

Informing a User of Robot’s Mind by Motion

Kazuki KOBAYASHI¹ and Seiji YAMADA^{2,1}

¹ The Graduate University for Advanced Studies
2-1-2 Hitotsubashi, Chiyoda, Tokyo 101-8430 Japan
kazuki@grad.nii.ac.jp

² National Institute of Informatics
2-1-2 Hitotsubashi, Chiyoda, Tokyo 101-8430 Japan
seiji@nii.ac.jp

Abstract

This paper describes a nonverbal approach for a robot to inform a human of its internal state. It is implemented by executing particular motion. In practical cooperation of a human and a robot, the robot often requires human’s help to achieve a task. In such a situation, a robot needs to send useful information on its internal state like intention, to guide a human to understand it and to make him/her to execute actions for help. A simple solution for how to inform a human of the robot’s internal state is an explicit way in which a robot sends verbal information like speech synthesis. However, in terms of human-robot interaction, implicit and effective approach is preferable because it must be more natural and inexpensive like the interaction between humans. Thus we propose a motion-based approach for a robot to inform a human of its internal state. By such an approach, a robot is able to tell the internal state to a human naturally, and he/she can understand the robot’s state effectively. Some experiments are made for evaluating the advantage of our method over other nonverbal ways.

1 Introduction

In recent years, home robots including sweeping robots and pet robots have been widely spread not only in robotics laboratories but also ordinary homes. By using such home robots, a user tries to achieve tasks like sweeping cooperatively with them. Since a robot often can not achieve its tasks by itself, it needs to request a user to help it. For example, a sweeping robot can not remove a heavy obstacle like a chair or a table, so it needs to request a user to remove it for sweeping the region under it (Fig. 1).

Thus it is a significant problem how to inform a

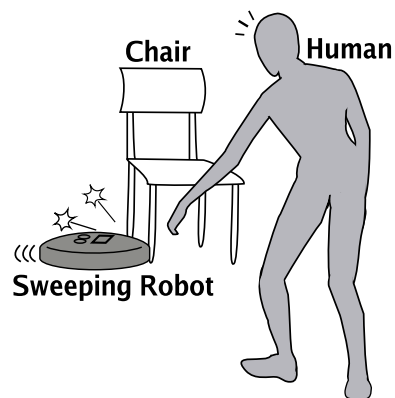


Figure 1: Robot needs user’s help.

user of the robot’s internal state. We call such robot’s internal state *mind* because it may correspond to human mind in psychology, especially theory of mind[1]. It is not a trivial problem to develop a method to inform robot’s mind to a user because the robot should tell him/her it as naturally as communication between humans. The simple way to inform robot’s mind to a user is to use verbal communication with speech synthesis like saying “Help me. Please remove the obstacle.” However such verbal communication significantly depends on language and needs additional expensive equipments for speech synthesis. We then focus on nonverbal communication because some researches show that nonverbal communication has rich information. Watanabe et al.[2] have argued the importance of nonverbal information, head moving like nodding on the communication in their virtual space. Komatsu[3] has reported that users can infer attitudes of a machine by hearing its beep sounds. Matsumaru et al.[4] have showed that their mobile robot indicates its direction of movement by a laser pointer or an ani-

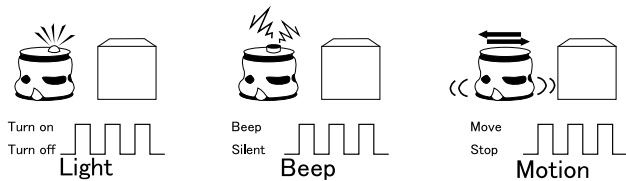


Figure 2: Some nonverbal ways to inform a user of robot’s mind.

mated eye, and confirmed those availabilities. Nonverbal information is an essential factor for human-robot social interaction[5] and instruction methods which a robot observes human actions[6, 7]. Thus nonverbal methods are preferable because of rich information, no or the least additional equipment and independence of language.

In this paper, we propose a motion-based method for a robot to inform a user of its mind in a nonverbal way. We can consider several nonverbal ways to inform a user of a robot’s mind. For example, a robot can employ motion like struggle behavior, sound like beep, lighting of LED and so on (Fig. 2). We consider a motion-based informing to be the best way in terms of the feasibility and the effectiveness for designing the concrete motion to inform a user of robot’s mind in an obstacle-removing task. The motion is designed according to ethological policy. By applying ethological policy, we are able to execute motion so that human or animal may perform so and narrow the candidates of motion. In an obstacle-removing task, we designed back-and-forth motion in front of an obstacle. We conducted experiments in comparison with other nonverbal methods, and obtained promising results.

