Immersive tele-collaboration with Parasitic Humanoid: How to assist behavior directly in mutual telepresence

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ABSTRACT

Telexistence allows you to control a robot intuitively without the need to learn special skills by exploiting the complete physical association between a controller and a robot. In this technology, sensory and motor information based on the robot's and user's embodiments is translated to digital data, which can be recorded, and transmitted to each other to share their experiences. The technology can be available not only for interactions between a robot and a human but also between humans. In realizing this system, how to share the motions and sensations of humans and how to adjust or revise their motions become important. In this paper, we propose an approach for sharing first-person perspectives. We have developed a view-sharing system to realize such interactions using the Parasitic Humanoid (PH). PH is a wearable robotic human interface for sampling, recording, and replaying the sensory and behavioral experiences of the wearer from the first person perspective. Connecting PH wearers can realize skill transmission, telecollaboration, and sharing of experiences between humans.

KEYWORDS: Embodiment, Motion Induction, Human Hack, Ability Extension.

INDEX TERMS: K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

1 INTRODUCTION

Telexistence is a technology that enables a human operator to feel that he or she exists where a robot exists, rather than where they actually exist when controlling the robot [1,2]. The feeling of presence makes it easier for operators to recognize the surrounding environment and to achieve a task with the robot because they feel as if they are actually working there instead of the robot. For telexistence technology, effectively communicating sensations and motions between an operator and a robot in real-time is important so that the operator feels present. The technology applies not only to robot-human interaction but also to human-human interaction between two distant people [3]. A human works as if he exists at the distant place by "possessing" a partner even if he does not actually exist there. In the same way as robot-human interaction, sensations, perceptions, and motions must be shared between humans. By capturing human behaviors, we elicit key factors to establish effective interactions that can be applied to robot-human interactions.

In the situation of ordinary telexistence in Fig.1(a), the purpose of the person A is to assist the robot B in the scene B. In the system shown in Fig1.(b), the purpose of the person A is also to assist the person B in the scene B. It is a kind of mutual human to human telepresence. It is an ideal method for directly assisting behavior.

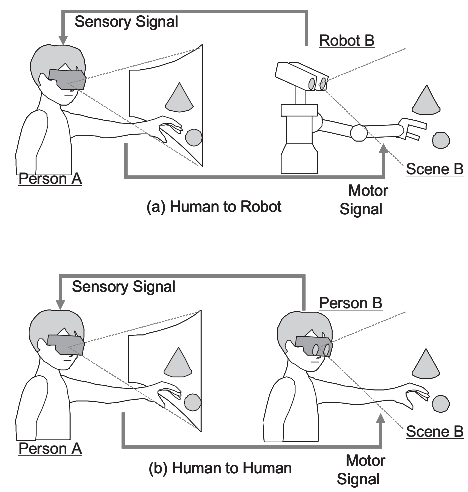

Figure 1. Mutual telexistence for tele-collaboration

To realize the system in Fig. 1(b), the person B should act the role of the robot B in Fig.1 (a). There are a few problems to be solved.

1. How to intercept Person B's sense and motion information.
2. How to synchronize Person B's behaviour to Person A's behaviour.
3. How to keep the sense of reality in the scene B for Persons A and B.

We propose solutions for these problems as follows.
The solution for 1 is Parasitic Humanoid technology.
The solution for 2 is the method of motion induction.
The solution for 3 is the view sharing system with image stabilization technique.

The view sharing system is a system for mutual telexistence. It transmits the information of senses and behaviors between Parasitic Humanoids optimized to make the wearers share their experiences in their first person perspectives.

2 MUTUAL TELEPRESENCE FOR IMMERSIVE TELE-COLLABORATION

In conventional studies to establish human-human collaborative interactions between two distant people, the feeling of presence is

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not seriously considered for the following two reasons. First, most studies only pay attention to how visual information should be presented or shared without considering the viewpoints. For example, to simplify collaboration and increase effectiveness, Kuzuoka et al. [4] and Fussel et al. [5] developed similar shared-view video support systems where a worker's view is captured by a head-mounted camera, but the captured images are displayed to an instructor on a monitor on a desk. The instructor can see the worker's view, but the perspectives are not consistent.

