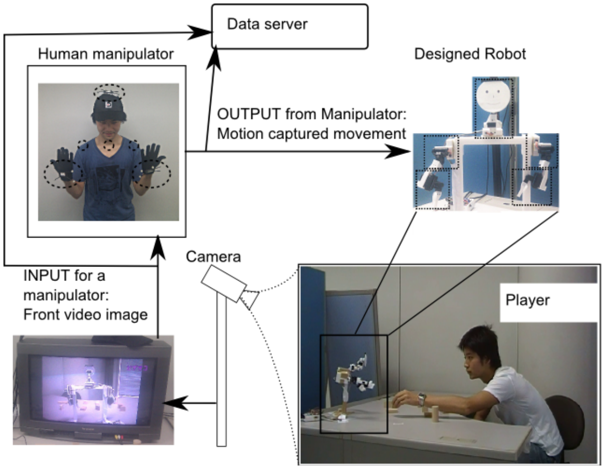

Fig. 5. System implementation

5 Experiment

To research how our method evaluates the design and modalities of a nonhumanlike robot, we compared human-humanlike robot and human-nonhumanlike robot interaction using the PoRoS robot. In nonhumanlike robot interaction, we fixed the head of the robot to decrease the modalities for confirmation. We also prohibited verbal communication during interaction to emphasize the role of the head.

As a demonstrative task, we also setup the assembly of wooden blocks to evaluate our method.

5.1 Pre-evaluation for Creating Evaluation Method

Humans nod for confirmation. Nodding is conducted by the human head. Head nodding has a regulatory role in turn-taking in human-human communication and human-computer interaction [23]; [24].

At first, we examined what kind of procedures humans apply to make buildings by observing human-human interaction. We gathered six participants for this evaluation and assembled three sets of pairs from them. One of the members of a pair took the role of the manipulator. Another member took the role of a player. The manipulator instructed the player to build three kinds of buildings as shown in Fig. 6. All examples in Fig. 6 consisted of five kinds of blocks. First, the manipulator watches the buildings in Fig. 6. Second, she/he sat down in front of the player. Last, she/he instructed the player how to construct the buildings. All manipulators were prohibited to directly touch the blocks. The number of instructions during the evaluation is between five and eight and the construction time is between 30 s and 60 s. The result confirmed that human-human interaction is based on turn-taking strategies. Each pair's turn-taking happened according to each user's nodding and shaking motion.

In detail, the processes are as follows. In the first turn, the player pointed out one of the blocks. If the block was the right one, the manipulator nodded and communication continued to the next turn. If the block was wrong, the manipulator shook her/his head and the player repeated the first turn. In the second turn, the player brought the block to the manipulator and the manipulator directed the player to rotate the block. Then, the player put the block on the building. If the placed position and direction was right, the manipulator nodded and communication returned to the first turn until they completed the building. If the position or direction was wrong, the manipulator shook her/his head. Then, the player placed the block on the desk and repeated the second turn.

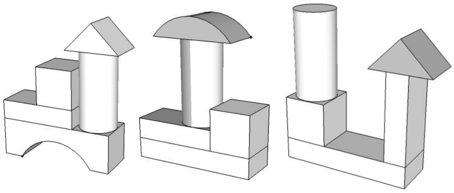

Fig. 6. Example buildings

5.2 Evaluation Method and Hypothesis

Based on the findings from the previous sections, we compared the humanlike group and head-fixed group for validating the proposed method. In the humanlike group, the manipulator could handle the PoRoS robot without any restrictions. However, in the head-fixed group, the neck motor switches were turned off by the system and the manipulator could not control them.

This restriction forced both manipulator and player to use other confirmatory behaviors for turn-taking or it forced both persons to use different communication strategies. When they selected communication strategies other than the turn-taking method, the confirmatory behavior decreased in the head-fixed group.

5.3 Environment for the Experiment

The experimental setup is shown in Fig. 7 left. The manipulator and the player are in separate rooms. The robot is fixed on a desk and placed in front of the player. There are eight blocks on the desk between the player and the robot. The viewpoints of the camera and the robot are located in the same direction. The manipulator can confirm the face of the player. All input and output data are recorded and stored in the data server for later analysis.

We show the scene of manipulation in Fig. 7 right. The manipulator is standing on the left side of Fig. 7 right. Motion-capturing cameras surround him. The video screen is in front of the manipulator and the screen shows the robot, the blocks, and the player as shown in the right top part of Fig. 7 right. An image of the building is pasted on the right side of the screen, and the manipulator instructs the player how to assemble the blocks via the robot.

