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Research Article

Development of a Pictogram-Type Interface for Service Robots Based on the Concept of Human-Centered Design

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Abstract:
In recent years, service robots have found applications in various sectors, including healthcare, food and beverage, and logistics. Service robots may experience decreased productivity when exposed to environments different from their design environment. To address this problem, designers must develop service robots using human-centered design (HCD) along with agile development methodologies. However, few studies have applied HCD and agile development methodologies in the design of "service robot-delivered services". This study proposed an agile development interface based on HCD using a combination of pictograms and augmented reality (AR) markers. Experiments confirmed the effectiveness of the interface and the tendency of the subjects. Groups with varying levels of robotics knowledge were asked to teach a robot. Based on the results, it was confirmed that the group without knowledge of robotics tended to teach the robot through repeated trial and error. Therefore, the effectiveness of the proposed interface was confirmed.

Keywords: *Service robots, Human-Robot interaction, Human-Centered design, Agile development, ROS 2, Pictogram*

1. Introduction

In recent years, Japan has been facing an issue with a decline in productivity as a result of its shrinking working-age population. According to estimates [1], the working-age population is expected to decline from 75.96 million in 2017 to 59.78 million by 2040. Service robots are being utilized in various industries to supplement the productive force, and the sales of service robots are increasing by 41% annually [2]. However, there have been verified cases where service robots have been deemed disadvantageous in their surroundings, rendering them unsuitable for use in certain fields [3]. In such cases, the issue lies in the reduced productivity of service robots. Bhimasta et al. conducted a study to identify reasons why service robots are unpopular among employees and customers by examining the problems associated with current service robots [4]. This study focused on human–robot interactions at the Henn-na Hotel and analyzed online reviews to evaluate the performance of service robots. The results indicated that one of the reasons for the low popularity of service robots was the inadequate consideration of design space by designers. To address this problem, this emphasizes the importance of user evaluations during the design stage. Several studies have also been conducted on user-centered evaluations to identify problems associated with service robots [5-8]. Willis recommended using a human-centered design (HCD) approach to minimize problems encountered in service robots [9]. This study highlights the significance of the HCD process and the required methods to achieve optimal results.

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This study emphasizes the importance of identifying user needs and utilizing flexible prototyping in the development of service robots, as user needs can change dynamically. The development of service robots using the HCD process has been studied extensively [10-14]. However, while several studies have focused on the development of service robots, few have focused on service design of service robots. Service design must consider the needs of end-users to meet their dynamic requirements, and employees should design services for service robots dynamically. Agile development methods [15] are essential for dynamic service design. Currently, robot developers and System Integrators (SIers) design robot services, but employees familiar with the field must also be involved in the service design process. In addition, employees work in diverse sectors, such as medical, logistics, and food services, and a robotic interface must respond to various employee contexts to cover a variety of sectors. To address this issue, this study proposes a pictogram-type interface that can be used in various fields to reflect employee opinions on service design.

2. Human-Centered Design for Service Robot

2.1. Defining the Users in Service Design for the Service Robot

Five possible stakeholders should be considered in the design of service robots. The first is the development of a service robotics company. The second type is SIers, which supports the introduction of service robots. The third category uses service robots. The fourth category comprises onsite employees. The fifth category comprises consumers who receive services. Currently, service-robot development companies and SIers design services for these robots. Onsite employees cannot be deeply involved in the design of operations. However, to properly understand consumers' dynamic needs, employees familiar with the field must be involved in the design of service robots. On-site employees are important stakeholders in the service design of service robots. Therefore, this study defines onsite employees who are unfamiliar with robots or programming as service-robot users.