The inconsistent perspectives require the user (instructor) to consciously interpret from the displayed images such situations as the worker's movements and the spatial relation among objects and the worker. On the other hand, a consistent perspective induces an immersive experience and the feeling of presence, and users can unconsciously understand the surrounding environments.

If an immersive environment has been established to display images, it can produce such illusions of self-sense as self-ownership [6], body-swapping [7], and pseudo-haptics [8] by artificially manipulating visual and tactile sensations. In the rubber hand illusion, a rubber hand's incongruent directions suppress the induction of the rubber hand illusions [6], which suggest that it can be seen as the user's body from different perspectives. This observation shows that, for users, perspective is crucial for inducing the illusion of feeling their own bodies. Another reason is that previously studied collaborations have been collaborative work between workers and instructors. The worker tries to achieve a goal with an instructor's help, meaning that the worker always needs to understand the instructor's behaviors as instructions. For example, the mutual view sharing system proposed by Nishikawa et al. provides consistent perspectives, but the worker and the instructor perform different tasks, such as achieving a task and instructing behavior to teach the worker procedures [9].

Consequently, the feeling of presence is never exploited in conventional ways. In the present work, we consider collaboration where the worker and instructor are simultaneously performing the same action in an immersive environment.

Mentally rehearsing movements is an effective way to acquire skills [10]. Even though mental rehearsing is purely imaginary, we hypothesize that if an immersive environment can be established between two humans and a non-skilled person can see a skilled person's movements as if there were her/his own movements, the skill can be effectively transmitted. Therefore, we share first-person perspectives between humans in which a non-skilled person easily recalls the body images or movements of skilled persons to acquire a skill or to achieve a task in real-time with help from skilled persons.

Below we tested our hypothesis. In the next section, we introduce a system developed for sharing first-person perspectives. Then we examine simple collaborated behavior in interaction between two subjects to clarify the fundamental effects of our view-sharing system. We exploited the collaboration findings and applied our view-sharing system to a concrete juggling skill and evaluated skill transmission performance. Finally, the results of our view-sharing and skill transmission are discussed.

3 Parasitic Humanoid: Wearable Robotics as Behavioral Interface

What is the information which assists an individual behavior? To answer the question, it is necessary to consider how a human perceives the world.. The world is filled not by information but phenomena. Only the act of measurement can convert the phenomena to information. Measurement is defined as the evaluation of a physical phenomenon according to some method and scale. For the information of human perception, the scale is defined by the scale of the human body. In human information technology, it is important to recognize the significance of scaling and measuring in relation to human embodiment. Most wearable computers today derive their usage from concepts in desktop computing such as data-browsing, key-typing, device-control, and operating graphical user interfaces. If wearable computers are anticipated to be fitted continuously as clothing, we must re-examine their use from the viewpoint of behavioral information. In this paper, we consider the role of wearable computers as a behavioral interface.

The Parasitic Humanoid (PH) is a wearable robot for modeling nonverbal human behavior [1]. This anthropomorphic robot senses the behavior of the wearer and has internal models to learn the process of human sensory motor integration, thereafter it begins to predict the next behavior of the wearer using the learned models. When the reliability of the prediction is sufficient, the PH outputs the difference from the real behavior as a request for motion to the wearer. Through this symbiotic interaction, the internal model and the process of human sensory motor integration approximate each other asymptotically. This process is available to transmit modalities such as senses of sight, hearing, touch, force and balance with human embodiment. This synergistic multimodal communication between distant people wearing PH can realize experience-sharing, skill transmission, and human behavior supports.

3.1 The Usage of Anthropomorphic Robots

Wearable computing and wearable robotics have separate histories. Most recent research on wearable robotics is motivated by interest in powered assist devices [2]. These devices are typically too heavy and consume too much energy for mobile use. On the other hand, research in mobile wearable robotics [3] does not take advantage of the embodiment of wearable devices.

Consider the usage of anthropomorphic robots as an interface for human behavior. This is perhaps the only pragmatic usage, because the anthropomorphic shape is usually disadvantaged compared to optimized designs for other purposes. One successful example is the Telexistence system [11]. However, such a robot is too complicated and expensive to be an interface of human behavior, and therefore too socially unacceptable to be considered as a pragmatic solution, except for some specific purpose, such as teleoperation of robots in a hazardous environment (although commercial systems are quickly driving down the cost of such devices). A more serious concern regards the safety for the users under common circumstances in modern life. There will be situations of disorder in which the control system of the robot continues to move although it has to stop to avert a collision. A solution in this situation is a lightweight and low power design such that a surveyor can easily prevent undesirable motion. However, this strategy makes it difficult for the robots to support themselves.

