Touch-based Information Transfer from a Robot Modeled on the Hearing Dog

Michihiko Furuhashi, Tsuyoshi Nakamura, Masayoshi Kanoh, and Koji Yamada

***Abstract*—Research on physical human-robot interaction has been attracting attention recently, focusing on robot embodiment. The work reported here proposes Active Touch Communication Robot (AcToR), a robot that is modeled on the hearing dog. A hearing dog is a type of dog assist people who are deaf or hard of hearing by alerting their handler to important sounds. AcToR uses the sense of touch to notify a human of the intention to transfer information. For example, when AcToR detects that a cell phone that is in another location has received a call, AcToR moves to the user's location and makes contact with the user's body to notify the user of the incoming call. The AcToR robot is based on the Roomba®and uses the Roomba's bumper and contact sensors to detect contact. This paper reports the results of psychological experiments using the AcToR robot that indicate the feasibility of using touch to transfer information from a robot to a person.**

Keywords*—*pHRI, Hearing dog, touch-based information transfer.

I. Introduction

GIVEN the remarkable recent research and development advances in robot-related research, we can envision the future when robots will be integrated and actively involved in everyday lives of humans. This being so, we must also assume the ability of robots to interact with humans and support interpersonal communications. This communication must be as barrier-free and unimpeded as communication between people. As the human-robot interaction (HRI) advances, service robots have started to work in daily environments. Service robots for domestic tasks and entertainments have recently been developed [12], [13], [23], [31], [34] . These robots are more familiar to us than industrial robots. This trend will continue and more service robots will be developed.

Robots that have a physical existence in the real world differ greatly from agents that are represented by computer graphics in a virtual environment in that they have an actual body. There are experimental studies that have directly compared embodied robots and virtual agents, and the effects of having a body and its psychological effects on humans have been discussed [22], [18], [19], [21]. The interaction between embodied robots and humans under various circumstances has also been studied. For example, Lee et al. [20] developed a snack delivery robot that was used in an office and the robot's social interaction with humans was observed over a four-month period. There are also human-robot interaction studies on robots giving advice to people and walking in close company with people [26], [35]. Many of the studies suggest that having a body provides a sense of presence that is not possible with a virtual presence, and by sharing the physical space with humans, natural communication can be expected.

Fig. 1. A hearing dog's task

We also benefit from communication with things other than robots that have bodies in the real world in which we live. One example is the service dogs that assist disabled people. The hearing dog, in particular, uses body contact or visual signals for communication. A hearing dog helps a person who has a hearing disability enjoy a lifestyle that is safer and less stressful by using touch to inform the person of important sounds and leading the person to the source of the sound [1], [2], [3]. Examples of sounds that a hearing dog responds to include alarm clocks, intercoms, mail arrival, boiling pots, faxes, children crying, emergency alarms and other sounds that are important in our daily lives (see Fig. 1). There are also many anecdotes about pet dogs and cats that behave in ways similar to trained hearing dogs, urging owners to get out of bed or alerting about dangers by body touching.

For those reasons, we propose information transfer by active touch that is initiated on the robot side, using the hearing dog as a model. Features of the hearing dog are that it effectively uses contact with its body to convey information, and contact acts on the human sense of touch. The other feature is that dogs move around on four feet, so even if they are away from where the person is located, they can move to the person to convey the information. Having a body and the ability to move around are features that many robots have, and that makes

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them similar to the hearing dog. On the other hand, a hearing dog is a living animal, so problems arise when they share a living environment with humans. We can easily imagine how robots would be preferable in that respect. Although hearing dogs are service animals for assisting people who have hearing disabilities, the robot that we propose is not limited to that task, but can be used for a variety of general purposes.

A special feature of conveying information by touch is that the information is given directly to the intended person and not to others. In communication between people, for example, we have probably all had the experience of being tapped on the shoulder from behind or nudged from the side by a friend or acquaintance. The information communicated by touch in that way can be known only to the person who was touched. The sense of touch stimulated by the contact does not affect other people, so the range of the effect is very small. A stimulus for the sense of hearing extends over a much wider area, which is the range within which a sound can be heard. That large difference in range between the sense of touch and the sense of hearing and the nature of the two sensory modalities must be considered when using them to convey information. For example, consider the arrival of mail at a cell phone or smartphone. The alert sound for when mail arrives, which is an auditory stimulus, is easily perceived, but in many cases when there are other people nearby, the use of an auditory stimulus is restricted. Alert sounds are unsuitable or undesirable in public places or situations where quietness is required or in noisy environments. We can think of hospitals, libraries, theaters, conference rooms, places where children are sleeping, and factories as examples.

