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THE HRI EXPERIMENT FRAMEWORK FOR DESIGNERS

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ABSTRACT:

In the robot development, the level of technology and stability is recognized in a different way from the real elements of robot mechanisms through interaction design. So robot designers research on not only appearance design but also interaction design based on an understanding of HRI.

This study focused on robot designer's experiment and suggested a framework for efficient experiments planning. Through our case studies of several robot design projects, this framework was found to help designers overcome lacking of technical knowledge and easily determine and solve design-centered HRI problems.

Several case studies reveal that our experiment framework for designers can leaded to significantly better performance and less effort than other technically complex HRI experiment which employ fully functioning prototype. Some practical tips described in case studies showed

that our experiment framework enables designers, even non-experts, to quickly create and test HRI prototypes and makes designers lead HRI developing process.

1. INTRODUCTION

Social robots, whose potential has been widely recognized by researchers and industries, have not only contributed to an expansion of market size but also helped promote a wide variety of interdisciplinary studies. Among them, the field of robot design delivers the high-end technology of robotics to those users who have yet to experience robots in communication media suitable for their daily lives (Kim, et al. 2006). The importance of robot design has been growing daily, for it imagines revolutionary products such as robots, within a range that allows application to people's daily lives and one step ahead of other disciplines.

Meanwhile, robots are recognized by users in different ways depending on the interaction systems applied even when the same technologies are utilized. So research on human-robot interaction (HRI) has an extensive impact on the entire process, from setting the concept of a robot to designing its exterior accordingly. Therefore, a robot designer has to have a thorough understanding of HRI as well as exterior design work. While the robot design process proceeds on this basis, the designer should continue to experiment and examine whether the designed HRI system is applicable to the final design plan.

Unfortunately, the robotics expertise required to build HRI systems interrupts designers to participate in the HRI design process. Furthermore, the enormous costs and time required to build even a simple moving appliance make it difficult for designers to plan for HRI experimentations.

To overcome difficulties faced in conducting HRI research, this study first sought to understand the design process of robots and define user-oriented HRI. With understanding HRI experiment, the limits of robot designers, who perform HRI experiments, were identified. And a framework for HRI experiments was suggested to overcome such limits. Also, case studies were conducted to verify the effectiveness of the framework.

2. ROBOT DESIGN PROCESS

At the point of product-designer's view, whole robot design process is divided into three groups roughly: character design, appearance design, and interaction design (Oh, J. Kim, M. Kim 2005): (Fig. 1). This is based on the properties of social robots: form, modality, social norms, autonomy, and interactivity (Bartneck 2004)

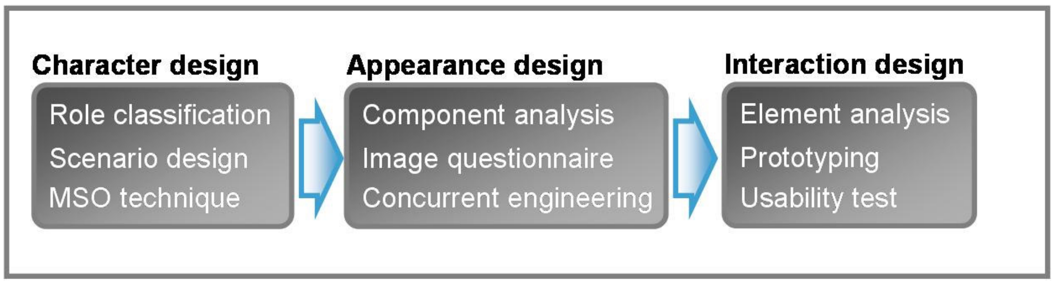
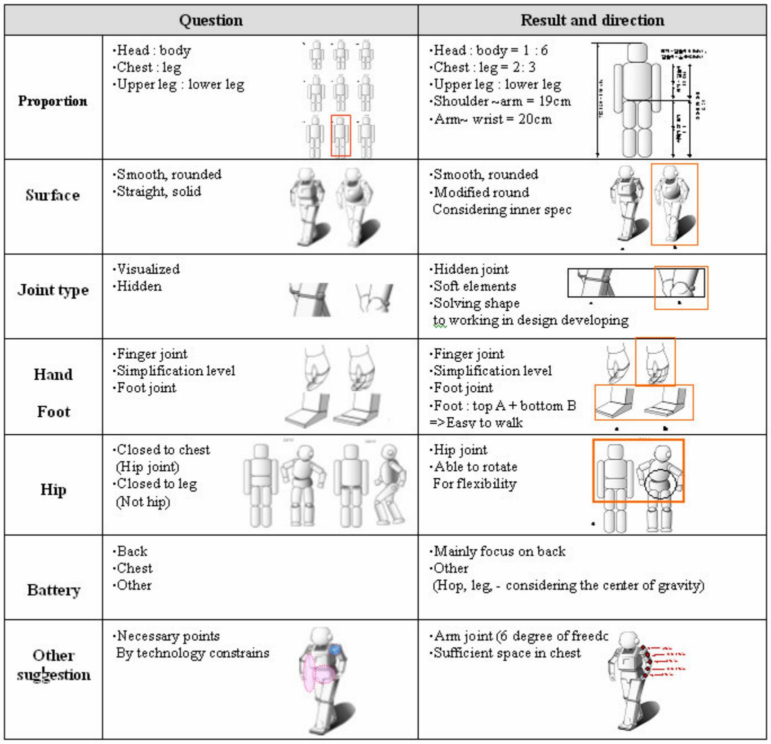