Wearable technologies supply a solution to the problem. Wearable sensory devices can construct a wearable humanoid without muscles and skeletons, if they are of the proper type and in sufficient number (Figure 1). This robot may be too weak to move by itself, and can not assist the wearer with mechanical power. However, it is safe and light for the wearer, and can assist his or her behavior with multi-modal stimulation, when the worn robot is continuously capturing, modeling and predicting the behavior of the wearer.

3.2 Parasitic Humanoid

We refer to such a wearable robot as Parasitic Humanoid (PH). PH is a wearable robot for modeling nonverbal human behavior.

This anthropomorphic wearable robot senses the behavior of the wearer and has internal models to learn the process of human sensory motor integration, thereafter it begins to predict the next behavior of the wearer using the learned models. When the reliability on the prediction is sufficient, the PH outputs the difference from the real behavior as a request for motion to the wearer. When the correction is not adequate, the wearer does not follow it. In this case, the PH corrects its internal model by the difference and continues learning. When the correction is adequate, the wearer follows the correction and corrects his internal behavioral model for himself. In this case, the PH does not correct its internal model and raises the estimation of the reliability to the model. Through this symbiotic interaction, the internal model and the process of human sensory motor integration approximate each other asymptotically. As a result, the PH acts as a symbiotic subject for information of the environment. The relationship is similar to oneness between horse and rider, although the role of the wearer corresponds to the horse, not following like a sheep. The symbiotic relationship between these partners acts as a high performance organism.

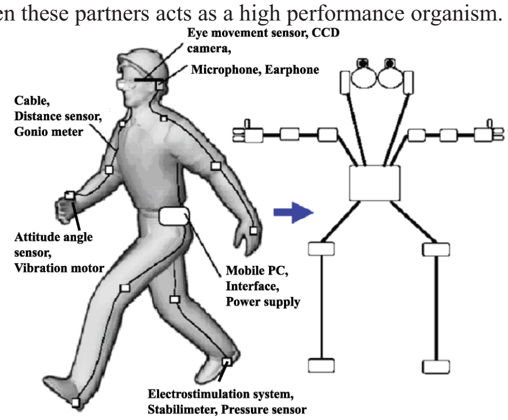


Figure 2. Wearable sensory devices construct a wearable humanoid without muscle

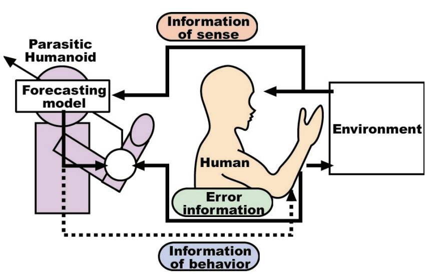


Figure 3. The symbiotic relationship between the wearer and the Parasitic Humanoid.

3.3 Capturing and Retrieving Sense and Behavior

The most direct usage of PH as a behavioral interface is capturing and retrieving behavior. It is not only for scientific research to analyze human behaviors, but also to enhance daily life. When you play golf, you may want to capture and retrieve your best shot. Or, you may download the data of the swing from the PH of Tiger Woods. You may exchange data for dance steps like name cards in a ballroom. You may share today's behavioural experiences with a distant person like telephone communication. Behavioral interfaces will make up a new style of communication.

Video see-through head-mounted displays are a common and useful method to record, transmit and reproduce visual information in human sight. When using a video see-through head-mounted display in telexistence or augmented reality, it is important to arrange the camera eye and human eye in conjugate in optics. However, earlier studies do not attempt to realize this. They align only the optical axis because of the difficulty of implementation. In this method, we may misidentify the distance to the object because of the difference of the angle of vergence. Moreover, the user's action may be obstructed because of the difference of motion parallax. In PH, we designed a video see-through head-mounted display in which camera eye and human eye are arranged in conjugate in optics. We investigate the influence given to depth perception and work performance when there is agreement or disagreement in viewpoint by using this system. This device is especially useful for skill transmission between PH wearers.