2.2. Human-Centered Service Design in Service Robot

To date, robotic development has been based on waterfalls. During waterfall development, user opinions are not adequately incorporated into the process, from conceptual to service design. Waterfall development only considers user needs during the concept design phase. In waterfall development, it is difficult for users to improve their UI/UX after the delivery of a robot. Enhance the UI/UX of service robots, developers must identify user needs and usage conditions and incorporate them into the robot design. Therefore, current service robot developers utilize the HCD process [16] to design their robots, as illustrated in Fig. 1, to better address user requirements. Despite the emphasis placed on the design phase, there has been limited discussion on implementing the HCD process in the service design of service robots. Within the HCD process, developers must identify the user and consumer requirements for the functionality of a service robot. Similarly, during service design, the service robot development should consider the needs of both users and consumers. Adopting the HCD process is crucial in comprehending these requirements for service design. In addition, consumer and user needs for service robots are subject to change dynamically. To correctly identify dynamic needs, employees familiar with the field must participate in the service design of service robots. In response to these changing, it is necessary to apply HCD processes and agile development methods to enable flexible and rapid development. Based on the aforementioned information, this study proposes a human-centered service design method for service robots, as shown in Fig. 2.

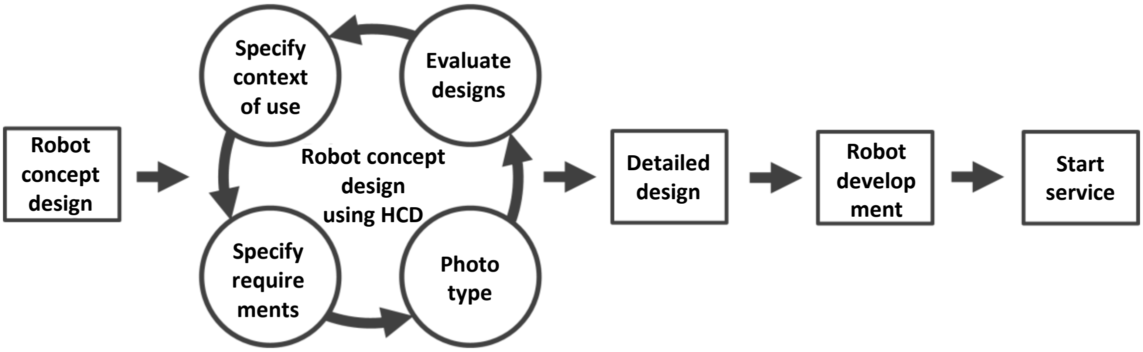


Fig. 1. Conventional service robot design process by HCD [16].

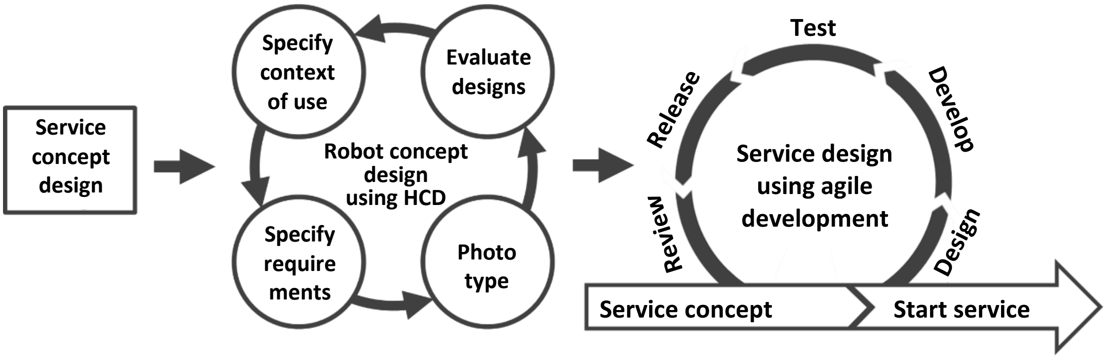


Fig. 2. Proposed Human-centered service design method for service robots.