Figure 1: Robot design process

In character design stage, the designer defines the role and characteristics of the robot by using scenario methodology like as MSO techniques. Appearance design refers to the design of the exterior style of the robot. This design stage includes structure as well as mechanisms, shape, material, and color. In contrast to widely used sequential process such as a first engineering-second designing approach, robot designer often apply the concurrent engineering method, which could help smooth communication between the design team and engineering team: (Fig.2).



	Question	Result and direction
Proportion	·Head : body ·Chest : leg ·Upper leg : lower leg	·Head : body = 1 : 6 ·Chest : leg = 2 : 3 ·Upper leg : lower leg ·Shoulder ~arm = 19cm ·Arm~ wrist = 20cm
Surface	·Smooth, rounded ·Straight, solid	·Smooth, rounded ·Modified round Considering inner spec
Joint type	·Visualized ·Hidden	·Hidden joint ·Soft elements ·Solving shape to working in design developing
Hand Foot	·Finger joint ·Simplification level ·Foot joint	·Finger joint ·Simplification level ·Foot joint ·Foot : top A + bottom B => Easy to walk
Hip	·Closed to chest (Hip joint) ·Closed to leg (Not hip)	·Hip joint ·Able to rotate For flexibility
Battery	·Back ·Chest ·Other	·Mainly focus on back ·Other (Hop, leg, - considering the center of gravity)
Other suggestion	·Necessary points By technology constrains	·Arm joint (6 degree of freedc ·Sufficient space in chest

Figure 2: Image questionnaire for communication between the design team and engineering team (Oh, 2005)

Human-Robot Interaction design is a process of determining the robot's appropriate behavior model and designing visual, auditory, and haptic interaction. With extensive understanding of overall hardware and software, robot designers should imagine and test how information channels, such as buttons, touch panels, camera, speacker and microphone, will work in human-robot interaction scenario. For this reason, designers are required to make experiments through various simulation techniques such as prototyping in interaction design process.

Natural interaction system is bulided by iterative design process rather than single-trial. Thus designers need to keep trying to find user requirements and apply these to their design through the circulative HRI test and evaluation. User-centered HRI system can be accomplished through designers' understanding of not only technical performance but also emotional effects on robot users eg; the style and way robot system listen, thinking and talk.

3. USER-CENTERED HRI

Interaction should be designed based not on the development of specifications and technologies but on an understanding of users' needs and environments. This is the essence of user-centered design, and this principle is also applied to HRI design of robots.

Research on interactions between humans and robots can be seen from three perspectives. First is robot-centric research on interactions. This is how robotic engineers view HRI; most robot-centered studies focus on robots' perception and cognition of humans and related action (J. Kim, M. Kim 2005). Rodney A. Brooks, Cynthia Breazeal and others at MIT are prime examples of robot-centric interaction researchers who focus on robot control and implementation technologies.

The second perspective is system-oriented interaction research. This form of research is mostly carried out by computer engineers, who observe how a knowledge database is built and utilized in an HRI environment. The focus is on systems where humans and robots can interact, such as overall robot-operating environments and information flows. Ubiquitous robotics falls into this category.