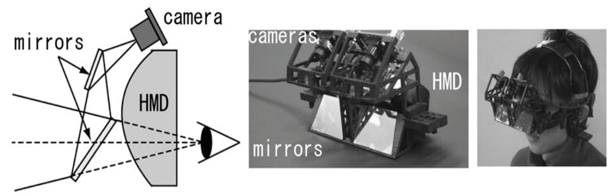


Figure 4. Zero Eye Offset and Orthoscopic Video See-Through Head-Mounted Display (VST-HMD)

4 How to Induce Human Motion: Behavioral Interface Devices using Illusion in Sensory Motor Process

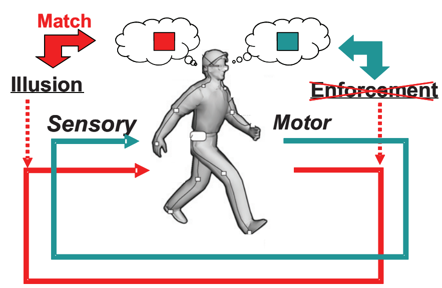


Figure 5. The concept to induce human behavior: Not by physically force but by sensory

In this system, when the wearer and the PH target the same behaviour, their targeted motions should be realized in a very similar manner. If the wearer knew the correct motion targeted by PH, he would achieve the motion naturally. What is the way to induce the motion in the wearer as if he knew the motion targeted by PH?

In the only neat way to induce human motion, the behavior might not be enforced physically but induced with sensory illusion. Human motion and sensory perception are not independent. These are integrated in a continuous relationship in neural processing as a loop connected between human embodiment and the outer world (Figure 5). In the first state, the subject has the motion plan A, and has the perception A. When outer force changes the motion from A to B physically, it also causes the change of the perception from A to B. The subject may become aware of the conflict between the motion plan A and the perception B. In contrast, when an illusion changes the perception from A to B, the subject may change the motion plan from A to B voluntarily. The latter case might be a better way to induce human behavior, avoiding a conflict to the free will of the subject.

We propose sensory motor interface devices using illusion for behavioral assist on Parasitic Humanoid system. These should realize the synchronization of the wearer's motion with the target motion collaboratively. When the distant PHs share the sensory and motion data with telecommunication, the wearers should also share their behavioral experience like the mutual telexistence in Figure 1(b). In this situation, the collaborative persons would trace each other's behavior. It is an advantage

5 TELECOMMUNICATION NETWORK WITH PARASITIC HUMANOID: SYNERGISTIC MULTIMODAL COMMUNICATION IN COLLABORATIVE MULTIUSER WITH PARASITIC HUMANOID

PH is also an electro mechanical device. Therefore the sensory motor information of wearer measured by PH is available to be recorded, transmitted and reproduced as electrical information. When many PHs and their wearers connect to an information network with sensory motor information, a novel synergetic multimodal communication might be realized providing the oneness not only between PH and the wearer but also among collaborative users. Our aim to transmit modalities such as senses of sight, hearing, touch, force and balance is to realize experience-sharing, skill transmission, and human behavior supports between distant people. This system may create a situation such as if an expert exists right in front of injured people, instead of the cooperator who is actually there, through multimodality transmission by PH network. The skills of the doctor are communicated to the cooperator and their experiences are shared with each other. Such multimodal communication is non-verbal, immediate and intuitive. It might break the limits of learning skills through verbal communication.

5.1 VIEW-SHARING SYSTEM

Here, we assume the situation such as the scene of an accident as an example (Figure 6). Our concept is that the bystander performs the emergency treatment according to the expert's direction transmitted from another place. As shown in Fig.1, two users in different places wear the video-see-through HMD. The user on the left (a) is a doctor who can direct the emergency treatment, and the other (b) is a bystander who is a layperson, and executes treatment according to the expert's directions. We name user (a) "expert", and user (b) "bystander". The expert, who has knowledge of techniques for emergency treatment, is not on site, and uses the view sharing system to understand the condition of the injured person and the environment. The expert then directs the bystander. The bystander achieves cardio pulmonary resuscitation performing, for example, cardiac massage. The bystander can receive the method of cardiac massage; the posture, the position to place the hands, timing, etc., by sharing the view with expert. For the expert user, in order to provide the bystander user with precise direction, sharing their first person view is important. Because sharing their first person view helps the expert to understand the situation at the bystander's location with accuracy, such as the spatial relationship of the bystander and injured person, and furthermore notice what within arms' reach is required.

