ChiCaRo: Tele-presence Robot for Interacting with Babies and Toddlers

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ChiCaRo: Tele-presence Robot for Interacting with Babies and Toddlers

The progress of super-aging societies is decreasing opportunities for interaction between grandparents and grandchildren due to increased nuclear families. This paper reports a tele-presence robot named ChiCaRo, which is designed to promote interaction with babies/toddlers and encourage remote communication between grandparents and grandchildren. We experimentally investigated ChiCaRo's social acceptance with 17 adults and 19 children in a play room environment. The adult participants evaluated ChiCaRo highly in the context of remote interaction with their children. Next we conducted field trials in real home environments with three nuclear families and their grandparents who operated ChiCaRo to investigate its effectiveness. After one-week field trials, the grandparents reported that ChiCaRo encouraged both interaction with their grandchildren and supplemented childcare, e.g., watching babies/toddlers instead of their parents.

Keywords: child-robot interaction; tele-presence; childcare

1. Introduction

For such developed countries as Japan and Germany, falling birth rates and aging populations are huge problems. To tackle them, robotics researchers continue to focus on the physical and mental support of elderly people through interaction with robots: socially assistive pet robots for mental support [1], autonomous wheelchair robots for locomotion support [2], shopping support robots for daily activity support [3], information-providing robots for elderly people in care home environments [4], and tele-operation robots as conversation partners [5].

However, to tackle problems in super-aging societies, both supporting elderly people and increasing birth rates are important issues. Past research reported that supporting childcare is essential to raise birth rates, and the role of such support is often assumed by grandparents [6]. Aging populations increase the number of nuclear families [7], and living apart obviously increases geographic distance, which is a strong factor that reduces the frequency of contact between grandparents and their grandchildren [8] by decreasing the interaction opportunities. In fact, the average period of contact between grandparents and grandchildren is roughly one month or less [9]. Another work reported that the decline in the frequency of contact is accelerating compared to about 40 years past [10]. These factors must be tackled if opportunities for interaction between grandparents and grandchildren are to be increased in the context of childcare support.

Unlike various works that support seniors through robots, relatively scant attention has focused on supporting childcare. A few research works have proposed supporting childcare using robots, e.g., sensor networks and/or wearable sensors to recognize the behaviors of young children (mainly four to six years olds) in kindergarten environments and easing the paperwork burden of childcare workers [11] [12], a robotic toy box that motivates young children to pick up their toys [13], and investigating the social acceptance of robot childcare support systems [3]. Several tele-presence robots are used in preschools and kindergartens [14-19]. These research works developed robots systems and investigated their effectiveness in particular tasks or education support contexts for young children; however, they less focused on increased opportunities for interaction with in home environments. The social acceptance and effectiveness of such tele-presence robots from the viewpoints of parents and grandparents also remain inadequately investigated.

In this research work, we developed a tele-presence robot named ChiCaRo (*Ch*ild-*Ca*re *Ro*bot) that can interact with babies and toddlers and conducted web-based surveys and gathered more than 200 opinions about its appearances and functions. We conducted an experiment with ChiCaRo in a playroom environment to investigate social acceptance toward it from parents/grandparents in the context of remote interaction with babies and toddlers (Fig. 1). Next, we conducted a field trial in real home environments to investigate its effectiveness, i.e., whether it encourages interaction between grandparents and grandchildren, and investigated whether it might be able to support childcare. Thus, this study answers the following questions:

- What features and characteristics are required in a tele-presence robot that focuses on interaction with babies and toddlers?

- Is a tele-presence robot for babies and toddlers socially accepted by parents and grandparents?

- How will grandparents use a tele-presence robot for babies and toddlers in real home environments?

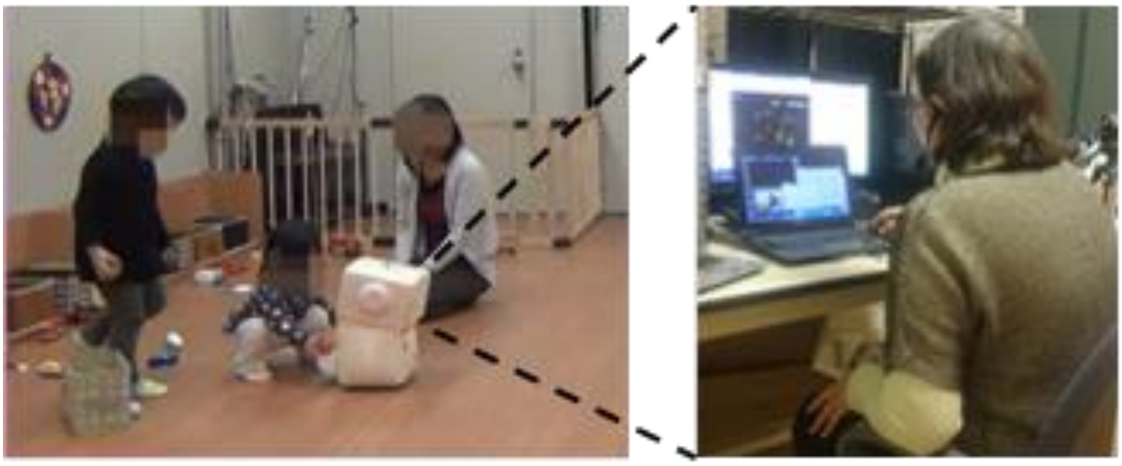


Fig. 1 Grandmother (on the right) remotely interacts with her grandchildren through ChiCaRo's hand