3. Pictogram-Type Interface

3.1 Interfaces to Accommodate Various User Group

Service robot users work in various fields, including healthcare, logistics, and the food and beverage industry. Additionally, users come from various backgrounds, including those who are not familiar with robotics or programming. Users without knowledge of robotics or programming require a robotic interface that nonexperts can handle. A robotic interface for non-experts is required to design services using an agile approach. In addition, the status of the service robot must be known to ensure effective collaboration. The state of the service robot can refer to its current tasks, routes, and other operational aspects. However, current interfaces do not disclose the state of the service robot in its external environment. Consequently, users have difficulty in actively collaborating with them. As shown in Fig. 3(a), conventional interfaces are limited in their ability to share the status of a service robot with the user. This results in users being passive about the robot's actions because they cannot grasp details such as the robot's tasks and routes. A user-friendly interface should allow for appropriate disclosure of the service robot's status to the user, facilitating active cooperation between the user and service robot.

3.2. Pictogram Marker

To enable users to design services, it is essential to provide a service robot with an intuitive interface that allows them to operate the service robot without any prior knowledge of robotics or programming. This study developed an interface by combining augmented reality (AR) markers and pictograms suitable for non-expert users from diverse backgrounds. AR markers provide an intuitive way for users to operate service robots, while pictograms allow for ease of use regardless of cultural background or knowledge. The pictogram-type interface facilitates clear understanding of the service robot's status, including tasks and routes, as shown in Fig. 3(b). The user can efficiently collaborate with a service robot by knowing its status. Efficient collaboration leads to an increased productivity in service robots. The pictogram-type interface also allows humans and service robots to easily recognize markers.

(a) Conventional service robot interface (b) Pictogram-type interface for sharing information

Fig. 3. Interaction between user and service robots.

3.3. Distributed System for Service Robot

Considering the interoperability of various service robots, we developed a distributed processing system using Robot Operating System 2. The system recognizes AR markers using a web camera and displays the processed image data in a game engine. A block diagram of the system is shown in Fig. 4.

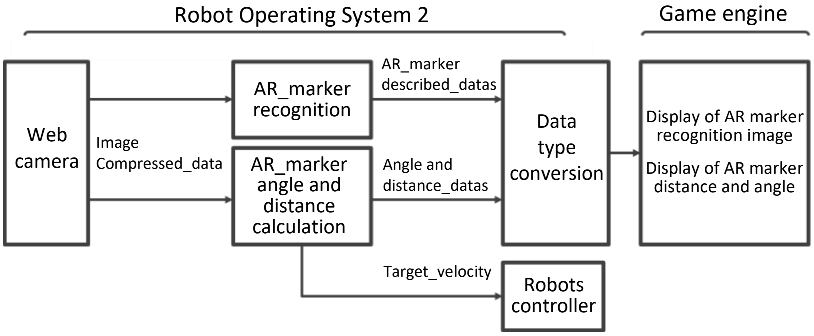


Fig. 4. Distributed system for service robots.

4. Experiment

The following experiment aimed to verify the suitability of using pictograms for service robots; ten participants aged 22–24 years participated in the experiment. The number of subjects was set to 10, based on the methodology of a previous study [17], as the main objective was to evaluate the effectiveness of the interface. Of the 10 subjects, five had no prior knowledge of robots or programming, while the remaining five had knowledge of robots and programming. The participants were asked to perform two service designs for the robot under different experimental conditions. Condition 1 involved designing services using a pictogram-type interface, and Condition 2 involved designing services using a flowchart-type interface. For the evaluation experiment, the time elapsed from the start to the finish of the task was measured, and a questionnaire was administered. The questionnaire used a 7-point Likert scale [18]. The experimental setup is illustrated in Fig. 5. The experimental procedure was as follows.

1. Initially, the participants completed a questionnaire using 15 pictogram markers. The questionnaire asked the participants to rate how well they understood the commands indicated in the pictograms. After the questionnaire, the experimenter explained the interface to the participants.

2. The participants began their work after receiving the “start” signal from the conductor. They initiated the measurement by pressing the stopwatch button and then proceeded to design the service, which in this case was receiving tea from the robot.

3. The participants were tasked with designing a path for the robot to complete the assigned task. In condition 1, they were given 15 pre-prepared pictogram markers to choose from and placed them in the desired locations to create a path, as shown in Fig. 6 and 7. In Condition 2, the study participants used a flowchart-type interface to design the robot’s route by combining four functions, as illustrated in Fig. 8.