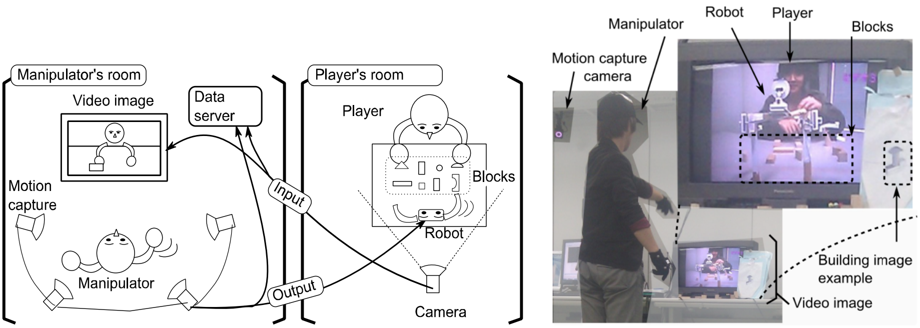

Fig. 7. (left) Experimental setup (right) Experimental scene

5.4 Participant and Experimental Flow

Thirty-six participants participated in the experiment. There were 34 males and 2 females. We assigned 18 participants (including one female) to the humanlike group and the remaining 18 participants to the head-fixed group. Eighteen participants on each group were paired (a manipulator and a player). Each group had nine pairs.

The experiment was divided into the testing phase and the recording phase. Before the experiment, we instructed the participants as follows: "In this experiment, you need to create general communication strategies for the robot with the assembling task. Do not use any kind of code that is incomprehensible to other person." This instruction served the purpose to keep the designed communication strategies general.

At first, each manipulator calibrated the robot parameters to the scale of his/her body. Then, the pairs started the testing phase. During this phase, each manipulator gave instructions for any kind of buildings she/he could imagine. The members in each pair made trial-and-errors efforts and improved their communication strategies.

When the pair determined that they could not improve their manipulation time anymore, the experiment moved to the recording phase. We assigned the manipulator one of the three examples in Fig. 6 and recorded the interaction. The pair required to assemble the building within 300 s. When the recording finished, each participant answered the questionnaire and the experiment was terminated.

5.5 Prediction: Overlapped Time Ratio and Confirmation Ratio

Pre-evaluation confirmed that turn-taking behavior was used in human-human interaction with instructions on how to assemble the blocks. The evaluation also revealed that head movement played a key role on regulating turn taking. However, turn taking itself is difficult to evaluate by video recording data, especially when this evaluation lacks verbal cues.

We used the overlap time ratio as an indicator of turn-taking behavior between each manipulator and player. A previous HRI study using humanoids showed that the increase in overlapped verbal cues of both persons suggests failure of turn taking [25]. We extended this idea to nonverbal situations. If turn taking took place without any problems, the behavior of the robot and the human did not overlap. In contrast, if turn taking did not succeed, the overlapped time ratio increased. In this paper, we defined overlapped time ratio as robot's moving time during user's lifting per user's lifting time. Note that the failure of turn taking does not directly mean failure of communication. If the task is successfully completed, this increased overlapped time suggests different communication strategies between the manipulator and the player.

We used the player's lifting block time to monitor the player's behavioral time. We counted the behavioral time from the input video-recorded data. We used the robot's moving time to monitor the manipulator behavioral time. When the motor moves more than ten angles in 1 s, we counted this as the behavioral time of the manipulator. The behavioral time of the player did not include the suspending time in air. However, if there was a difference in the overlapped time between the humanlike and the head-fixed group, this difference suggested that the two groups used different turn-taking methods.

Our predictions for the head-fixed group in comparison with the humanlike group are the following:

- Prediction 1: The overlapped time ratio will increase depending on the failure of the turn-taking behavior.
- Prediction 2: The ratio of confirmatory behaviors will decrease.

In the head-fixed group, we asked the manipulator questions such as "Did you use confirmatory behavior? If so, what kind of confirmation did you use?".

6 Results

One male pair in the humanlike group and two male pairs in the head-fixed group could not finish assembling the blocks. Other pairs succeeded in this task.