2. RELATED WORKS

2.1 Telepresence robots

There are many tele-presence robot products in the world: Doubles by Double Robotics, Beam/Beam+ by Suitable Technologies, QB Avatar by Anybots, Kubi by

RevolveRobotics, and so on. These robots are already being used in real environments, such as offices, hospitals, and homes, but their target users are mainly adults, unlike our research targets. Romo by Romotive is a tele-presence robot that interacts with children using additional software, but its main purpose is to support education.

Researchers also use tele-presence robots to understand how people interact with others and develop functions for more natural remote communications [20] [21]. For example, Rae et al. showed that a tele-presence robot’s mobility is important for increasing the feelings of its presence in remote users [22]. Wada et al. developed a tele-operation system that captures special knowledge from domain experts to develop a robot’s interaction contents [23]. Zheng et al. developed a tele-operation system to control multiple social robots for conversation and navigation [24].

However, these research works generally focused on interaction between adults, i.e., evaluating the functions of tele-operation or interaction with adult participants. Even the few research works that conducted trials with a tele-presence robot and young children addressed how children interact with robots or used education contexts for young children, not babies or toddlers. In this paper, we evaluate the social acceptance and effectiveness of a tele-presence robot that is designed for interaction with babies/toddlers through two kinds of trials involving parents and/or grandparents.

2.2 Robots for children

Child-robot interaction is one active research topic in robotics, especially education for school-aged children. For example, Tanaka et al. developed an educational application for Pepper (Softbank. Co. Ltd.) to learn with children [14] and proposed a care-receiving robot concept that enables children to learn by teaching the robot, instead of the robot teaching them [15]. They conducted a field trail using a child-operated telepresence robot [16] and investigated how children interacted with it through a long-term field trial [25]. Kim et al. investigated the effectiveness of videoconference technology by comparing a telepresence robot and a simple video system for children [17]. Tamura et al. developed a story telling system for children with multiple robots [26]. Social robots have also been used as educational tools for autistic children [27].

Interaction with babies/toddlers is another growing research topic in the human-robot interaction research field. For example, Fink et al. developed a robotic toy box that encourages young children to pick up their toys and investigated its effectiveness through a Wizard-of-OZ technique [13]. Abe et al. investigated play strategies for children by gathering interaction data between children and a tele-operated robot controlled by a preschool teacher [28]. Hieida et al. investigated the effects of shaking hands in interaction between a tele-operated robot and kindergarteners [29]. However, these research works focused on developing functions for autonomous communication robots to interact with children, observations of child-robot relationships, or understanding human decision-making processes under the context of child-adult interaction.

Unlike these research works, we focused on a tele-presence robot for interaction with babies and toddlers for remote interaction with parents and grandparents. Moreover, we experimentally investigated the social acceptance of our developed robots and their effectiveness through field trials in real environments.

3. Design of a Telepresence Robot for Babies and Toddlers

What kinds of design features/characteristics are needed for a tele-presence robot that can interact with babies and toddlers? As described in the introduction, size and mobility are essential for rich remote interaction. If locomotion is enabled, such strict safety functions as an autonomous-stopping function are needed. Moreover, when we are playing with toddlers, since we often engage in such interactions as playing house, a tele-presence robot requires a hand-like device to expand the range of playing options. In fact, past research with tele-presence robots realized that locomotion capabilities and hand devices are critical for smoother interaction with young children, even though these works weren't focusing on babies and toddlers [16, 17].

Based on these contexts, we decided to tackle such designs based on the opinions of the actual future users, i.e., parents, not the researchers' perspective. For example, if the actual users disagree that mobility is needed for remote interaction, developing such tele-presence robots is futile. We conducted a web survey of parents and grandparents who are potential users and gathered their opinions about a tele-presence robot for interacting with babies and toddlers.

3.1 Web-based survey

Our web-based survey about a tele-presence robot for interacting with babies and toddlers investigated preferred size and whether mobility and a hand-like device are needed for remote interaction. In addition, we investigated their preferences of the current tele-operated robots for interaction. In our survey of 208 Japanese adults (52 females and 52 males with preschool children and 52 females and 52 males with preschool grandchildren, the participants answered the following items on a 1 to 7 scale, where 7 is the most positive:

1. Preferred robot size:
    - 1-1, Taller than children (120 cm or more)
    - 1-2, Similar to children (60~120 cm)
    - 1-3, Shorter than children (20~60 cm)

1-4, Much shorter than children (20 cm or less)