5.2 Sensory-Motor Collaboration by View Sharing System

As the prototype of the synergistic communication between collaborative users, we have a developed view-sharing system to share the first-person perspectives between remote two people [12]. The system consists of a head-mounted display and cameras, which realize a video-see-through system. The users wearing the video-see-through HMDs can see his own and the partner's view and also can send his own view to the partner. The sharing system has been applied to a skill transmission and learning task.

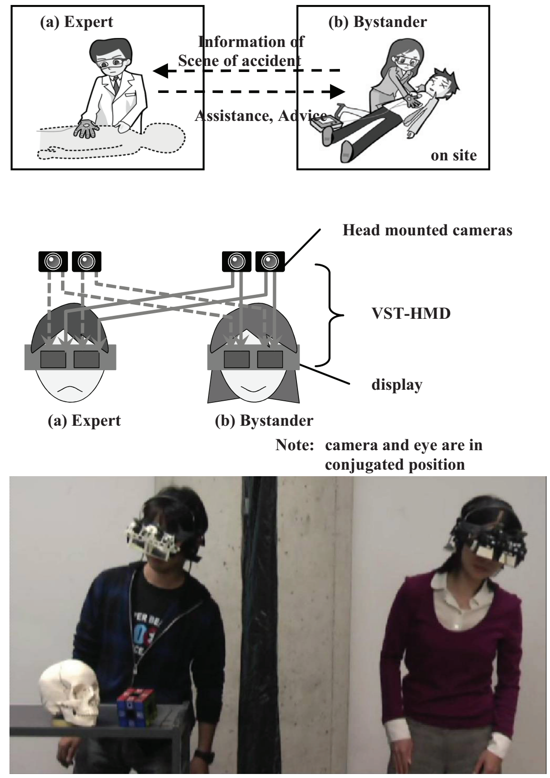
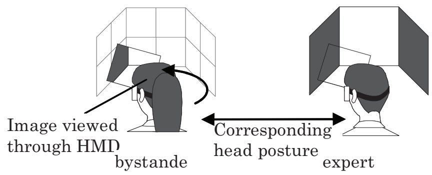


Figure 6. View sharing system.

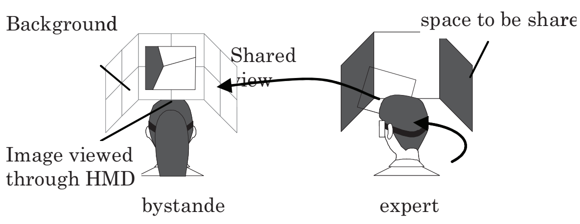
However, there are two problems in the system that may make the performance of the system for sharing senses and motions less effective. One is that the displayed view swings regardless of the person's own motion because the view is captured on the basis of the partner's motion. The discrepancy between motion and visual information causes a breakdown of the user's embodiment, which makes it difficult to maintain proper spatial perception such asthe positional relationship between an object and the world, a recognition of posture with which the partner sees the view, and the relationship between his own and the other world (Figure 7). This problem can be overcome by giving both the sender's motion and visual information to the receiver to maintain the coherence between them in the receiver's situation. By realizing an interface device that supports the receiver to follow the sender's motion and that displays the flow of images in response to the receiver's actual motion, the embodiment or coherency between motion and visual information can be maintained and the proper spatial perception can be sent to the receiver.

Another problem is a narrow view angle. Conventional video-see-through HMDs are not capable of sufficient view angles compared with the naked eye. It is shown that wider view angles improve the immersiveness of the view, and abilities of spatial perception and searching in a space [13][14]. A new design for video-see-through HMD with wider view angles resolves the lack of the visual information in the view-sharing system.

We propose a spatial stabilizer of flow of views on a video-see-through HMD with a wide view angle to overcome these two problems. The effect of the spatial stabilizer and view angles are tested and evaluated by the performance of communication of spatial perception from one to another. As shown in Figures 6 and 7, two users wear the video-see-through HMDs at the different places. The left user (a) is an expert who can direct the emergency treatment, and another (b) bystander is a layperson who actually executes it under the instruction of expert's direction. In order to follow the other user's head motions, a tracking support using guide markers is introduced. In Figure 8, two markers are in front of the user, (A) is fixed in front of the user, indicating the posture of user's own head. Another one (B) is the target marker, and it shows the partner's current head posture. Therefore, the positional relationship between center marker (A) and target marker (B) reflects the positional relationship between the user and the partner. The user has to follow the target marker by moving their head.