The third is user-centered interaction research, which is focused more on how humans perceive and cognize robots, and act on their interactions with them, than on how robots view humans: (Fig.3). This is research on interactions from the perspective of robot designers rather than robot engineers. These designers aim at studying emotional bonds or feelings that users develop using robots in the real world, as robots penetrate humans' daily lives more deeply than other products and bring about multidimensional changes in their lives.

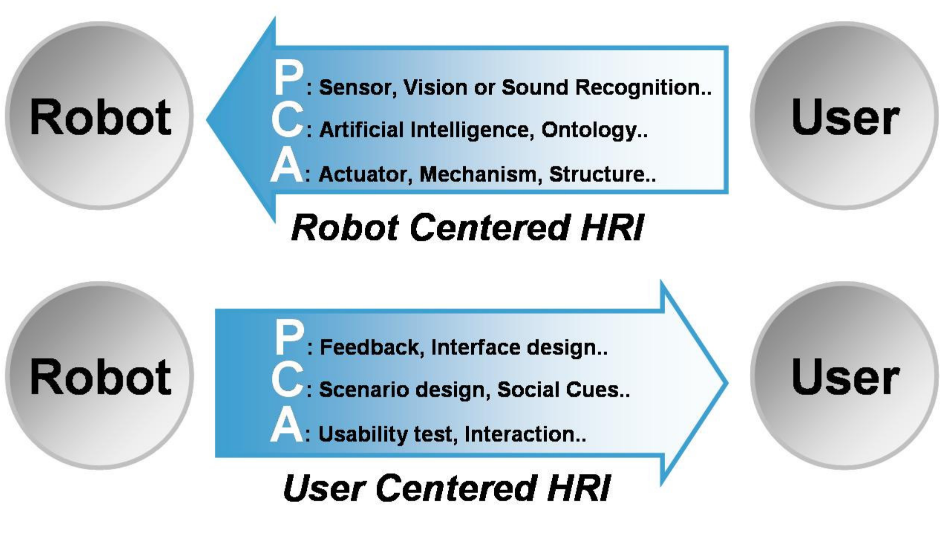


Figure 3: User-centered HRI element.

For instance, robot-centered HRI research aims at facilitating robots to better perceive users, resemble human facial expressions, and effectively deal with tasks given. User-centric HRI research, on the other hand, is different in that it seeks to nurture spontaneous intimacy between users and robots while they cooperate on tasks such as puzzle games or watch TV together. This is because the human-like qualities of a robot are more suitable for carrying out emotional tasks with humans than for efficiently performing work.

4. HRI EVALUATION AND PROTOTYPING

Closely related to the overall image of a robot and implementation of its actions, user-centered HRI should be studied from the initial stages of development. Most robots, however, have been developed without consideration of the HRI needed from the perspective of users; these robots often contradict users' requirements or expectations. Therefore, designers should first identify the interaction needs of users and then design the HRI on this basis. As most users have no experience of using robots, however, interviews alone are not sufficient to determine their actual needs, and thus sophisticatedly-constructed experiments for observing their inner selves as they interact with actual robots should be conducted. This is why robot designers must conduct HRI experiments.

Unlike human-computer interaction (HCI), HRI has such characteristics as a sophisticated cognitive environment, technology intensity, mobility, action-based interaction, object recognition-based artificial intelligence, a multi-user concept, a human-like exterior, and implementation of physical functions. Designed in consideration of such aspects, HRI experiments should be conducted on robots or other products performing similar functions to those of robots. Furthermore, interactivity—the degree of interactions—is calculated as continuous varied values, rather than being classified as either true or false, and is determined by the objects' dialogic attributes. Therefore, HRI experiments require experiment settings where continuous interactions between users and robots can be induced and observed.

In reality, however, it is very difficult for designers to produce robots. Owing to insufficient knowledge of the users, they fail to explain multi-dimensional interactions and interfaces to the users with their two-dimensional pictures of robots alone.

This is why prototyping techniques are utilized to partly reflect functions of robots in terms of their exterior, acting functions, and cognition. Compared to actual production of robots, prototyping is easier to be made, and it also suggests in advance future outcomes of a design. By demonstrating the functions that can be made possible and locating where technical defects exist, the technique leads to creative and substantial ideas.

Bartneck's research provides insight into several prototyping techniques for HRI experiments (Bartneck 2004). He divided prototypes based on two axes. The horizontal axis represents the level of exterior completion; it depends on the level of fidelity. The vertical stands for functional levels and is determined by the level of artificial intelligence and implementation of movements. He suggested such techniques as scenario, paper mock-up, mechanical mock-up, and Wizard of Oz (WOz). In the WOz technique humans perform operations to complement the insufficient intelligence of the system; it is very useful in simulating cutting-edge technologies, such as ubiquitous and wireless network environments.