2 Related work

Some previous work on human-robot interaction is concerned with our study. Ono and Imai[8] studied how human familiarity to a robot influenced human recognition of robot’s mind. At beginning of an experiment, a participant had experience in growing a life-like agent on a PC, and his/her familiarity to the agent significantly increased. Then the life-like agent moved from the PC into a mobile robot and appeared in a laptop PC on the mobile robot. Finally participants tried recognition of a robot’s noisy speech, and the results showed that a robot with an agent is much better than a robot without an agent. Their work is very important in the sense of interesting attempt to develop a concrete method to increase the familiarity

between a human and a robot. However they did not investigate which modality is effective for mind reading of a robot, and we try to develop a motion-based method to facilitate mind reading.

Psychology, in particular, TOM(theory of mind)[1] is closely related to our work. In TOM framework, first a person P-1 recognizes the other person P-2. Then P-1 recognizes an object which P-2 gazes (joint attention), and the trinomial relation among P-1, P-2 and the object occurs. P-1 eventually uses theory of mind to infer the P-1’s mind. Our work deals with a situation in which a mobile robot faces an obstacle and can not remove it for going ahead. Since P-1, P-2 and an obstacle correspond to a human, a mobile robot and an object respectively, our work is understood with TOM framework. Though TOM is useful for describing our task, it does not provide how to design interaction for facilitating human’s mind reading of a robot. We give a solution to such a problem.

In addition, our study has a close relation to the research about understanding of intentions. Dennett[9] has mentioned that human beings use three kinds of stances when they try to understand a system’s actions. However, it is difficult to apply his ideas to designing a robot because the elements which the robot should have for informing a user of its mind is still unknown. Terada[10] and Sato[11] discuss artifacts which behave in agreement with human intentions. In general, intention understanding needs a high processing costs and much knowledge about robot’s tasks. In contrast, we investigate the robot which indicates its mind by simple methods in a simple task, and try to obtain general knowledge for designing robots.

3 Informing a user of robot’s mind by motion

We explain an obstacle-removing task and propose a method to inform robot’s mind in the task.

3.1 Task: requesting a human to remove an obstacle

We can easily imagine that a sweeping robot which can not remove an obstacle like a chair requests a user to remove it for sweeping the region under the obstacle (Fig. 1). We call such a task an *obstacle-removing task* and employ it as a general test bed task for our work because it occurs frequently and easily in various cooperative tasks of a human and a robot. In order to achieve an obstacle-removing task, a robot needs

to inform a user of its mind which shows that it has difficulty in removing the obstacle and wants him/her to remove it.

3.2 Nonverbal approach

One of the main objectives in human-robot interaction is to construct *natural* interaction between a human and a robot. Thus as developing a method to inform a user of the robot’s mind, the method should be natural for a user and should not force him/her cognitive load. Also TOM tells us that one of natural interaction between humans is nonverbal communication. Hence we consider nonverbal approach informing robot’s mind to a user to be preferable to verbal one, and develop such a nonverbal method.

3.3 Advantage

We have some alternatives of modalities for such a nonverbal method like sound, lighting, motion and so on. A robot can employ motion like struggle behavior, sound like beep, lighting of LED (Fig. 2). We consider a motion-based informing to be the best way for the following reasons.

- *Feasibility*: A robot must be designed to execute motion for achieving various tasks. Thus a motion-based informing method needs no additional and expensive implementation like a LED or a speaker. In contrast, other nonverbal approaches need such implementation.
- *Variation*: By motion-based approach, we can design motion as informing methods for various tasks. The variation of motion-based informing methods are far larger than that of other nonverbal methods.
- *Less stress*: Other nonverbal methods, particularly sound, may force a user to direct his/her attention to a robot and take more stress than motion. The motion-based method sends no bothering signal to a user, and the user may just see the motion naturally.
- *Effectiveness*: We intuitively consider motion-based informing to be more effective than other nonverbal ones. Because the interesting motion seems to adequately attract user’s attention to a robot without stress.