(a) The expert moved and the image is send to the bystander's eyes.



(b) The bystander moves following the expert, and the bystander's orientation corresponds to expert's. It means the expert's direction is transmitted to the bystander.

Figure 7. Overview of view sharing and motion tracking.

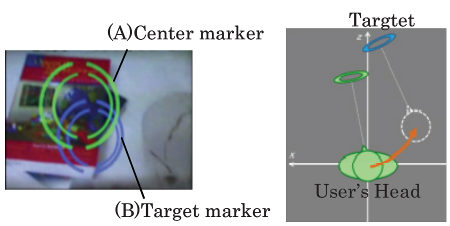


Figure 8. Positional relationships of guide markers.

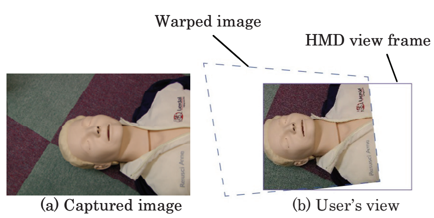


Figure 9. Method of image stabilization.

When both markers are aligned, the user and partner's motion are successfully corresponding. It is not easy for the user to track the marker in the partner's view, because when the users are moving, the image provided to the user does not correspond to their head motion. Ordinary, one's view of the background and its optical flow is an important cue of one's orientation during head motion. In this system, a background that does not correspond to the user's head motion makes the user feel disoriented or that the scene wobbles. As a result, the user's head movement is disturbed. The shaky images due to inconsistent motions between two must be eliminated.

5.3 Image Stabilization

If the user can track the other's vision with precision such that their view corresponds to the user's head motion, the user can recognize the other user's view as their own background naturally. However, perfect correspondence is difficult. The background image that does not correspond the user's head motion gives the user a disturbance during the task. The shaky images due to inconsistent motions between the two must be eliminated. In this section, the method for eliminating and stabilizing the background will be introduced. The stabilization technique is sometimes used in the field of tele-robotics [15] where the camera image attached on the mobile robot needs to be stabilized. We also used a stabilization technique in our system. The function, named "image stabilizer", transforms the image to generate the nearest image to the correct one. The function slides, warps and rotates the partner's camera image according to the relative position and orientation between the user and the partner in real time. The concept image is shown in Figure 9. We investigated the effect of our proposed stabilizer function and view angles in the spatial perception task sent by the partner. From the results of our experiments, it was shown that the view angle is crucial to perceive the positional relationships between objects in the partner's image flow and that the stabilizer function could compensate for the gap of ability of spatial perception between narrow and wide view angles (Figure 10)

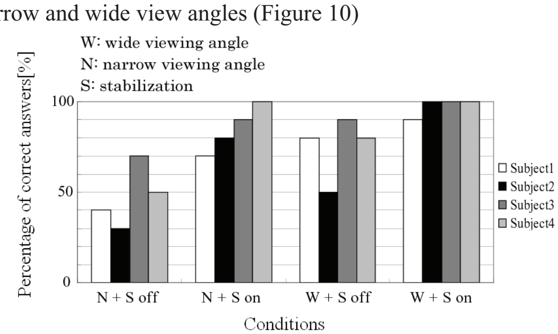


Figure 10. Performance of spatial cognition.

6 MOTOR SKILL TRANSMISSION IN VIEW-SHARING SYSTEM

Mentally rehearsing movements is an effective way to acquire skills [16]. Even though mental rehearsing is purely imaginary, we hypothesize that if an immersive environment can be established between two humans and a non-skilled person can see a skilled person's movements as if they were her/his own movements, the skill can be effectively transmitted. Therefore, we share first-person perspectives between humans in which a non-skilled person easily recalls the body images or movements of skilled persons to acquire a skill or to achieve a task in real-time with help from skilled persons. We tested our hypothesis.

For example, we exploited the collaboration findings and applied our view-sharing system to a concrete juggling skill and evaluated the skill transmission performance. Here, the skill transmission immediately improved a non-skilled person's performance with online PH assistance by an expert. In addition, skill transmission is different from skill acquisition. If the skill was acquired, the number of failures should also be decreased in the unassisted trial in Figure 11.