One major reason for using robots to convey information is that they are mobile. When there is an incoming call on a cell phone, we probably notice it. When an incoming call is indicated by vibration or a light, the indication is difficult to notice unless the phone is touching our body or is in our hand. Unfortunately, the phones that are now being sold do not have wheels or wings and cannot move around, so they cannot move from a remote place to where the user is to inform the user of an incoming call. The best current solution to that problem is the wearable terminal. But many people find them bothersome and resist using them. Addition to that, there are some problems e.g. dead battery and slight vibration. Another approach would be to have a robot connected to the cell phone by Bluetooth or something, and as illustrated in Fig.2 when the robot detects an incoming call it moves to the user's location to notify the user. When the user is informed of the incoming call by the robot's touch, he knows that he should retrieve the phone. In this way, the user does not have to keep the phone at hand and a wearable terminal is not needed.

The development and implementation of conveying information by intentional contact by robots requires some basic surveying and investigation in addition to overcoming the technical problems. The first question to be solved is whether it is possible for robots to convey information to humans by touch. The philosopher Daniel Dennett [11] has described the intentional stance as one strategy for understanding and predicting human behavior. Terada et al. conducted experiments to test Dennett's idea of the intentional stance [17]. If we recast our question as "Can a person understand the intention of the robot's touching behavior?", then we can treat it as a test of intentional stance.

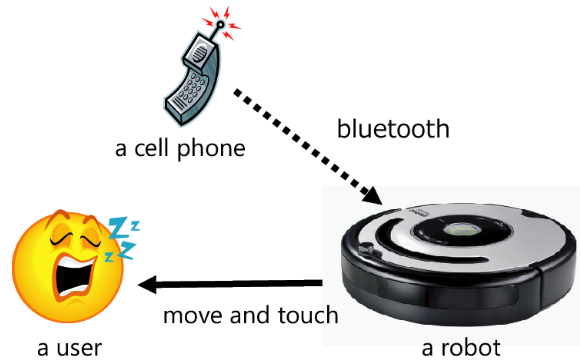


Fig. 2. Robot detects incoming call and moves to the user's location to notify the user

In the research reported here, we performed a experiment to test the effects of the robot touching behavior. The experiment addressed the question, "Can a person understand a robot's touch as an intentional act rather than an accident?" On the basis of the experimental result, we discuss the feasibility of conveying information by robot touching behavior.

II. Related works

Other research related to active touching by robots includes the work of Nakagawa et al. [27], who reported changes in the motivation of humans depending on whether or not touching was involved when robots requested the execution of tasks by humans. Those results suggest the effectiveness of touch between humans and robots as a means of communication. Fukuda et al. [15] use the Ultimatum Game to study the effectiveness of touching by robots to evoke altruistic behavior towards the robot. In other work, Chen et al. [9] developed a nurse robot and investigated the human reaction to touching by the robot when the touching is accompanied by speaking. The purpose of our research is to consider touching by robots as a means of conveying information, as described above, so our work differs in purpose and implementation from the research just cited. Nevertheless, there is a common point in using touching by robots as an interface with humans.

In a future society where humans and robots coexist, physical contact between robots and humans will be difficult to avoid. Accordingly, there has also been research on robot design premised on physical contact with humans and harm to the human body resulting from contact with robots. Oudeyer et al. [28] developed the humanoid robot Acroban and equipped it with an intuitive physical human-robot interaction (pHRI) function. An example of research on safe pHRI in a workspace shared by robots and humans is the work of Augstsson et al. [7], who proposed concepts related to safety zones for industrial robots. When robots and humans share a working environment, safety zones change according to the locations of the robots and humans. Other reports include implementation for the KUKA LWR-IV robot arm [10] and contact sensor

Fig. 3. AcToR(Active Touch Communication Robot)

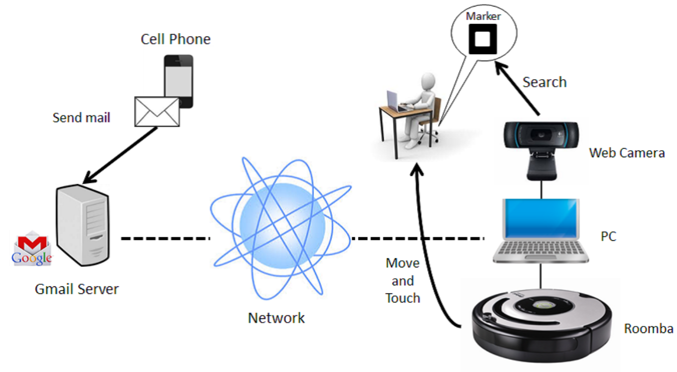


Fig. 4. The System Configuration of AcToR

technology using artificial skin [14]. Studies on safety concerning physical bodily contact with robots are necessary for practical applications of physical human robot interaction, and the results and technology reported in the works cited here will be useful in the near future.