The average overlapped time ratio in the humanlike group is .608 (SD = .062). The average overlapped time ratio in the head-fixed group is .761 (SD = .125). We applied the Welch t-test to both groups and the p-value is $.0043 < .05$. This statistical result shows that the overlapped time ratio in both groups is significantly different. This result supports the first prediction. The overlapped time ratio is shown in Fig. 8. When we removed the failed pairs, the average overlapped time ratio in the humanlike group is .792 (SD = .132) and the overlapped time ratio in the head-fixed group is .132 (SD = .151). The p-value from the Welch's t-test is $.01 < .05$, which also suggests significant difference.

The questionnaires after the experiment showed that all manipulators in the humanlike group used head nodding and shaking for confirmation. In contrast, nine manipulators in the head-fixed group raised their hand for confirmation and shook their hand for denying. Two manipulators in the head-fixed group answered that they did not use confirmation in their communication. Based on this result, we counted the raising and shaking hands as confirmation in the head-fixed group.

The players use two kinds of confirmations before and after lifting the blocks. Confirmation before lifting the blocks (before-confirmation) was used to point which block is right or wrong. Confirmation after lifting the blocks (after-confirmation) was used to point which location and direction is right or wrong. We counted both confirmations.

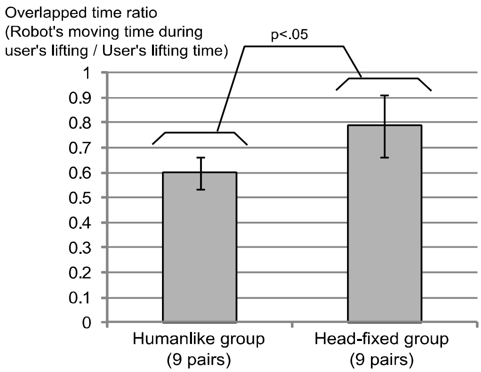

Fig. 8. Overlapped time during humanoid and hand robot

The average before-confirmation ratio is .63 (SD = .22) in the humanlike group and .09 (SD = .19) in the head-fixed group. We applied Welch's t-test to both groups and the results showed p-values of .00003, which is less than .0001. When we removed the failed pairs, the average before-confirmation ratio is .62 (SD = .22) in the humanlike group and .11 (SD = .20) in the head-fixed group. The p-value of the Welch's t-test is .0006, which is less than .001 and suggests significant difference.

The average after-confirmation ratio is .78 (SD = .21) in the humanlike group and .30 (SD = .24) in the head-fixed group. We applied Welch's t-test to both groups and the result showed p-values of .0005, clearly smaller than .001. When we removed the failed pairs, the average before-confirmation ratio is .78 (SD = .23) in the humanlike group and .28 (SD =.25) in the head-fixed group. The p-value of the Welch's t-test is $.001 < .005$, suggesting significant difference.

We also counted the manipulation time including the before- and after-confirmation of the robot and the lifting time of the player. The average time is 7.7 s (SD = 2.4 s) in the humanlike group and 12.8 s (SD = 5.0 s) in the head-fixed group. We applied Welch's t-test and found significant difference ($p = .017 < .05$). When we removed the failed pairs, the average time is 7.1 s (SD = 1.8 s) in the humanlike group and 13.3 s (SD = 5.4 s) in the head-fixed group. The p-value of the Welch's t-test is $.02 < .05$, suggesting significant difference.

In contrast, the average lifting action is 10.9 (SD = 6.0 s) in the humanlike group and 13.2 (SD = 10.8 s) in the head-fixed group. We applied Welch's t-test and found no significant difference ($p = .58 > .05$). When we removed the failed pairs, the average lifting numbers were 9.1 (SD = 3.0 s) in the humanlike group and 8.4 (SD = 2.9 s) in the head-fixed group. The p-value of the Welch's t-test is $.65 > .10$, which suggests no significant difference.

7 Discussion

7.1 Predictions

We found significant differences in the overlapped time ratio and confirmation ratio with and without the failed pairs. These results support our predictions.

Pairs in the humanlike group follow the player-first protocol. After the lifting motion, the player sometimes skipped to check the movement of the robot when they rotated a block and placed it. Confirmation by the robot is sent after the placement in this case. The manipulator usually confirmed every movement of the player. In eight pairs of the humanlike group, the manipulator first pointed the target, the player subsequently pointed the same target, and then the robot confirmed. The failed pair skipped first pointing and it caused more misses. They spent their entire 300 s and the task failed. The recorded video also shows that almost player used turn-taking style strategies because the player watched the robot periodically.