Note that the feasibility, the variation and the less stress properties of motion-based informing are valid,

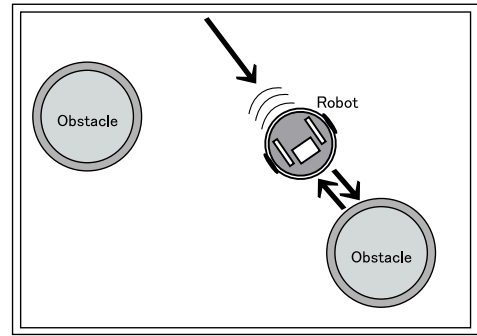


Figure 3: Back-and-forth motion.

however the effectiveness is a assumption we believe and it should be verified by the experiments. Thus such experiments will be conducted in later sections.

3.4 Design policy of motion

We design concrete motion for informing robot’s mind in an obstacle-removing task. We propose *back-and-forth* motion as general motion which is needed in various tasks. A robot goes back and forward four times in a short period of time in front of an obstacle along its trajectory. Fig. 3 shows behavior of the back-and-forth motion.

We design back-and-forth motion according to ethology. Most of animals have action patterns and repeated them[12]. The back-and-forth motion expresses properties of such universal actions of the animals in terms of repetition and a sudden change of movement. A user can easily understand the robot’s mind by looking its motion. We call this *ethological design policy*. Arkin et al.[13] have applied ethological models for robots and investigated its effectiveness. In our study, some other types of motion for a robot are available, however, we consider the back-and-froth motion to be the most attractive for a human.

Back-and-forth motion is easily implemented because a robot may repeat just going back a little along the trajectory and going ahead a little. Also this back-and-forth is applicable to any situation in which an obstacle is in front of a robot, thus it is considered a general method to achieve tasks including obstacle-removing.

4 Experiments

The purpose of the experiments is to verify the effectiveness of our motion-based informing in an

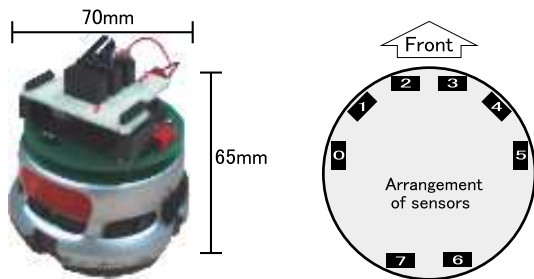


Figure 4: KheperaII

obstacle-removing task. We compare the motion-based method of a robot with other two nonverbal methods.

4.1 Method

Fig.6 shows the experimental environment which has a flat surface (400mm \times 300mm), a wall surrounding it and two obstacles. It simulates an ordinary human working space like a desktop. The obstacles correspond to an object such as a pen-stab, a remote controller and so on and can be moved easily by a human. We use a small mobile robot KheperaII (Fig.4). The robot has eight infrared proximity and ambient light sensors with up to 100mm range, a processor Motorola 68331 (25MHz), 512 Kbytes RAM, 512 Kbytes Flash ROM, and two DC brushed servo motors with incremental encoders. The program written by C-language runs on the RAM.

Participants observe the robot which sweeps out the floor in the environment and indicates its mind in the following three methods:

- (1) **back-and-forth motion:** the robot performs back-and-forth motion which is composed of four back-and-forth actions and four stop actions. The robot behaves back-and-forth at the 'on' in Fig.5, and stops at the 'off'. It goes back for 0.075 sec. and goes forward for 0.075 sec. in a back-and-forth action.
- (2) **LED light:** the robot performs LED lighting action. The robot turns the light on at the 'on' in Fig.5, and turns it off at the 'off'. The red colored LED with diameter of 3mm is equipped on its top. We chose the red color of LED because it means warning like a traffic signal.
- (3) **beep sound:** the robot performs beeping action which is composed of beeping and muting. The robot beeps at the 'on' in Fig.5, and is silent at

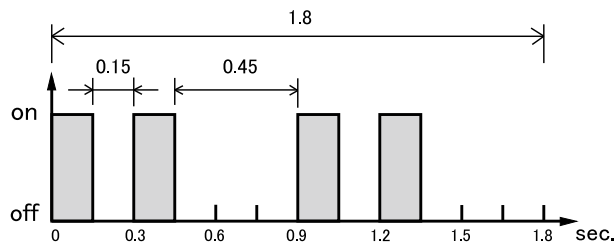


Figure 5: Pattern of the behavior.

the 'off'. A buzzer which makes the sound of 6kHz and 53dB (at 100mm from it) is equipped on its top. We determined the sound pressure to be a human conversation level (50dB – 60dB) on the equal loudness curve (ISO226), and the experimental room has the sound pressure of 34dB.