5. HRI EXPERIMENT FRAMEWORK FOR DESIGNER

Although there are several applicable prototyping techniques, most robot designers have relied upon 2D or desktop-based work that falls short of fully materializing the attributes of robots.

This is partly because it is still difficult to produce robot prototypes that meet the requirements of users in terms of HRI. The more fundamental reason, however, is that these designers are not accustomed to setting questions and environments for HRI experiments. Definition of problems and formulation of hypotheses as predicted results are the keys to experiment design. Nevertheless, these aspects have been largely neglected, as it remains unclear what problematic areas for robots can be dealt with by designers. Under such circumstances, designers' HRI experiments have ended up as one-time, local events.

Most HRI experiments conducted thus far have been led by robot engineers with the aim of mechanically identifying human responses from interactions. For instance, experiments have been carried out to analyze emotional changes in humans based on fMRI results or oxygen-hemoglobin levels.

As designers conduct HRI experiments for purposes different from those of engineers, they should take a different approach from the very definition of problems. That is, the outline and framework of experiments for designers should be developed in advance.

Robot designers conduct HRI experiments to determine three elements. The first is related to the exterior of robots; it pertains to emotions felt from the robots' exterior shapes or actions. Studies on the shapes and proportions that users feel are adequate for the character and role of the robots have been carried out, as well as research on what kind of materials will are suitable for given purposes of using robots. One example is research on the level of human-likeness depending on robots' exterior elements and on uncanny valleys.

The second is research on the usability of robots. These studies address whether the implementation of robots' physical functions is safe to users and how input/output devices should be set to ensure effective interactions. Robots' movements are basically operated by users, but they demonstrate qualitative differences from other existing products in that they autonomously perform functions on the basis of dialogues with users and identification of circumstantial elements. Therefore, it is necessary to observe harmonization with users rather than mere ease of operation.

The third is research on social contextuability that users gain from their interactions with robots, such as intimacy, bond, trust, and emotions. These studies investigate changes in humans' role setting, life patterns, and values resulting from the inclusion of robots in their daily lives. The human facial features and body elements given to robots' exterior shapes have significant impacts on the cognition process of users. Therefore, experiments should be conducted over long periods of time in specially-designed social settings such as role plays.

The three experiment elements described above are in line with what Norman referred to as the three leves of design: behavioral, visceral, and reflective (Norman 2002).

By clarifying such ultimately sought-after elements and setting manipulatable independent variables for designer-led HRI evaluation experiments, it is possible to conduct effective HRI experiments only with low-fidelity prototypes.

The framework for designers' HRI experiments is significantly different from that for robot engineer-led frameworks, which aim at identifying the very variables representing the HRI's impact on the perception and actions of robots and users. For instance, designers regard subtle robot-human interactions and the resulting impacts as unknown functions. They analyze the output information from the independent variables (input information) and seek to identify user requirements existent in the functions. The framework for HRI experiments suggested here is shown in the Figure 4.

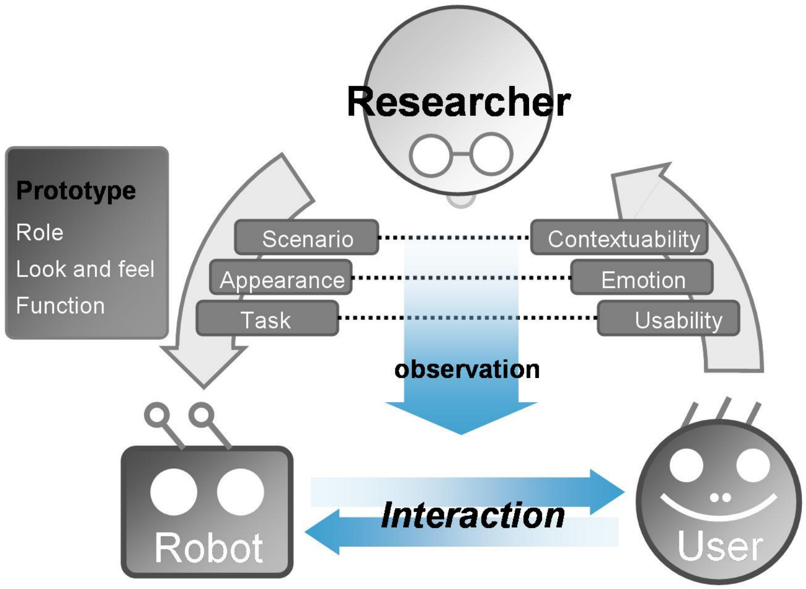


Figure 4: HRI experiment framework for robot designers.