4. After designing the route, the participants were able to control the robot.

5. If the robot failed to accomplish a task, the participant started the task again in Step 3. When the task was completed, the participants pressed a button on the stopwatch to complete the measurement.

6. Subsequently, the conductor designed a new service for the robot. The participants were then asked to predict the route the robot would take and where it would arrive. After the participants made their predictions, the conductor controlled the robot to complete the new service.

After completing the aforementioned procedure, the study participants participated in two questionnaires. Figure 9 shows the questionnaires.

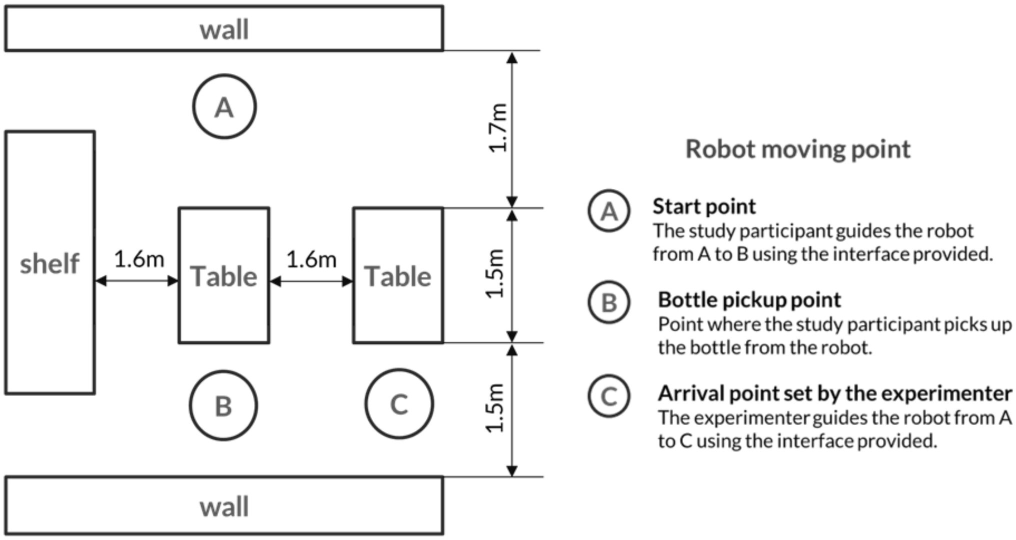


Fig. 5. Experimental setup and robot tasks for tea serving.