2. Mobility for a tele-presence robot

    2-1, Only rotation ability

    2-2, Forward/backward and rotation abilities

3. Usefulness of a hand-like device

    3-1, Only video chat function

    3-2, Hand-like device for richer interaction

4. Preference of current tele-operated robots for interaction

    4-1, Beam+

    4-2, Romo

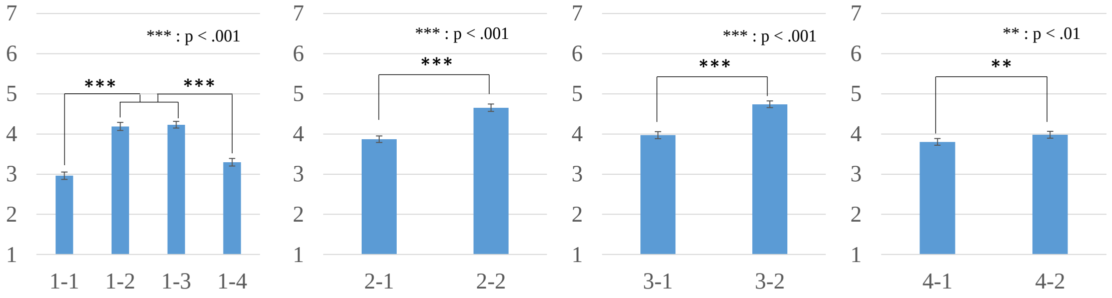
3.2 Results of web-based survey

Figure 2 and Table 1 show our web-based survey results. We analyzed the preferred size with a one-factor between subjects ANOVA (Fig. 2-a) and found a significant effect (*F* (3, 621) = 46.459, *p* < .001, *partial η2* = 0.183), and a multiple comparison with the Bonferroni method revealed significant differences: similar and shorter > taller and much shorter (p<.001). There were no significant differences between similar and shorter, and taller and much shorter. Based on these results, we chose the size of our tele-presence robot to be between 20 cm~120 cm.

We conducted a one-factor between subjects ANOVA for the mobility of a tele-presence robot (Fig. 2-b) and found a significant effect (*F* (1, 207) = 35.962, *p* < .001, *partial η2* = 0.148). The result showed that participants not only wanted a rotation function but also a forward/backward function. Since past research also reported the importance of a moving function for tele-presence robots in interaction with young children [16], we implemented both functions in our robot.

We also conducted a one-factor between subjects ANOVA on the usefulness of a hand-like device (Fig. 2-c) and identified a significant effect (F (1, 207) = 46.413, $p < .001$, *partial* $\eta 2 = 0.183$). The result showed that participants believe a hand-like device is useful for remote interaction. Since past research work also reported that a robot with hands encourages more interaction with young children [16], we developed a hand-like device for our robot.

Finally, we prepared two candidates from existing tele-operated robots, Beam+ and Romo, both of which can interact with children (Fig. 2-d). Beam+ is about the same size as a child, and Romo is smaller. Both robots have forward/backward and rotation abilities and no hand-like device (to the best of our knowledge, no tele-presence robot consumer product has both hand-like devices and moving ability). Currently, Romo’s video chat function cannot be used because Romotive’s official services have been suspended, but it can still see video images and select such behaviors of animated characters as smiling. Therefore, it has enough capability to remotely interact with babies and toddlers. We also conducted a one-factor between subjects ANOVA and found a significant effect (F (1, 207) = 7.208, $p = .007$, *partial* $\eta 2 = 0.034$). Participants preferred Romo over Beam+ during their remote interaction with babies and toddlers. We used this result for determining an alternative robot for our experiment and describe the details in Section 5.4. We note that there is no free description form in our web survey therefore the main reason of why the participants preferred Romo more than Beam+ is still unknown, but we thought that the based on robot’s size. Romo is basically designed for children, therefore its size is smaller than Beam+; therefore, even if Romo collides children, it would not cause serious problem than Beam+ due to its size.



(a) (b) (c) (d)

Fig. 2 Web-survey results

Table 1 Average and S.E of each item

	Ave.	S.E.		Ave.	S.E.		Ave.	S.E.		Ave.	S.E.
1-1	2.96	0.09	2-1	3.87	0.08	3-1	3.97	0.09	4-1	3.80	0.08
1-2	4.19	0.10	2-2	4.65	0.09	3-2	4.74	0.08	4-2	3.98	0.09
1-3	4.23	0.09									
1-4	3.30	0.10									

4. ChiCaRo

Based on our web-survey results, we developed a tele-presence robot named ChiCaRo (Fig. 3), which is 350 mm (height) x 270 mm (width) and weighs 4 kg. It has a 7-inch LCD monitor as a head (2 DOFs) and differential wheels for movement (2 DOFs). ChiCaRo has a small hand-like device (width: 103.5 mm, radius: 60 mm) on its front that can open and shut for accepting toys from children, calling them, and attracting their attention. Six touch sensors and four infrared-based distance sensors ensure safety, and one color sensor tracks the person with whom it is interacting. ChiCaRo is equipped with a stick PC (MS-NH1-AMZN, MouseComputer) for video chat, Arduino Mega and Nano for motor control and color as well as touch and distance sensor processing.