The back-and-forth, the lighting and beeping are the same in timing of the 'on' and 'off.' We consider the pattern of Fig.5 to be valid because the robot can performed easily and a user can observe the pattern certainly. The robot stops and performs their indication when they meet an obstacle or a wall. After indicating, they turn left or right and then go ahead. If the robot senses an obstacle on its right (left), it turns left (right) for a given length of time. The robot repeats such actions while an experiment is performed. Note that the robot cannot sweep the dust away.

Participants are instructed as follows: *“This robot is a sweeping robot. Actually, it cannot sweep the dust away. So, please consider the floor to be cleaned by the robot. You can move or touch everything in this environment. Please help it if necessary.”* A participant performs a training and two trials and experiences three methods : back-and-forth, lighting and beeping. The order of the methods for the participant is random. A training or a trial is finished when the robot meets obstacles three times, or the participant replaces an obstacle when the robot indicates its mind.

4.2 Evaluation

We measure the number of times which the robot meets obstacles until a participant moves the obstacle placed near it. It means ease of understanding for robot's mind. To measure the period from the beginning of an experiment to the moment which a participant moves an obstacle is better for the evaluation, however, it is difficult because the time which the robot reaches the first obstacle is somewhat different in each trial. Slips of robot's wheels cause its trajectory to be changed.

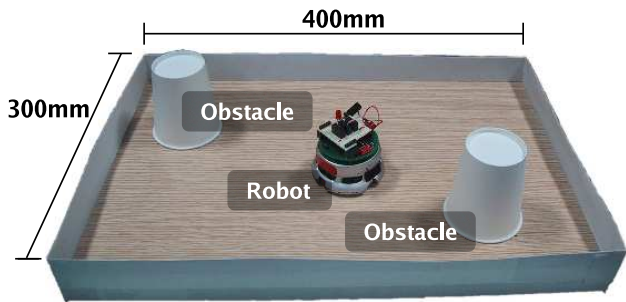


Figure 6: Experimental environment.

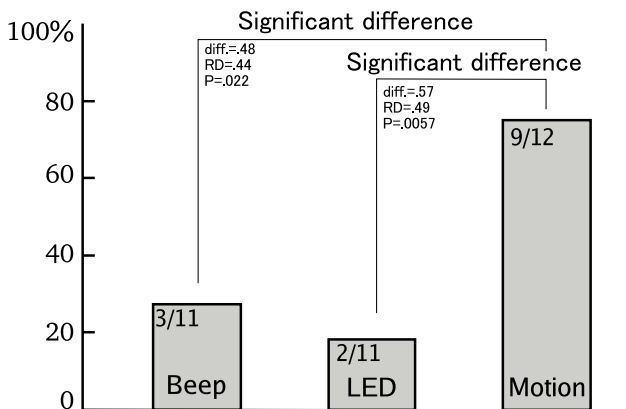


Figure 7: The ratio which a participant moved the object at robot's first indication.

4.3 Results

Participants are 17 persons (male:11, female:6, age:21–44). Fig.7 shows the results of the experiments. In the figure, each bar represents the ratio which a participant moved the object at robot's first indication. A numerator represented in each bar is the number of persons who moved the object, and a denominator is the total number of persons who experienced the method. The ratio of the motion is highest value. The result of the statistical test, Pearson's Chi-squared test shows a significant difference among those three methods ($\chi^2 = 8.947, df = 2, P = 0.0114$), and the multiple comparison, Ryan's method also shows significant differences between the motion and the LED (diff.=0.562, RD=0.492, $P=0.00568$, $\alpha' = 0.0167$) and between the motion and the beep (diff.=0.477, RD=0.444, $P=0.0221$, $\alpha' = 0.0333$). Fig.8 shows the appearance of a experiment. Participants sat on the chair and helped the robot on the desk.



Figure 8: The experimental appearance.

5 Discussion

5.1 Generality of our approach

In section 4, we obtained the promising results in the experiments for comparison with other nonverbal methods. However, how general are the results? How widely are the results applied to? The answer mainly depends on the generality of an obstacle-removing task. As we mentioned before, a robot frequently and easily needs the obstacle-removing in cooperative tasks between a human and a robot. Thus we consider the obstacle-removing task to be general in the cooperation of a user and a robot.