Figure 12 shows the theremin performance which is defined as the RMSE of tone pitches between the master and the beginner. The horizontal axis shows the trial number and the labels over the bar shows the condition of each trial (I : Individual condition, S: Side-by-side condition, V: View sharing condition). The performances of the same conditions are connected with the lines. At the first trial, the beginner has to play the theremin alone without any knowledge after listening to the target song once. The performance of the first trial shows the original skill that the subject has. After that, the subject learns how to move their hand from the master in the side-by-side condition. The performances improve over the original ones. However, as shown in the figure, the subject can show the best performance with the view-sharing system although the difference becomes smaller through repeated learning since the individual skill of the subjects improves at the same time. However, it is obvious that the skill of the master is transmitted to the beginner through the view-sharing system. At the 3rd and 5th trial, where the condition is view-sharing, the beginner can already play the song as well as he plays at the end of the experiment. This result can be seen in another pair as well.

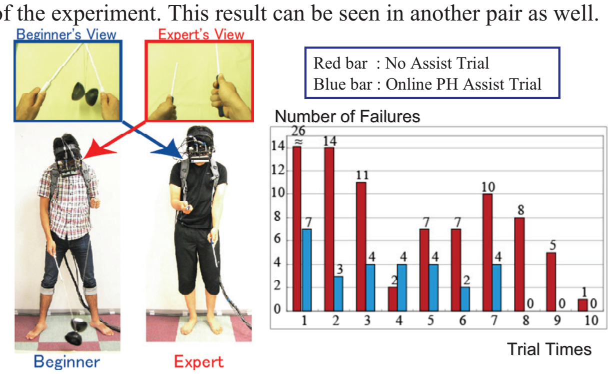


Figure 11. Performance of juggling skill transmission in Online PH Assist.

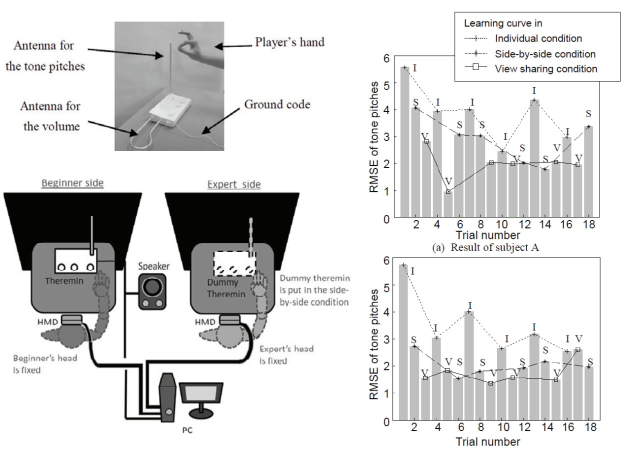


Figure 12. Performance of playing theremin skill transmission in Online PH Assist.

Our results indicate that the skill is transmitted better to the beginner with the view-sharing system than with side-by-side method. What we focus on in this paper is the online skill transmission which means that the master skill is continuously transmitted to a non-skilled person in a short time span. Actually, the beginner could not play the song well soon after the view-sharing condition in which he played well. This means that skill acquisition cannot be expected here. Another aspect of the system is the offline skill transmission which indicates the improvement of learning skills over a long time span as a skill acquisition. Our view-sharing system can be regarded as a learning method for this case. These two aspects are not exclusive but complementary. Actually, the skill acquisition would happen in our experiment as well. The view-sharing system would work better in the skill acquisition in the same manner of the online skill transmission but other experiments are required to clarify the effectiveness.

7 Conclusion

In this paper, we proposed an approach for sharing first-person perspectives to establish collaboration and to transmit a skill from one to another. We developed a view-sharing system to realize such interaction using the Parasitic Humanoid (PH). PH is a wearable robotic human interface for sampling, modeling, and assisting nonverbal human behavior. This anthropomorphic robot can sample, record, and replay the sensory and behavioral experiences of the wearer from the first person perspective of himself. PH can also transmit and share the experience to the other PH wearer. It is a novel technique of telepresence from human to human that can realize telecollabolation and skill transmission between PH wearers.

8 Acknowledgements

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