The reasons of why ChiCaRo's size as 350mm height are mainly two kinds: the first reason is because the participants in the web-survey preferred 20~60cm and 60~120cm and also they preferred Romo than Beam+; we thought that participants preferred more safety size robot for babies and toodlers, therefore we designed the ChiCaRo's size between 20 ~ 60cm firstly. The second reason is to cope with both enough display size and locomotion capability for ChiCaRo. Through testing with prototype system with babies and toodlers several times, we decided this size for ChiCaRo.

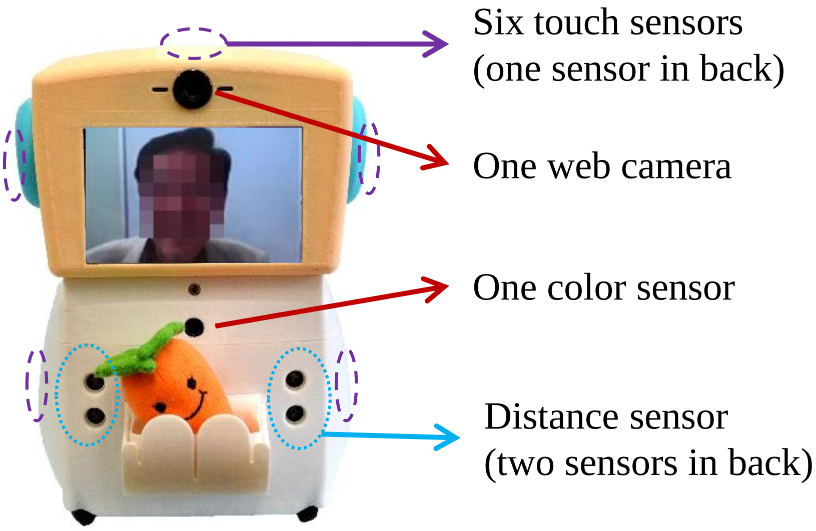


Fig. 3 Appearance of robot and location of sensor

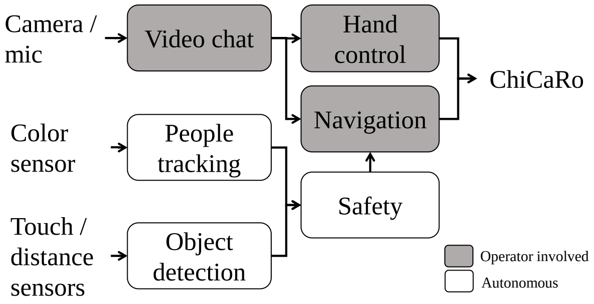


Fig. 4 Software architecture of ChiCaRo

Fig. 5 Tele-operation user interface

4.1 Software architecture

There are three main functions involved in this study: video chat, hand-control, and navigation. Fig. 4 shows the software architecture that illustrates the relationship among these functions.

4.1.1 Video chat

We used Linphone, which is open-source VoIP software, as a video chat function for ChiCaRo. The operator uses a web camera for video chat, allowing the children to see the operator’s face through ChiCaRo’s monitor. Its web camera transfers the interacting children’s faces and voices to the operator.

4.1.2 Hand-control

The operator can open/shut ChiCaRo’s hand-like device through the user interface. As described above in the section 4, the operator uses the hand-like device to play house, call children, and so on. Considering safety and protecting the servo motors, the hand servo is only energized when the hand is in motion.

4.1.3 Navigation

The operator can freely navigate ChiCaRo through a user interface (described in subsection 4.2). Safety is secured by an autonomous system. The robot’s movement is autonomously stopped based on the distance between the robot and the nearest obstacle. For instance, when obstacles exist within 300 mm in front/back of the robot, or touch sensors detect physical contact with the robot, it is immediately stopped. We limited the robot’s speed to 300 mm/sec in the experiment.

ChiCaRo also has a function for following a target child. The color sensor recognizes color pixels based on pre-registered information and calculates the orientation of the gravity point in the sensor image to follow a target child. The operator can select whether to use this function through a user interface.

4.2 Tele-operation user interface

Figure 5 shows a user interface for tele-operation. The primary information sources are images from ChiCaRo's camera (left panel in Fig. 5) and sounds from its microphone. The operator can navigate and control its hand behaviors through controller buttons (right panel in Fig. 5).

5 Experiment

We experimentally investigated the social acceptance and usefulness of our developed robot in a play room environment. We note that investigating each feature in WEB-survey would be useful to understand the effectiveness of them, however such bottom-up approach has difficulties in reality because of the number of features and combination effects between them. In particular human-robot interaction is multi-modal, therefore it would be difficult to clearly find the effectiveness of each feature. Therefore, we compared the effectiveness of ChiCaRo by directly comparing with an alternative robot in this study.

5.1 Hypothesis and prediction

Even though various tele-presence robots or robotic toy systems exist, they focus less on remote interaction with babies and toddlers. Hence, we developed a prototype of a tele-presence robot, ChiCaRo, for interacting with them based on opinions gathered by web-surveys. We expect that people will evaluate ChiCaRo more highly when they are remotely interacting with their children than existing robot systems from both social acceptance and usefulness viewpoints.

Prediction: People will more positively evaluate ChiCaRo's interaction ability with their children than existing tele-operated robots.