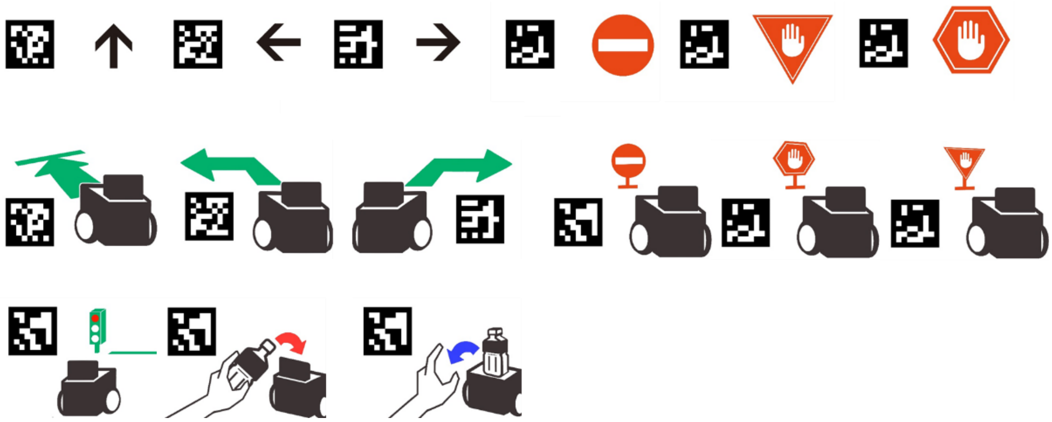
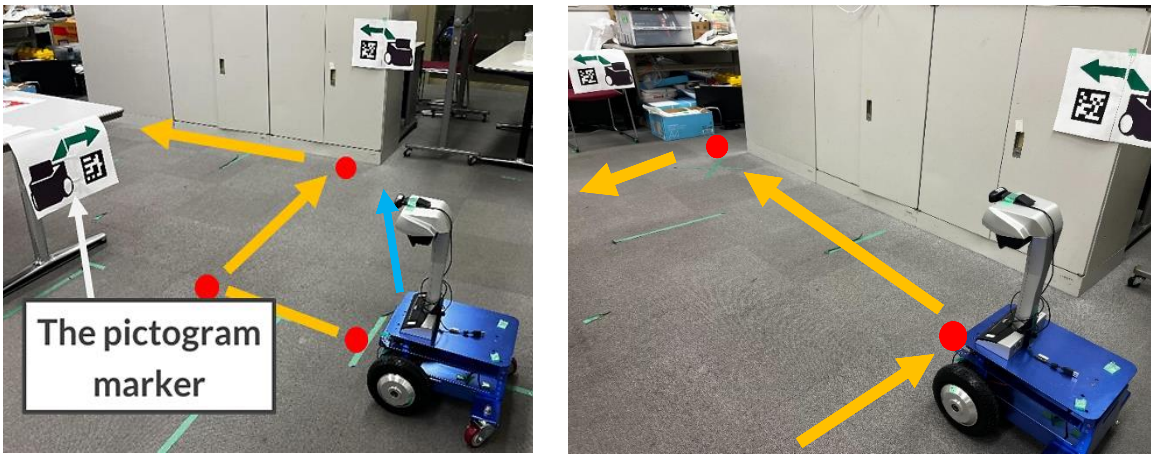


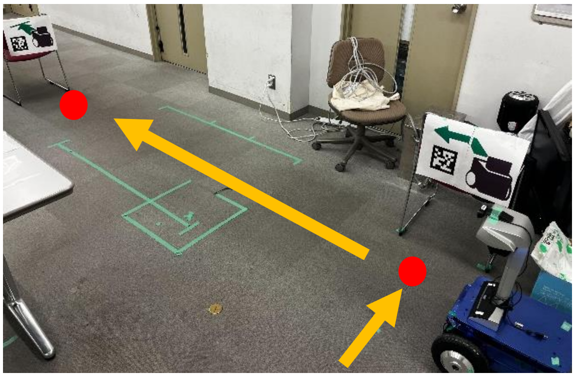
Fig. 6. Proposed pictogram-type makers for service robot path planning



(a) Command the robot to turn right and left

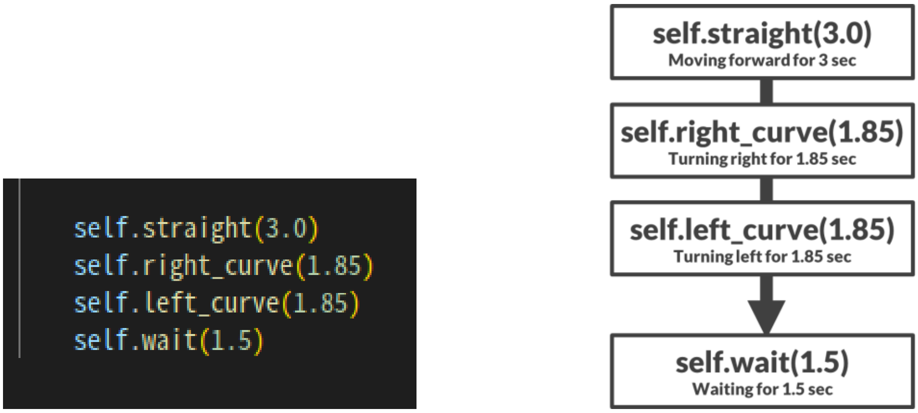
(b) Commanding the robot to the left and left

Fig. 7. Set of pictogram markers for robot path planning.