In contrast, the pairs in the head-fixed group follow the robot-first protocol. The manipulator in the head-fixed group sometimes omitted the before-confirmation. In this case, when the robot pointed to a block and the player took it, the player moved the block while observing and following the movement of the robot's arms without any confirmation. The manipulator also omitted the after-confirmation and moved on to the next block. However, omission is happened more in before-confirmation than in after-confirmation. The recorded video also supports that they used following the robot strategy because the player carefully watched the robot during the lifting time.

The manipulation time including lifting time significantly increased in the head-fixed group more than the humanlike group. Based on the video recording, this result suggests that each manipulation time increased in the head-fixed group because they watched the robot motion and followed it. The insignificant difference on the lifting action suggests that the assembling order process is not influenced by the change of modalities. These two results suggest that the change in the head modality did not drastically change the entire communication strategy only the manipulation strategy from the turn-taking style to following the robot style.

These findings support our hypothesis that the turn-taking strategy changed in the head-fixed group. In the head-fixed group, they used robot-leading strategies. We estimate that the limited confirmation modalities forced the pairs to use robot-leading interaction.

7.2 Discussion about the Design Process

The entire design process discussed in Section 3 supports the fact that we can have an alternative communication strategy for nonhumanlike robots using the Possessed Robot method.

The Possessed Robot method shows the potential power of the human computation in robot design. The human brain is the most intelligent computer we can access. It has the most flexible learning and most sophisticated communication algorithms. It can provide the most appropriate response to unpredicted situations. For example, we estimated that the manipulator needed a lot of calibration time even for the motion-capturing system. However, the manipulator quickly customized to the robot body and could behave as if she/he was robot.

We also made variations of design process by different usage of human resources. Participants' free-writings in the questionnaire suggests that swapping the manipulator and the player during the design process will reduce the thinking time. The questionnaire from the manipulator also suggests that usage of a third person who does not know the purpose will increase the generality of the strategy.

7.3 Limitations and Future Work

The purpose of this paper is to evaluate the validity of our method by assembling a block task. Our results show one example of the head-fixed design with no verbal cues leading the robot-first instructions. From the experimental conditions, we infer that this change in the communication strategies is caused by the lack of confirmatory modalities in the head-fixed robot. Our experiment only uses nonverbal communication. Our findings may be useful if the field where verbal interaction costs lead to high cognitive load (like rescue and guiding robots). However, the result cannot be directly applied to human-robot interaction studies if verbal cues are used.

Our findings from the experiment may need further research to show their general applicability, however, our method validates the usefulness of the Possessed Robot method in HRI studies because it can find different communication strategies in human-nonhumanlike robot interaction. Such different strategies are hard to find in the previous approaches that designed and implemented robot shapes and modalities according to human-human interaction. Our results suggest that the robot-leading design may be optimal in the case of headless or head-fixed design robots, such as SmartPal and BIRON [7][8]. It is also possible to assemble guidelines (what design is reasonable and what design is unpredictable) using Possessed Robot method. These guidelines reduces useless investment for development of robot's interface.

In future, we also need to discuss how to find optimal ways to connect the robot I/O to human I/O. In this experiment, we started our simplified demonstration from the viewpoint of decreased human design. Even if the human is a powerful problem solver, we estimate that it is still difficult to handle additional input and output that do not come to humans natively. We predict that studies about prosthesis and augmented human technologies will expand the possibility of human scale.

8 Conclusions

We proposed an alternative approach called the Possessed Robot method to find a robot's unique communication strategy. Previous robot shapes and modalities are designed by imitating human-human interaction. This approach has restricted robot design and behavior within the limitations of the possible human modalities. In our approach, the human manipulator behaves as if she/he possesses the robot and finds the optimal communication strategies based on the shape and modalities of the robot.

We implemented the Possessed Robot system (PoRoS) including a reconfigurable body robot, an easier manipulation system, and a recording system to evaluate the validity of our method. We evaluated the block-assembling task by PoRoS with turning on and off the modality of the robot head.

Synchronized motion significantly increased in the head-fixed design, and the ratio of confirmatory behavior significantly decreased. Based on the results, we find an example case for the optimal communication strategy in the head-fixed design. In this case, the robot leads the users and the user follows the robot compared with the turn-taking communication style in the humanoid condition. This result shows the feasibility of the Possessed Robot method in finding the appropriate strategy according to each robot design.

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