5.2 Participants

In our experiments, 36 people (17 adults and 19 children whose ages ranged from zero to three) participated. Some families participated together (cumulative total number is 41, 17 adults and 24 children). Adult participants were paid 4,000 yen (about 36 dollars, including transportation expenses). 17 adult participants (13 women and four men), comprised of four grandparents and 13 parents, answered questionnaires.

5.3 Environment

Figure 6 (left) shows the experiment environment. The room was about 40 m^2, big enough to accommodate more than ten people (five adults and five children). We installed two web cameras for recording and showing images to the operator. Toys, books, and chairs are available in the room for the participants.

Fig. 6 Experiment environment and Romo

5.4 Conditions

The study had with a within-participants design with the following two conditions:

ChiCaRo condition: In this condition, the adult participants used ChiCaRo to remotely interact with their children. Before starting this condition, they moved to an operation space. The maximum experiment time was ten minutes, but if the children were scared by the robot, the session was immediately ended.

Alternative condition: Following the web-survey results (Section 3.2), in this condition, adult participants used Romo (Fig. 6, right) to remotely interact with their children. We controlled it with an iPod Touch and official software that enables the adult participants to see the video image from Romo, navigate it, and select various behaviors of animated characters. Before starting this condition, they also moved to an operation space. The maximum experiment time was 10 minutes, but if the children were scared, the session was immediately ended, as in the ChiCaRo condition.

5.5 Procedures

In the experiment, we asked participants to act freely in the environment for two hours. In the first hour, the children became acclimated, and the adults learned about the ChiCaRo and Romo tele-operation systems.

In the second hour, the adult participants controlled ChiCaRo or Romo and interacted with their children. After the tele-operation of either robot, they controlled the other robot and again interacted with their children for five minutes and answered questionnaires after controlling both robots. The order of manipulating the tele-operation robot was counterbalanced. If multiple adult participants were present, we asked each of them to control each robot sequentially. To avoid combination effects of multiple robots, only one robot was used at a time.

5.6 Measurements

We investigated two measurements by questionnaires on a 1 to 7 scale (7 is most positive): intention to use and usefulness. We measured the former because in studies of the acceptance of new technologies [29] and social robots [3, 30], it is modeled and indicates social acceptance. This scale consists of three items that were adapted from Heerink et al. [31], including, “I’m planning to use this robot in the next few days.”

Note that the Cronbach's alpha statistics [32] of intention to use were 0.873 and 0.948 in the ChiCaRo and Romo conditions, which are within a good range. We measured usefulness by a single item, "I think that ChiCaRo will be useful for remote interaction with children and grandchildren," to investigate whether they felt the robot was useful for interaction.

5.7 Results

5.7.1 Verification of prediction

Figure 7 and Table 2 show the questionnaire results for *intention to use* (ITU) and *usefulness*. For *intention to use,* we conducted a paired t-test and identified a significant main effect between conditions (*t* (16)=5.533, *p*<.01, r=0.81). This means that the adult participants evaluated ChiCaRo's *intention to use* higher than Romo.

For *usefulness*, we conducted a paired t-test and identified a significant main effect between conditions (*t* (16)=5.636, *p*<.01, *r*=0.82). The adult participants evaluated ChiCaRo's *usefulness* higher than Romo. Thus, our prediction was supported.

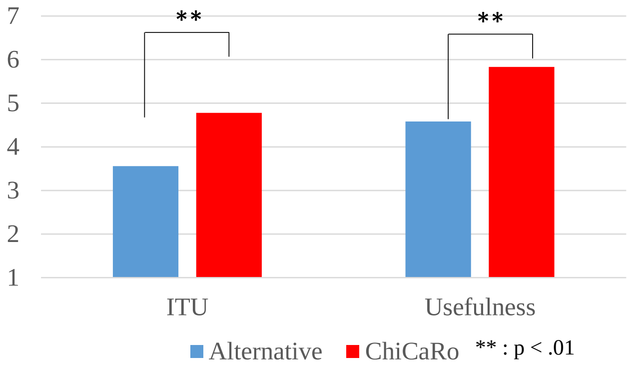


Fig. 7 Questionnaire results

Table 2 Average and S.E. of the questionnaire results

	ITU		Usefulness	
	Ave.	S.E.	Ave.	S.E.
Alternative	3.556	0.411	4.583	0.336
ChiCaRo	4.778	0.358	5.833	0.297

5.7.2 Observations of interaction with robots

In both conditions, the typical interaction pattern was that the children looked at the robot and chatted with the operator by ChiCaRo or played with Romo. In the ChiCaRo condition, first, the adult participants greeted their children by ChiCaRo and asked if they wanted to play. Several adult participants asked their children to put toys in ChiCaRo’s hand to play with them. When children moved around to find appropriate toys to hand over, the operators navigated ChiCaRo to follow the children. Fig. 8 shows a typical interaction scene between ChiCaRo and a child:

Operator (grandmother): “What’s that?”

Boy: “A ball” (he puts a yellow ball in ChiCaRo’s hand).

Operator: “Please show me more balls.”