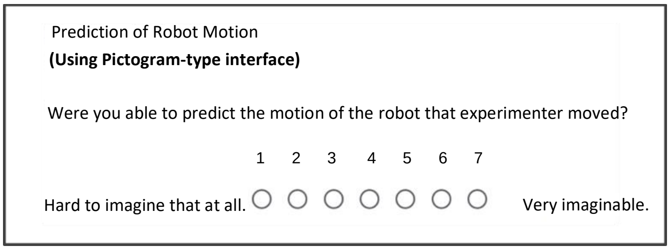
(c) Commanding the robot to the left and straight

Fig. 7. (Continued) Set of pictogram markers for robot path planning.



(a) Prepared program functions (b) Robot path planning using the functions

Fig. 8. Conventional program functions of the flowchart-type interface.



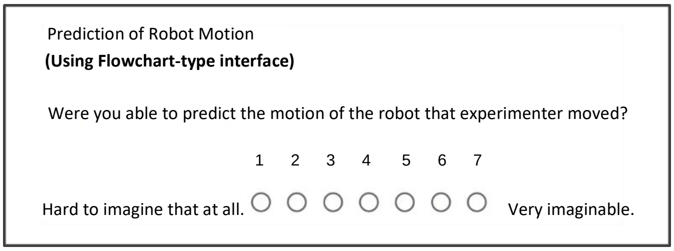
Prediction of Robot Motion
(Using Pictogram-type interface)

Were you able to predict the motion of the robot that experimenter moved?

1 2 3 4 5 6 7

Hard to imagine that at all. ○ ○ ○ ○ ○ ○ ○ Very imaginable.

(a) Questionnaire survey on the robot's status -sharing potential of pictogram-type interfaces



Prediction of Robot Motion
(Using Flowchart-type interface)

Were you able to predict the motion of the robot that experimenter moved?

1 2 3 4 5 6 7

Hard to imagine that at all. ○ ○ ○ ○ ○ ○ ○ Very imaginable.

(b) Questionnaire survey on status-sharing potential of flowchart-type interfaces

Fig. 9. Questionnaire survey on the robot's status-sharing.

5. Results

Figure 10 presents a box-and-whisker plot of the questionnaire results. The questionnaire investigated whether the participants could predict the path of the robot controlled by the conductor. As shown in Fig. 10, the mean of the questionnaire results for the interface was 6.6, while the mean of the questionnaire results for the flowchart interface was 3.4. The results of the corresponding t-tests of the questionnaire scores showed a statistically significant difference (t (18) = 3.17193, p = 0.01133) between the pictogram- and flowchart-type interfaces.

Figure 11 shows box and whisker plots of the measurement time. this portion as the results of the t-test showed that there was a statistically significant difference between the mean measurement times for the pictogram and flowchart interfaces (t (18) = 4.30399, p = 0.00198), with a mean measurement time of 5.39 minutes for the pictogram interface and 11.54 minutes for the flowchart interface.