Kaoy et al. [6] proposed a hearing robot, which is similar work to our proposed robot from the point of view of supporting deaf people. The hearing robot use visual communication signals to communicate people. Thus the hearing robot is far different from our robot which use touch communication signals from the point of view of interaction.

Hearing dogs provide therapeutic benefits to humans with physical and mental illnesses as well as provide assistance to people with disabilities [4]. Although not directly related to our work, other robots that are modeled on animals include Paro [24], which opened up the field of robot therapy. The design for the appearance and behavior of th robot are factors to be considered in the future of our work. Addition to them, there are some works on interaction between robots and humans [8], [16], [25].

III. Robot configuration

The objective of the research reported here is active touching of humans by robots. The robot we are developing is based on the Roomba®cleaning robot produced by the iRobot corporation[30], [36]. The robot is controlled from a laptop computer connected by a USB interface. We will refer to this Roomba connected to the control computer as AcToR (Active Touch-communication Robot) (see Fig. 3). We use the Roomba because it is mobile and has a bumper on the front to absorb the shock of contact, and contact sensors are installed on the bumper. Also, the Web camera of the computer that is mounted on the Roomba can be used to recognize and measure the distance to objects such as chairs or desks to which augmented reality markers are attached.

Fig.4 illustrates the system configuration of AcToR. AcToR hires RSNP (Robot Service Network Protocol)[5] as a service platform to develop network applications. RSNP makes it possible for service providers to implement and deploy secure services easily. We have developed an AcToR prototype. The prototype can connect to the internet and detect an e-mail incoming, where the prototype uses gmail service. After detect the e-mail incoming, the prototype searches an AR marker, which is attached to a user's chair or bed, and bump it.

IV. Experiment

As the research question for basic evaluation of the proposed robot, we experimentally investigated whether or not a person could sense the intention of a robot to convey information by touch.

Sensors attached to the Roomba that serves as the base for AcToR and sensors connected to the control computer detect obstacles. AcToR is designed to avoid obstacles, but the robot may sometimes come in contact with walls or objects in the room, depending on the environment in which it is placed. The design for touch-based information transfer should therefore make it possible to distinguish between accidental contact and the intentional contact whose purpose is to convey information according to the contact behavior alone. That is important because the interface design should involve interaction that is intuitive and easy for a person to understand through experience.

We therefore conducted the following experiment.

A. Method

The experimental conditions are that a chair in which a person is sitting is bumped by the robot(see Fig. 5). It would also be possible for the robot to touch the person's leg directly, but these experimental conditions were chosen to ensure the safety of the test subjects. Preliminary experiments confirmed that the person is able to perceive the robot's contact with the chair indirectly by vibration robot's contact causes. An office chair was used (Sanwa Supplies model SNC-T135KBL). The experiment was conducted using between-subjects design. We divided the test subjects into two groups for comparison of the psychological effect of contact conditions. Each group consisted of 15 persons, including 13 men and two women between the ages of 19 and 24. For group A, the contact condition was regular and for group B, the contact condition was irregular. For the regular contact condition, the robot approached the chair, made contact, and retreated at intervals of two seconds and the series of actions was repeated five times. For the irregular condition, the robot advanced towards the chair, made contact, and reversed direction, imitating the Roomba cleaning behavior. The series of actions was repeated five times at random time intervals.

Fig. 5. AcTor bumps a chair in which a person is sitting

The experiment was conducted under the dual-task paradigm, with the dummy task set as an electroencephalograph experiment. As a measure to make the circumstances of contact by the robot not unnatural, the test subjects were asked to wear a simple brainwave sensor instructed to watch a video on a display monitor. At the same time, the test subjects were presented with loud music to block auditory input so that they could not hear the operating sounds of the robot or the work involved in conducting the experiment. Before beginning the experiment, the test subjects were made aware of the AcToR's presence by placing an operating AcToR within the visual field of the test subject, suggesting that the AcToR robot would be moving around behind the test subject during the experiment.