Boy: “Okay” (he hands over three balls).

He repeated such interactions several times and talked with his grandmother through ChiCaRo. After a few minutes of interaction with it, he left and started to play by himself, and then his younger sister approached and started to play with it (Fig. 9, left). She gave a pumpkin-like toy to it, and her grandmother said thank you. When the boy noticed their interaction, he stopped playing by himself and joined ChiCaRo and his sister. He put several food-like toys on a dish and showed them to his grandmother (Fig. 9, right).

In the alternative condition, adult participants typically navigated Romo in front of their children and changed its behaviors to attract them. Fig.10 is an example of such an alternative condition with a child. A mother controlled Romo to approach her son who actively interacted with it, e.g., touching and following it. Some children repeatedly asked, “where is the robot?” if they couldn’t catch Romo. After the experiment ended, a mother explained to her son that she had been controlling Romo. “Why don't you control Romo some more and play with me?” he asked.

Fig. 8 Boy interacting with ChiCaRo controlled by grandmother

Fig. 9 Boy and his little sister interacting with ChiCaRo

Fig. 10 Boy interacting with Romo

5.7.3 The acceptance degree

In this section, we investigated children’s acceptance degree toward each robot because we are interested in such acceptance degree and typical interaction patterns of children, it would provide interesting knowledge to install childcare support robots in real environments. For this purpose, we investigated whether children rejected each robot at the end of each session. If a child enjoyed his/her interaction with the robot or the parents thought their child had fun, we described this child as accepted. On the other hand, if a child did not want to interact with the robot, exhibited hesitation or fleeing behaviors, we described this child as rejected. Therefore, we compared the number of accepted/rejected children between ChiCaRo and Romo in the experiment.

Figure 11 shows the numbers of rejections for each robot. We verified the differences of the rejections among the two kinds of robots with a Chi-square test that revealed significant trend among the conditions ($\chi 2$ (1) = 2.923, p=.087, Cramer's V =.277). Therefore, children relatively accepted ChiCaRo compared to Romo, but the difference is not significant. Below, we investigated the detail behaviors of children.

Romo: In the experiment, eight children rejected Romo, and the other 11 accepted and played with it. The ages of the five girls and three boys who rejected it ranged from one to three (average: 2.38). The age of the seven girls and four boys who accepted it ranged from one to six (average: 2.82).

We identified three typical interactions of the children who accepted Romo: following, touching, and grabbing. The operators often tried to make Romo approach the children (Fig. 12, left). When they noticed that Romo was approaching, they also approached it (Fig. 12, middle), touched it, and grabbed it (Fig. 12, right).

The typical behaviors of the children who rejected Romo were running away, returning to their parents, or hiding in the ball area. For example, one boy fled an approaching Romo, which was being controlled by his older sister (Fig. 13, left). Another girl entered the ball area and hid from Romo while surreptitiously spying on it (Fig. 13, right). The children who rejected Romo seemed afraid of it from the very start of their interaction with it. When Romo started to move, they immediately fled. Even if the operators changed Romo’s face animations or had the robot retreat, the children refused to interact with it.

ChiCaRo: In the experiment, four children rejected interaction with ChiCaRo, and the remaining 15 children accepted and played with it. The ages of the two girls and two boys who rejected it ranged from two to three (average: 2.50). The ages of the ten girls and five boys who accepted it ranged from one to six (average: 2.67).

We identified two typical interactions of the children who accepted ChiCaRo: chatting and playing. Operators tried to make ChiCaRo approach the children to chat and play. The operators said the children’s name while approaching and the children quickly noticed ChiCaRo and their parent’s face on its screen. After approaching, the operators asked the children what they were doing or requested to see their toys (Fig. 14, left). Some children incorporated ChiCaRo into their play, such as playing house with toy food (Fig. 14, middle and right).

The typical behaviors of the children who rejected ChiCaRo were running away, returning to their parents (Fig. 15), or explicitly demanding that it stay away. For example, when one girl was scared by ChiCaRo, which was being controlled by a friend of her father, she asked her father to pick her up. Another boy aggressively rejected ChiCaRo, pointed at it, when it was being controlled by his mother, and commanded: “Don’t move!” (Fig. 16).