Emotions based on robot's exterior shapes, robot usability, and social contextuability—seen in the left of the figure—are output information that designers ultimately seek to understand. For this purpose, the designers can put such operational elements (or independent variables) as appearance, task performance, and scenario into the HRI experiment system as input information.

To apply each of the independent variables to the system, prototypes tailored to each element are developed and utilized in experiments. A 'look and feel' prototype needs to be devised to test users' emotions depending on robots' exterior shapes. This prototype is a visual expression of whether or not there are exterior elements and the proportional relations between them. A 'function' prototype is for performing intended functions and thereby identifying users' robot usage patterns; designers can conduct research by carrying out task performance experiments (e.g. first-letter-last-letter game, puzzle games). The 'role' prototype is designed to understand the context of robot usage; a prime example of experiments using this prototype is storyboard and other scenario-based techniques. By allowing users to imagine how they use robots in the future, the prototype identifies requirements with regard to social contextuability.

The framework for HRI experiments using the aforementioned three prototypes is easy to produce and analyze in areas observable for designers, because the experiments' independent variables and the resulting dependent variables are design-based elements.

6. HRI EXPERIMENT PROCESS

HRI experiments require thoroughly considered experimental environments, as they observe human perception and actions in their responses to robots. It should be noted that due to novelty effects, users interacting with robots for the first time tend to show excessively positive results in all items.

Designers' HRI experiments consist of three major stages. The first is the problem-setting stage, where, on the basis of the framework, it is determined what will be observed during the experiments and what observation technique will be applied. In this stage, not only the experimental settings should be defined but also research hypotheses, the period of experiment, the location for the experiment, and experiment subjects should be taken into consideration. For experiments regarding teacher assistant robots, for example, it should be determined what interactions are pursued from children, whether the experiments will be performed in elementary school, which schoolchildren (i.e. what grade) will be subject to the experiments, and what role will be given to the robots.

The second stage is experimental settings. "Fake automata" is relatively useful tool for designers who generally find it difficult to build technically functioning prototypes capable of making autonomous movements: (Fig. 5). Fake automata is quasi-intelligent robot that experimentor control on behalf of robots intelligence. Through fake automata, Designer can test HRI conept and observe responses of subjects quite easily without limitation of technical feasibility of robot system.

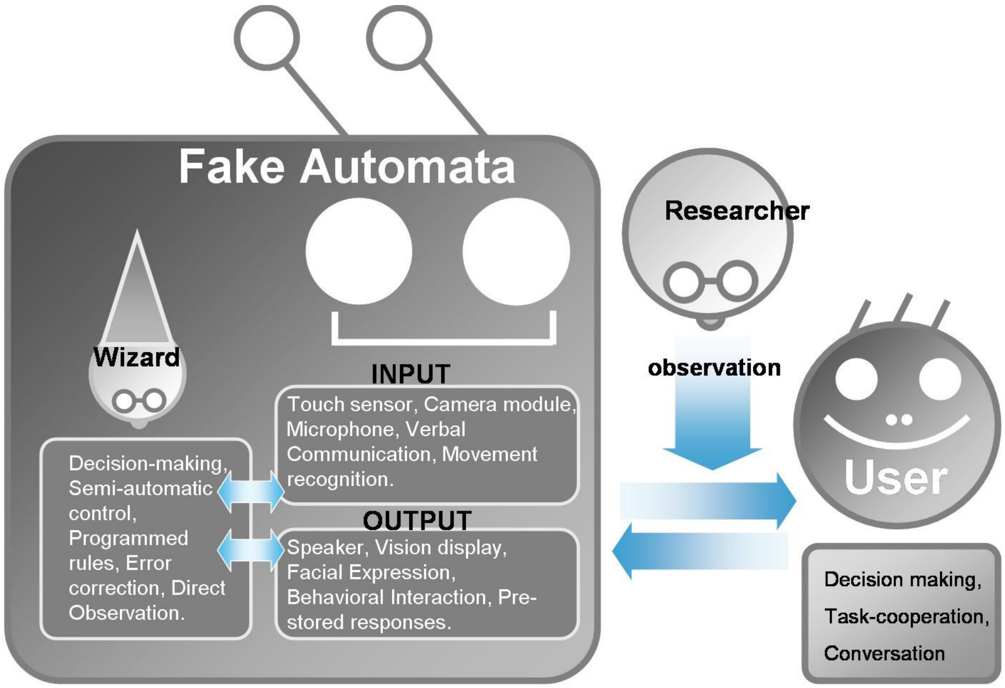


Figure 5: Interaction system through Fake automata.