On the other hand, for other tasks without obstacle-removing, we may need to design another motion. We consider that the ethological policy can be applied to other complicated tasks.

5.2 Manual free design

Users need to read manuals of machines when they buy those newly or want to use those more conveniently. However, reading manuals forces us to impose a high workload. It is better for a user to discover robot's functions easily and naturally without reading manuals.

The results of our experiments shows that the motion-based indication enables users to understand robots' mind easily. We then consider the motion-based indication to be useful for making manual free machines, and are currently constructing the procedure of discovering robot's functions naturally without reading manuals. The procedure is composed of

three steps: (1) indication of robot's mind, (2) action of its user, (3) reaction of the robot. The discovery of robot's functions is achieved when the user finds the causality between a user's action and a robot's one in the steps. Our experiments satisfy the step (1) and (2), and the motion-based indication could contribute for human to discover such causality easily.

6 Conclusion

We proposed a motion-based method for informing a user of a robot's mind in a nonverbal way. There are various nonverbal approaches like motion, sound, lighting and so on. We developed a motion-based informing as the best way in terms of the feasibility and the effectiveness. Then an obstacle-removing task was introduced as a general task for cooperation between a human and a robot, and we designed the back-and-forth motion to inform a user of robot's mind to request removing an obstacle. The motion is designed according to ethological policy. Eventually, we conducted experiments in comparison with other nonverbal methods, and obtained promising results.

References

- [1] S. Baron-Cohen, *Mindblindness: An Essay on Autism and Theory of Mind*. MIT Press, 1995.
- [2] T. Watanabe, M. Okubo, and M. Inadome, "Virtual communication system for human interaction analysis," in *Proc. of the 7th IEEE International Workshop on Robot and Human Communication*, 1998, pp. 21–26.
- [3] T. Komatsu, "Can we assign attitudes to a computer based on its beep sounds?" in *Proceedings of the Affective Interactions: The computer in the affective loop Workshop at Intelligent User Interface 2005 (IUI2005)*, 2005, pp. 35–37.
- [4] T. Matsumaru, K. Iwase, K. Akiyama, T. Kusada1, and T. Ito, "Mobile robot with eyeball expression as the preliminary-announcement and display of the robot's following motion," *Autonomous Robots*, vol. 18, no. 2, pp. 231–246, 2005.
- [5] T. W. Fong, I. Nourbakhsh, and K. Dautenhahn, "A survey of socially interactive robots," *Robotics and Autonomous Systems*, vol. 42, no. 3–4, pp. 143–166, 2003.
- [6] Y. Kuniyoshi, M. Inaba, and H. Inoue, "Learning by watching: extracting reusable task knowledge from visual observation of human performance," *IEEE Transactions on Robotics and Automation*, vol. 10, no. 6, pp. 799–822, 1994.
- [7] M. Nicolescu, M.N. and Mataric, "Learning and interacting in human-robot domains," *IEEE Transactions on Systems, Man and Cybernetics, Part A*, vol. 31, no. 5, pp. 419–430, 2001.
- [8] T. Ono and M. Imai, "Reading a robot's mind: A model of utterance understanding based on the theory of mind mechanism," in *Proc. of Seventeenth National Conference on Artificial Intelligence*, 2000, pp. 142–148.
- [9] D. C. Dennett, *The Intentional Stance*. MIT Press, 1987.
- [10] K. Terada and T. Nishida, "An active-affordance-based method for communication between humans and artifacts," in *Sixth International Conference on Knowledge-Based Intelligent Information and Engineering Systems (KES'02)*, 2002, pp. 1351–1356.
- [11] T. Sato, Y. Nishida, J. Ichikawa, Y. Hatamura, and H. Mizoguchi, "Active understanding of human intention by a robot through monitoring of human behavior," in *Proc. IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS'94)*, 1994, pp. 405–414.
- [12] P. J. B. Slater, *An Introduction to Ethology*. Cambridge University Press, 1985.
- [13] R. C. Arkin, M. Fujita, T. Takagi, and R. Hasegawa, "An ethological and emotional basis for human-robot interaction," *Robotics and Autonomous Systems*, vol. 42, no. 3–4, pp. 191–201, 2003.