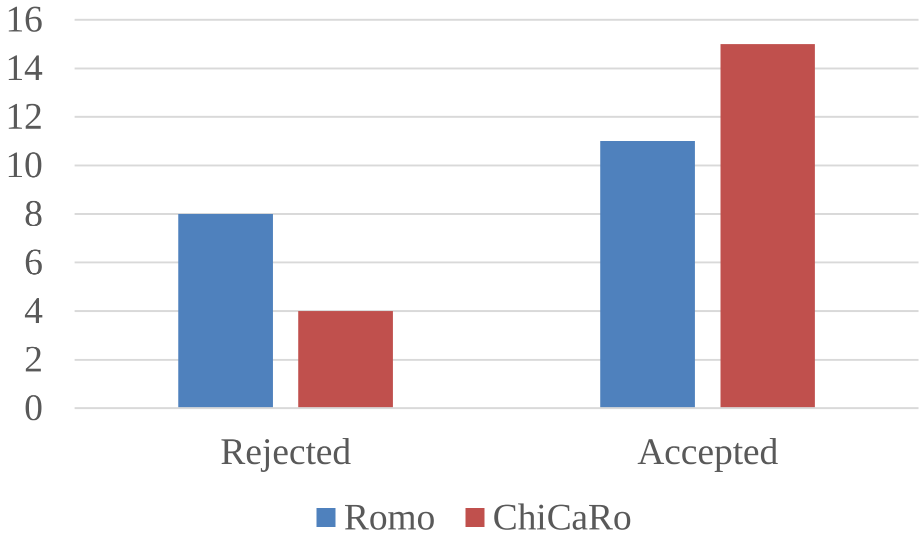


Fig. 11 The number of children in each category

Fig. 12 Children who interacted with Romo

Fig. 13 Children who rejected Romo

Fig. 14 Children who interacted with ChiCaRo

Fig. 15 Girl rejected interaction with robots

Fig. 16 Boy who rejected ChiCaRo

5.7.4 Observation of interaction with ChiCaRo’s hand

We investigated the interaction between ChiCaRo and children by focusing on a use of the robot’s hand. For this purpose, we counted the number of children who played with ChiCaRo through its hand. As a result, all children who accepted ChiCaRo (i.e., 15 children) played with their parents through its hand. Similar to past studies [16, 17], ChiCaRo’s hand encourages smoother interaction between parents and their children. For example, typically they used the hand to hand-over toys or receive them from ChiCaRo. Such interaction often happen in usual interaction between them while they are playing with. Moreover, some of parents used ChiCaRo’s hand to attract attentions of children, e.g., waving its hand around their children and saying their names. Therefore, ChiCaRo’s hand enables different kinds of physical interaction compared to locomotion capabilities, which contributed to realize richer interaction between parents and children through ChiCaRo.

5.7.5 Interview results

As reported in Section 5.7.1, the ChiCaRo condition resulted in better social acceptance and higher usefulness. We specifically asked the participants about their reactions in interviews at the end of the experiments.

Seven adult participants positively evaluated ChiCaRo’s locomotion abilities. For example, a grandmother said, “The moving function is good because it can follow a crawling baby, which is different from a video chat.” She often used video chat with her grandchild. Another grandmother praised ChiCaRo’s hand-like device: “its hand is useful for playing with children because it can give them different toys.” She often played house through ChiCaRo with her grandchildren. Another participant believed that ChiCaRo might be used for childcare and watching children.

During the interviews, a few negative comments surfaced. One participant expressed safety concerns if the robot were to suddenly malfunction. Because ChiCaRo’s purpose is to interact with babies and toddlers, she was worried that a broken robot might injure her son. Two adult participants thought the robot’s noise might frighten babies.

6 Field trial

Next, we conducted a field trial to investigate the effectiveness of the developed robot in real home environments.

6.1 Procedure

This field trial involved three nuclear families including preschool children and grandparents. Three grandchildren (two boys and one girl whose average age was 3.03 years) and four grandparents (three grandmothers and one grandfather whose ages ranged from 55 to 64) participated in our field trial. In these three families, the frequencies of the face-to-face interactions between the grandparents and the grandchildren were once a year, three times a month, and once every three months.

Each family freely used ChiCaRo over five or six days in their homes. The operators were grandparents who are living far away from them. On the first day, we installed ChiCaRo in their living rooms and explained how to use it to both parents and grandparents. At the end of the experiment, we interviewed both parents and grandparents to gather their impressions of ChiCaRo.

6.2 Results

During the field trial, the families used ChiCaRo an average of 2.63 times per day, and the average length of the time was 26.0 minutes per day. The operators mainly used ChiCaRo to play with their grandchildren, e.g., chasing them with ChiCaRo, looking at the children dancing around, watching TV together, and so on (Fig. 17); they also greeted their grandchildren with ChiCaRo or just talked.

Sometimes they watched the children's daily activities using ChiCaRo's locomotion ability. Different from video chats, the operators can follow children by ChiCaRo even if they are moving around. In fact, the operators reported that ChiCaRo's locomotion capabilities enabled longer conversations than video chat. Moreover, in interviews, mothers believed they benefited because grandparents watched their grandchildren through ChiCaRo during periods when the simultaneous burdens of cooking, meal preparation, and childcare overlapped. During the field trials, ChiCaRo assumed some of the childcare responsibilities of the parents.

All four grandparent operators positively evaluated ChiCaRo and expressed a desire to use it again because it increased opportunities to interact with their grandchildren as well as their own adult children. Three operators praised ChiCaRo's moving functions for interaction with their families.

The operators admitted that their daily activities were positively changed by using ChiCaRo. In an interview, one operator said, “We shared our daily life through ChiCaRo. My grandchild greeted me in the morning and at night, and so I could easily learn about his activities.” Another operator reported positive opinions, such as, “Interacting with my grandchild is really fun. When I knew that I was going to use ChiCaRo, I had a reason to tend to my appearance. Since I’m usually alone, I often neglect myself.”