Fake automata is closely related with WOZ technique; the general WOZ technique is very useful in case of macroscopic environment for experiment that people control the device. However, in general WOz it is impossible to presicly manipulate the environment in the experiment such as eye gaze interaction between robot and human. Fake automata can overcome the problem of the general WOZ; in the technique of Fake automata, a wizard takes a role of robot itself and direlctly use his voice and body from the perspective of robot. Therefore he can react intelligently according to user's situation and find their microscopic needs.

According to aspects designer want to test in the experiment, Fake automata can be divided into 3 categories; ‘look and feel’ prototype, ‘function prototype’, and ‘role’ prototype.

In the HRI experiment, it is quite important to set up the environment for observation as well as build robot prototype. In case of multiple subject experiment, appropriate environment is required to control their experience with robot for the removal of novelty effect. Meanwhile, in the course of the experiment, well-structured observation system such as one-way mirror and video camera should be equipped in the experiment environment. An experimentor can observe user's behavior pattern or unconscious activities with robot ; accidental change of facial expression against unexpected motion of robot prototype that it is hardly possible to grasp in the questionnaire.

The third includes experiments and data analyses. An important thing in the experiment using Fake automata is making participants recognize the fake automata as intelligent robot through appropriate explanation and warm-up session prior to main experiment. Regardless of the age of participants, experimentor need to make them naturally understand its restricted functions and induce them to react and think in the range of pre-designed functions.

Prior to the experiment, the explanation process can helps participants to be efficiently immersed in the HRI experiment. On the other hand deceiving participants can occurr quite frequently in the situation of Woz technique and this kind of circumstances can result in morality problems in research.

The role of wizard is also important. The discretion of the wizard should be adjusted according to the experiment. Whether wizard will perform the function of pre-programed system or controll some interaction in the range of designated interfaces or all of interaction need to be decided. Accordingly the number of wizards and expertise of wizard should be considered in designing experiment.

Contrast to human computer interaction, human robot interaction occurrs so widely in dimension and modality that data generated during the experiment are diverse and complicated. Data collected from video camera installed in robot and over the one way mirror by wizard and questionnaire which is gathered before and after experiment has to be analyzed systematically and comprehensively by using several standards. Also motion and gesture of user and robot has to be considered on the basis of standard anaysis factors such as activity, information, environment, communication, and context.

7. CASE STUDY

A number of case studies were conducted on the basis of the HRI experimental framework and process for designers. In these studies, adequate prototypes were developed and applied for experiments for each different goal. Through the case studies, it was verified that the framework suggested in this paper helps designers understand the problems with HRI and understand the requirements of users.

7. 1. FORM DESIGN FACTORS OF TEACHING ASSISTANT ROBOTS

In this research, Ryu sought to determine a combination of exterior form elements for an assistant robot to which elementary school students felt they could correspond with in the role image of a teacher (Ryu, 2007). She developed “look and feel” prototypes for this: (Fig. 6).

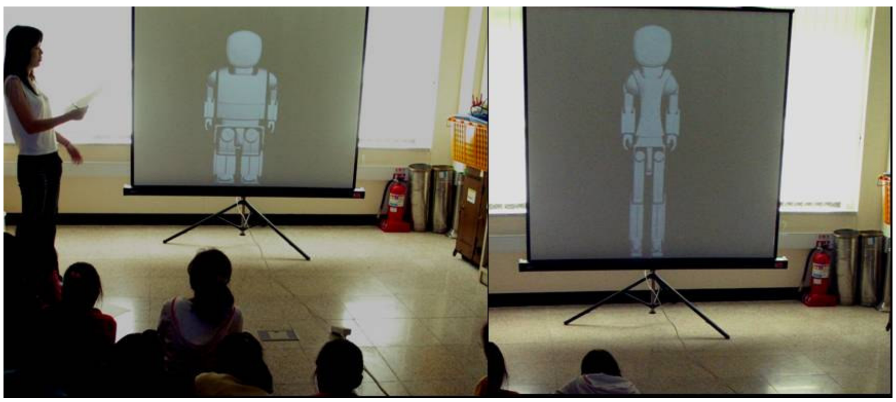


Figure 6: Look and feel prototype (2D projection image of 3D modeling).