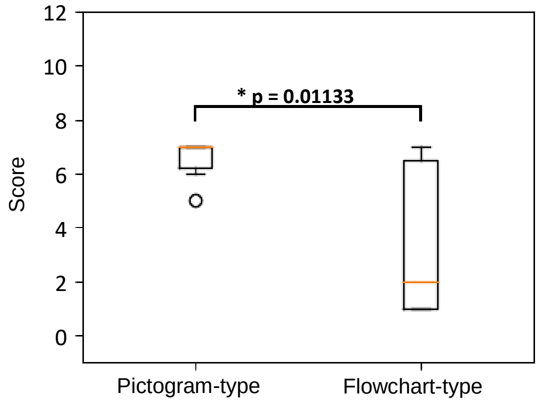


Fig. 10. Total results of robot state prediction

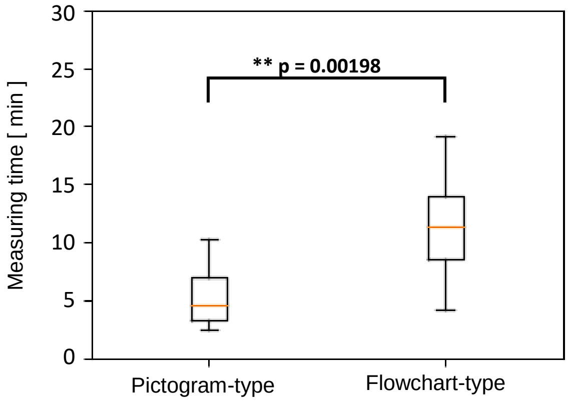


Fig. 11. Study participants' work time

6. Discussion

As shown in Fig. 10, the pictogram interfaces and program exhibited statistically significant differences in robot state sharing. Therefore, the pictogram interface can more easily predict the state of the robot, such as its paths and tasks. This difference can be attributed to the fact that the pictogram interface shared the robot's paths and tasks with the subjects. The proposed pictogram interface shared the robot's path and tasks with subjects who had no prior information about the robot and were in the same room. The subjects understood the path of the robot and predicted its arrival point using looking the pictogram interface. Based on the discussion above, it was found that the pictogram interface effectively conveyed information about the subsequent actions of the robot to a human who was present in the same room as the robot. Sharing a service robot's status with all parties in the field can incentivize active collaboration among employees. Employees can be encouraged to actively collaborate with a service robot by sharing their status with all parties in the field. As shown in Fig. 11, the same statistically significant difference was observed in measurement time, indicating that the pictographic interface was effective in enabling participants without programming or robotics knowledge to use the robot. In addition, the ability for users to design paths simply by placing pictogram markers along the robot's path allows for intuitive and rapid service design using a pictogram-type interface. The results suggest that pictograms can be used to design services that reflect a person's voice and preferences. The study revealed differences between the expert and non-expert groups to designing routes using the pictogram interface. Three experts verified the robot's movement by holding a pictogram marker in front of the camera before designing the route, while the non-expert group began planning the route without checking the movement of the pictogram markers. The study results suggest that the expert group focused on understanding the robot's actual movement, while the non-expert group relied on trial and error to get the robot to work. However, to design better services, non-experts need to have the ability to repeat the trial-and-error process. In this regard, a pictogram-type interface is necessary as it allows non-experts to design service routes intuitively and with ease, facilitating the trial-and-error process in service design.

7. Conclusion

This study evaluated the effectiveness of pictograms in the service design of service robots. In the experiment, a pictogram-type interface was compared with a flowchart-type interface. The experiment consisted of a questionnaire to determine whether the study participants could predict the robot's paths and destination in advance and measure the time required for the study participants to control the robot. The questionnaire results confirmed the statistically significant differences between the two interfaces. The results indicated that the pictogram-type interface shared the paths and tasks of the robot with the study participants, and that the time required to complete the task using the pictogram interface was significantly shorter than with the conventional interface. In addition, the observation of the subjects during the experiment revealed that the elements required for the pictogram-type interface tended to differ between engineers and non-engineers. Specifically, the non-expert group focused on getting the robot to work through repeated trial and error. Therefore, to design better services, it is important for non-experts to have the ability to repeat the trial-and-error process. The study also found that the pictogram-type interface facilitated this process by allowing non-experts to design service routes intuitively and quickly. As a result, the use of a pictogram-type interface can enable employees to develop services more agilely. The human-centered service design methodology proposed in this study has the potential to improve the quality of user services by involving employees in the service design process. By reflecting employees' opinions, services can be better tailored to meet the needs of users. However, it is important to note that the experiment was conducted in a laboratory environment and future studies should be conducted in real-world settings to further validate the findings.

In addition, more pictograms should be developed that are suitable for service robots, as this could improve the efficiency and effectiveness of service design using pictogram-type interfaces. The findings of this study have the potential to contribute to the wider implementation of service robots by highlighting the importance of considering the design of services that incorporate service robots in a human-centered way.

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