At a certain time after the beginning of the dummy task, AcToR approached from behind the test subject and made contact at a speed of 360 mm/s, which is sufficient to be perceived by the test subject. The method of contact is according to the two contact conditions described above, regular-interval contact and irregular-interval contact. Video recordings were made of the test subjects during the question sessions. After the experiment was completed, the test subjects responded to a experiment questionnaire and to oral questions. The content of the experiment questionnaire is listed below.

Q. How did you feel when the Roomba bumped the chair ?

1. I was startled.
2. I felt that it had information for me.
3. I felt that it accidentally bumped into something.
4. I felt that it was cute.
5. I felt that it was sending a signal.
6. I felt that it was simply vacuuming.
7. I was frightened.
8. I felt that it hit on purpose.
9. I felt that it hit without purpose.

The five subject responses were "No.", "Somewhat no.", "Can't say one way or the other.", "Somewhat yes." and "Yes." Each response was assigned a values from 1 to 5 in that order. Questions 2, 5, and 8, directly test the subject's understanding of what AcToR is trying to convey. Questions 3, 6, and 9 test for whether or not the subject regards the AcToR behavior as accidental rather than intentional. Questions 2, 5, and 8 are expected to have answers opposite to questions 3, 6, and 9. Questions 1, 4, and 7 do not relate directly to the investigation, but are dummy questions intended to obscure the purpose of the experiment from the test subjects.

B. Results

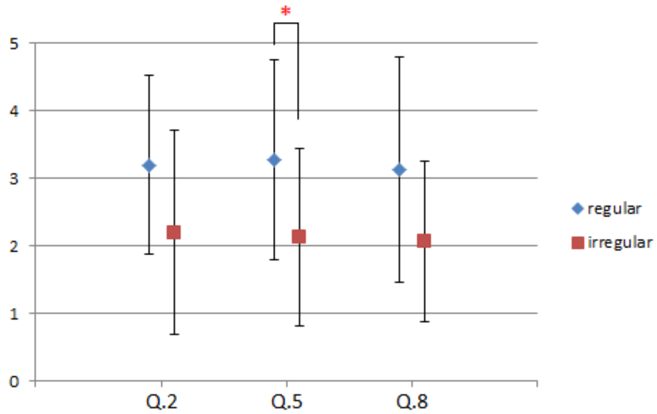
The average response scores and standard deviations for the experiment questions are presented in Fig. 6, Fig. 7 and Fig. 8. Each bottom table of the figs shows p-value of the MannWhitney U test. The results for questions 2, 5, and 8 indicate higher average scores for all three questions for the regular contact condition test group rather than the ones for the irregular contact condition test group. As the result of the MannWhitney U test, question 5 can confirm the p-value was smaller than 5%. The results for questions 3, 6, and 9 indicate higher average scores for all three questions for the irregular contact condition test group rather than the ones for the regular contact condition test group, and also question 3 and 6 can confirm the p-values were smaller than 5% and 1% respectively. In referring to dummy questions 1, 4, and 7, they look like no difference between regular contact condition test group and the irregular one.

Those results demonstrate the effectiveness of the regular contact interval condition. However, these results alone are insufficient to confirm a difference in psychological effect between the two test groups. We therefore test whether or not there is a difference in psychological effect according to the type of contact between the test subjects who experienced regular contact and the group that experienced irregular contact.

For the test, we calculated the sum score s, whose formula is shown below. The sum score was calculated for questions 2, 3, 5, 6, 8, and 9, excluding the dummy questions. Because the scores for questions 2, 5, and 8 and questions 3, 6, and 9 have opposite meanings, the scores for the responses to questions 3, 6, 9 were converted as shown in the formula. The term x_i in the formula represents the response score for question i.

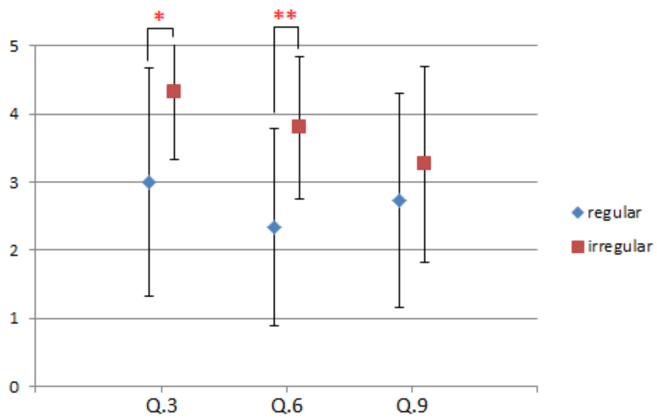
$$s = \sum_{i=2,5,8} x_i + \sum_{i=3,6,9} (-x_i + 6)$$