Initially, several robot models with various proportions were designed using 3D modeling. Turn table animations, from those 3D modeling images were then projected onto a movable 2D screen. This process allowed children (the participants) to see robot images of the actual size and volume. It was effective to the extent that most of the children recognized projected images as real robots.

Explanations and practice regarding appearance estimations before an experiment can help children match visual elements (appearance) and abstract elements such as role character images. However, this experiment utilized only a questionnaire; this was a weak point in that no observing data was collected regarding the reactions of the children, such as those concerning the size of the images on the screen.

Through this experiment, it was noted that robot prototyping without the physical embodiment of a robot can be completed effectively using computer modeling, augmented reality (AR), and mixed reality (MR) techniques.

7. 2. IDLE FEEDBACK FOR EMOTION EXPRESSION OF ROBOT

In this research, Lee sought to apply biological signals to the emotional expression of a robot (Lee 2007). To do this, a 'function prototype' was built that could express emotion on its face: (Fig. 7). This prototype was composed of a LCD board and the shell of the existing robot 'Hubo', which enhanced the immersion of participants in their interactions with the prototype. Through this research, it was observed that circumstances such as the working sound of the servo-motor affected the concentration of the participants in the HRI experiment.

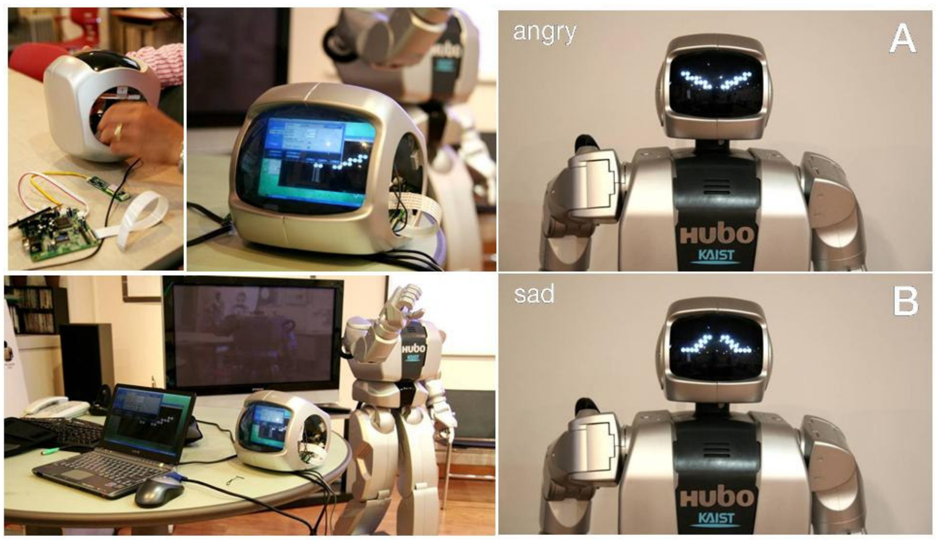


Figure 7: Function prototype (composed of a LCD board and the shell of a real robot).

7. 3. THE REQUIRED TIME FOR SMILING

This research aimed at seeking methods to increase the 'humanness' of the robot by facial expressions (Choi, Oh, and Kim 2006). To that end, Choi conducted experiments to determine the relationships among the time required for the transformation of facial features, the degree of external stimuli, and other elements. To do this, a box-like robot prototype was designed that could express its own emotions: (Fig. 8). The prototype, classified as a 'function prototype', increased the effectiveness of the experiment using a LCD monitor, although detail quality was not high.

Nevertheless, the participants could not fully concentrate due to lack of pre-explanations concerning the experiment. An experiment involving robots should guide the focus of participants carefully in an effort to help them keep track of the diverse traits of the robot. Especially with experiments that are related with expression or emotion, scenarios concerning why the robot expressed a particular emotion should be explained, as there are great differences between merely looking at specific images of facial expressions and understanding the entire context in which a robot is placed.