Even though we conducted field trials with the families for only about a week, all three families positively evaluated it. Using such tele-presence robots increased interaction opportunities and provided merits to both parents and grandparents. Interaction with grandchildren through tele-presence robots might strengthen the social bonds among family members.

Fig. 17 ChiCaRo in a home environment

7 Discussion

7.1 Implication and applications

One immediate design implication is that remote interaction with babies and toddlers is improved when it contains physical interaction. In reality, such interaction increases cost considerations because locomotion and hand-like device capability are more expensive than a simple video chat. We believe that robots for this purpose will be expected to have multiple functions, e.g., partial autonomous playing with children and watching them when an operator cannot briefly control the robot with a semi-autonomous robot approach [30]. For such purposes, a tele-presence robot that is designed for interacting with toddlers might be financially beneficial because it outperforms a simple pan-tilt type web-camera.

7.2 Future work

We thought that there are two kinds of future works exist: increasing autonomy based on tele-operation histories by professional childcare workers and a use of virtual agent.

About the increasing autonomy, we thought that operation and interaction histories by professional childcare workers would help this purpose. Because for people who do not have much experiences of interaction with babies and toddlers, even if they can easily operate ChiCaRo, they cannot interact well with the babies and toddlers. In such situation, if the system autonomously recommend appropriate play behaviors for operators based on sensing data, it will encourage more natural interaction between them. Already several past studies tried to develop autonomous system by using operation and interaction histories between semi-autonomous robots and people [23] [30], such knowledge would be useful to increase autonomy of ChiCaRo.

Of course, for this purpose, integration of several sensing system would be important to understand behaviors of the babies and toddlers and environmental situations. For this purpose, a use of environmental sensing system [31] [32] would be one possible approach to realize rich sensing capabilities for ChiCaRo. For example, past studies realized to estimate the interaction behaviors by using acceleration sensors in a small robot [33]; if we can distribute several toys including such sensors, the system could understand how children play with toys and use its information for interaction between ChiCaRo and them. Moreover, integration with wearable sensors and environmental human tracking system enables identification of people in the environment; such identification system also helps operation of ChiCaRo, in particular at crowded environments.

About the use of a virtual agent, it would be useful when an operator is non family member of children, e.g., childcare worker. If children find unknown people at ChiCaRo's display, they would be cautious about interacting with it; but if a virtual agent is shown in the display of ChiCaRo interaction with children is easier for these people. Also, a use of a virtual agent enables multiple people to interact with children via ChiCaRo anonymously, it might be useful for a use of ChiCaRo at nursery schools.

7.3 Limitations

This research work has several limitations. In our experiment, the adult participants interacted with their children for limited time periods. Also, open questions remains: How will their feelings toward ChiCaRo and Romo change in time and with more frequent exposure? How will the children change their interaction style toward ChiCaRo and Romo? Moreover, ChiCaRo’s appearance is essential for changing the impressions of children; its design can be modified through surveys from real users. We only tested two kinds of robots based on the web-survey results due to the number of combinations of each feature, therefore we did not clearly investigate each feature effects, and other possible features such as a colour or interaction distance are not investigated yet.

Moreover, at the experimental comparison between ChiCaRo and Romo, we could not use video chat function of Romo due to suspension of services by the Romo’s company. There is no commercial robots with similar size and locomotion capability, therefore we decided to use Romo in this study even if the video chat function was suspended; but it would make another limitations, because children might be attracted to video chat with their parents.

In this study, all operators are familiar members towards children. If an operator is an outsider for children, they would be cautious about interaction with ChiCaRo. Children would need a time to be acclimatized to such unknown persons. But, different to adult people, their curiosity often exceed their cautiousness. Thus, we thought that if the operator would have enough knowledge to attract children's attentions e.g., childcare worker, they will be able to interact with children well via ChiCaRo. In fact, past studies already showed that children can interact with a tele-operated robot which is controlled by childcare workers [28] [34]. Related to this topic, a use of virtual agent is one possible approach to decrease children's cautiousness, as described in the above section.

However, despite several limitations we believe this research work provides valuable knowledge for robotics researchers who are targeting child-robot interaction.

8 Conclusion

This paper presents a tele-presence robot, ChiCaRo, which is designed for remotely interacting with babies and toddlers to increase interaction opportunities between grandparents and grandchildren. We implemented video chat, navigation, safety measures, and a hand-like device for rich remote interaction between operators and babies/toddlers and to support operations through autonomous functions.

First, we conducted an experiment in a playroom to investigate ChiCaRo's social acceptance. We addressed intention to use and ChiCaRo's usefulness and compared it to an existing robotic toy that can also be controlled by operators. In our result, adult participants preferred ChiCaRo and children relatively accepted ChiCaRo compared to the existing robotics toy.

We also conducted a field trial in real home environments with three nuclear families and their grandparents to investigate the effectiveness of ChiCaRo. During one-week trials, grandparents effectively interacted with their grandchildren through ChiCaRo. Interaction through ChiCaRo also decreased the burden of mothers who were preparing meals and/or cooking by assuming the responsibility of watching children. We believe that our findings will lead to the development of tele-presence robots for babies and toddlers.

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