Before calculate s, we confirmed internal consistency between questions 2, 5 and 8 and questions 3, 6 and 9. Cronbach's alpha was .8562 for the results of the regular contact interval experiment and .7363 for the irregular contact interval experiment. In Cronbach's alpha, if the alpha value is more than .8000, there is enough consistency and also if the alpha value is between .7000 and .8000, there is consistency to a certain degree. Therefore, it was confirmed that it is adequate



	Q.2	Q.5	Q.8
p value	.0604	.0449	.1030

Fig. 6. Results for questionnaire items 2, 5, and 8



	Q.3	Q.6	Q.9
p value	.0212	.0082	.2951

Fig. 7. Results for questionnaire items 3, 6, and 9

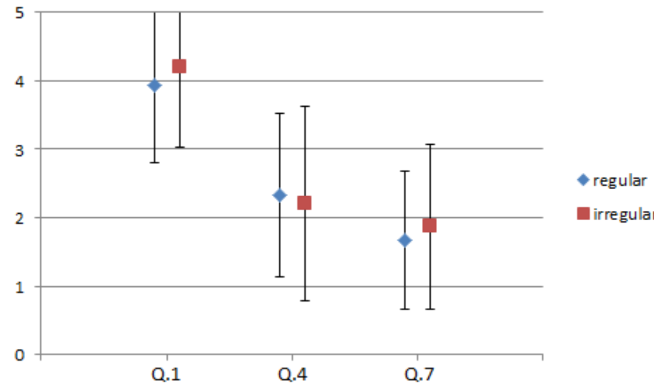
to calculate the above s in regard to both the regular contact interval experiment's score and the irregular one.

Addition to calculate s, the K-S test of normality was done because the groups of 15 test subjects were not large. The results of the test are presented in Table I and Table II. The p value was .7658 for the results of the regular contact interval experiment and .9130 for the irregular contact interval experiment. Both values aren't small to reject the null hypothesis that "there is normality".

The result of the parametric Student's t-test is shown in Table III. The p value is .0083, so we can expect that there is a difference in feeling of the test subjects between the regular contact condition and the irregular contact condition.

V. Discussions

The results described above indicate that the regular contact design is more effective rather than the irregular one, in giving people the impression that the contact behavior is intended to convey information.



	Q.1	Q.4	Q.7
p value	.2830	.6028	.6471

Fig. 8. Results for questionnaire items 1, 4, and 7

TABLE I. Results of the test of normality for the experiment under the regular contact condition

K-S test		
Statistic	Degrees of freedom	*p* value
.2042	15	.7658

TABLE II. Results of the test of normality for the experiment under the irregular contact condition

K-S test		
Statistic	Degrees of freedom	*p* value
.1539	15	.9130

TABLE III. Results of the t-test

Statistic t	*p* value
2.842	.0083**

In the interview after the examination, which was done separately from the experiment questionnaire, 12 of the 15 test subjects responded with "The fact that the contact occurred a number of times gave me the feeling that there was something happening.", or "The action of bumping the number of times made me think that the contact did not result from the cleaning process." and we can infer that the regular contact method gave the subjects the impression that the contact had some kind of significance.

VI. Conclusions

We proposed and implemented AcToR, which is based on a Roomba and modeled on the hearing dog. Some previous works employed a Roomba to study HRI or related fields [29], [32], [33], but they didn't focus on touch communication between robots and humans. AcToR is designed to convey information by actively making physical contact. We performed psychological experiments to compare the effects of regular and irregular contact behavior and confirmed the tendency of the behavior to transmit the robot's intention to convey information. At the same time, the results of the experiments revealed the tendency for people to not recognize information transfer by irregular contact behavior. Irregular contact by AcToR or other robots can easily occur because of a failure to recognize people or obstacles in the environment. We believe that the results of these experiments provide useful information for the future design of robot contact behavior.

In this work, we have proposed effective touching by a robot as a means of conveying information in physical human-robot interaction that is expected to be effective in situations that are not easily dealt with by the results of previous research or devices such as cell phones or smart phones that have been developed so far. On the other hand, many problems remain for future work, including the ability to avoid obstacles in our daily life environment, detecting the location of humans, identifying humans, and so on. We will continue with research and development to solve those technical implementation problems and design active touch methods that are based on cognitive science and are intuitively understandable.

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