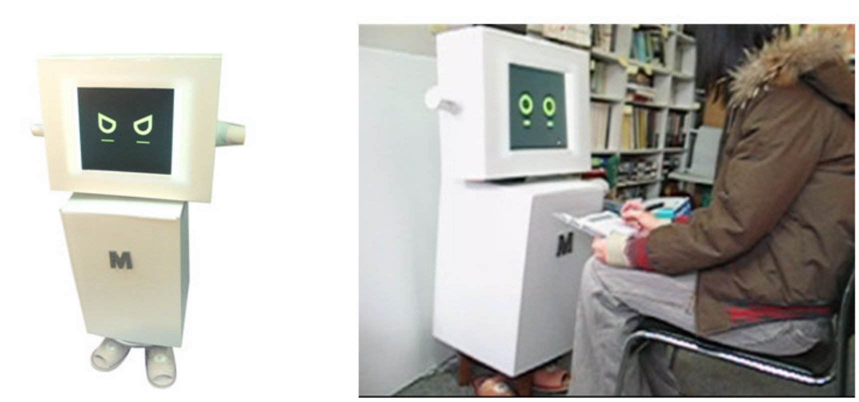


Figure 8: Function prototype (emotion expression robot).

7. 4. CHARACTER OF TEACHING ASSISTANT ROBOTS

In this research, three different types of robots, 'Ching-chan-ee', which gives 'positive reinforcement', 'Um-bul-ee', which gives 'negative reinforcement', and 'Sang-bul-ee', which gives both 'positive and negative reinforcement' were designed based on reinforcement theory and the token reinforcement system (Kwak, et al. 2006). Task performance, preferences, and physical intimacy were measured according to the types of robots and the types of participants.

For accurate comparisons, it was necessary to create a consistent scenario for each type of characteristics that could be recognized by children intentionally. A robot prototype with features of a ‘function prototype’ was necessary to make facial expressions and verbal communication for intuitive interactions with children.

Thus, Kwak created a ‘role-prototype’ using a storyboard method to translate an abstract image of characters into a scenario that could be easily understood by children: (Fig. 9). This process increased the level of understanding and concentration of children by helping them imagine the coexistence of children and the robot in everyday life.

Figure 9: Role prototype (storyboard).

A ‘function prototype’ was also created that utilized an embedded a remote-controllable PMP (portable multimedia player): (Fig. 10). This prototype could talk and make facial expressions through flash animation. The experiment was designed to allow character-dependent interactions between a robot and a child while the children were studying mathematics. Statistically significant differences in terms of motivation or accomplishment were found depending on the characters.

Figure 10: Function prototype (including the remote-control PMP).

8. CONCLUSION

Robots are a product as well as an icon of modern technology. Thus, the social effects and functions induced by their form should be taken into consideration. Additionally, these considerations cause robot designers to be more responsible for determining the concept of robots than robot engineers, who are likely to be more focused on the development of robot technology. For this reason, designers should plan HRI interaction experiments and observe the reactions of users in order to grasp their requirements.

In the present study, an experimental framework and process is suggested for robot designers who want to test and evaluate their HRI design efficiently. In the proposed framework, the categories of HRI prototypes are summarized into several types, as the outputs designers want to derive from the experiment are pre-defined. These are prototypes according to emotions based on the exterior shape of a robot, robot utility, and the social context.

On the basis of the proposed framework, case studies from robot design projects were introduced. These case studies can be seen to forecast changes of the social value and lifestyle as these concepts pertain to robot technology, and give designers interesting insights with which to draw future robot scenarios.

As HRI experiments conducted by designers are generally during the iterative stages of building and testing rather than the finalization of the system, 'Fake automata' with what is known as the Wizard of Oz (WOz) technique was applied at a low-fidelity level. Fake automata based on the framework were effective in the experiment to discover design problems in the case studies. In addition, the experimental process suggested in this paper provided beneficial information related to determining and examining the defects of each experiment. Particularly, Fake automata had the advantages of helping the experimenter observe the situation from the viewpoint of a product (robot), thus immediately grasping the details of interaction and inducing the interest of the participants to move to the intended elements in changeable situations.

The ultimate purpose of HRI experiments for designers is to elicit the needs of users rather than to enhance technical fidelity of prototypes. Thus, further study will be focused on the development of an analyzing tool to extract essential needs from collected data. The analyzing tool will include a flexible framework that can control the criteria of analyses, such as the input, output, content, and environment. Moreover, the tool should allow designers to alter its properties.

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