Doctoral Thesis

Design of Moral Interactions for Service Robots in Public Environments

Sachi Natasha Edirisinghe

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Department of Social Informatics
Graduate School of Informatics
Kyoto University

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Thesis Committee:	Takayuki Kanda, Professor
	Hiroaki Ogata, Professor
	Takayuki Ito, Professor

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Abstract

In the future, social robots will be a common sight in public spaces, performing tasks that human workers would perform and engaging with the public in roles such as security guards, store clerks, receptionists, etc. Robots' ability to serve customers in a friendly manner is the subject of numerous research projects nowadays, and as a result, the quality of their services is constantly rising.

However, human-employee service is not limited to simply providing friendly service. They make an important contribution to maintaining a polite and comfortable atmosphere in public spaces. They stop visitors' low moral behaviours (e.g. vandalism, and shoplifting) or norm-violating behaviours (e.g. queue jumping, and being noisy) through actions such as admonishing or by mere presence. Yet, existing robots in public spaces have little to no capability to prevent visitors' inappropriate behaviours; neither people consider them a moral entity. Indeed, only a few works have attempted to develop such capabilities for robots. Unfortunately, without such capability, robots are not ready to work on behalf of human employees in public spaces.

This thesis focuses on designing moral interaction capabilities for the robots that serve in public environments. We define *robot moral interactions* as "engagement with people while attempting to maintain a high level of morality in the robot's own and others' behaviours." We particularly focus on moral interactions that aim to prevent or stop inappropriate behaviour by visitors in public spaces. We attempt to address four challenges with designing such moral interaction capabilities: people's less compliance with robots, negative perspectives about the robots that attempt to regulate people, revealing people's perceptions and interactions with robots that execute moral interactions in public space, and a lack of knowledge in developing reliable robot systems to operate in the real world.

Our first study (Chapter 3) focuses on developing an acceptable admonishing service for a robot that tries to stop an individual's inappropriate behaviours. We also study how people perceive such an admonishing robot. As our example, we develop an acceptable admonishing service for a real-world shopworker robot. We want to include an admonishing capability for the robot while still projecting a positive image. We propose *harmonized design of friendly and admonishing service* as our solution. Based on the findings of our interviews with the shop staff, we suggest three design principles to achieve harmony: a friendly impression, zero erroneous admonishments, and polite requests. The results of our 13-day field study at a shop show that many customers and shop staff have a positive impression of the proposed robot, which indicates that the harmonized design could be a successful approach for an acceptable admonishing service.However, a few customers preferred human admonishing service due to the demerits of the robots', which need to be further studied and improved in the future.

In our second study (Chapter 4), we aim to develop a robot that can promote compliance and diminish people's negative attitudes in a scenario where it controls a crowd by instructing and admonishing in a public area. Furthermore, we aim to investigate people's impressions and interactions with a robot that provides such a service. We consider managing a queue of people as our example scenario. We propose *imbuing a professional impression in the robot* as our solution by mimicking the queue management role of the human security guard which is already socially acceptable and effective. We also present three design features to achieve a professional impression for the robot: duties, professional behaviour, and professional appearance. We have deployed our robot for queue management at a public event for 10 days and have investigated visitor interactions and impressions of the robot. Our field trial results show that many visitors complied with the robot, although some ignored it. Furthermore, our interview results, including the opinions of a few admonished visitors, indicate the majority of them have a favourable impression of the robot. Still, a portion of visitors pointed out the demerits of the robot. Thus, exhibiting the image of a professional security guard and performing admonishing as one function, among others, could be a successful approach for effective and acceptable crowd handling. However, the demerits of the robot need to be further addressed in future studies.

Our third study (Chapter 5) attempts to create a robot that can indirectly exert social pressure to discourage people's norm-violation behaviours without causing a negative impression. Furthermore, we aim to address the technical complexity and lack of knowledge of developing such a robot to autonomously work in real life. As our design concept, we propose to *exert social pressure through friendly behaviour.* Considering a shopworker robot as our example scenario, we have developed a robot to recognise visitors' shopping actions and express its awareness by giving friendly remarks that fit those actions. We demonstrate how to develop such a robot system to autonomously work in a real shop by integrating real-world data into the robot development process and offering solutions to several practical issues. Our 11-day field trial at a hat shop shows that such behaviour by a robot can create positive impressions in many visitors, yet the effectiveness of the robot in preventing norm-violation behaviour remains unclear and needs long-term data collection. Further, the field trial reveals that several visitors had negative impressions due to the demerits of the robot, which need to be further studied and improved in the future.

The robot designs proposed in this thesis provide some guidance for developing acceptable and effective service robots with moral interaction capabilities in a future society. Furthermore, the observations and interview results of our field studies broaden the knowledge of how people interact with and perceive robots with moral interaction capabilities in the real world. Thus, the findings of this thesis offer perspective on the development and deployment of robots with moral interactions in public spaces.

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CHAPTER 1

Introduction

1.1 Background

Below, we discuss important topics related to social robots' position in society and moral interactions.

1.1.1 Social robots' position in the society

The expectation of robots has changed from mere appliances to partners to humans that interact in daily life, which motivated the development of social robots, a class of robots that are specially designed to interact with humans using natural human communication modes such as voice, gestures, gaze, facial expressions etc. to simplify the communication [10]. They are expected to recognize and act according to human social behaviours and to follow social norms when they operate in human environments [65].

Social robots are becoming a part of daily life. Robots like Pepper have been produced in mass and widely used in houses and public spaces [72]. In domestic environments, social robots are used to improve the lives of elders [51], child health care [81], and as a learning companion for children [60]. Social robots in public spaces expect to serve on behalf of human employees. Existing robots in places such as airports, museums, shopping malls and hospitals socially interact with people and offer useful services such as guiding, providing information, entertaining, and educating [20, 25, 43, 59, 94]. Particularly, robots' potential benefits, such as cheap labour, novelty, and the capability to provide an enjoyable shopping experience [69, 84], have attracted business owners' attention to using them as frontline workers.

However, robots have a lower social power than humans. People comply less with a request or admonishment from a robot compared to humans [40, 62]. Furthermore, people have fewer concerns about abusing robots than about abusing other humans [6]. It has been reported incidents of robots being bullied by adults and children in public spaces [17, 78].

1.1.2 Morality, social norms, and violations of them

Morality refers to a set of rules that allow individuals to coexist peacefully in communities based on what society deems to be "acceptable" and "right" [52]. For example, honesty, protecting public properties, and being polite can be considered moral behaviors. Social norms refer to informal rules that govern the behaviour of groups and societies [7]. For example, waiting in line to get on the train and avoid speaking loudly in public places. While morality is universally valid, social norms may vary in a particular culture or society. However, both of them contribute to a civil society.

People sometimes violate moral and social norms, both intentionally and unintentionally. This results in undesirable situations that affect others. If no one intervenes in such incidents to stop those behaviours and protect moral standards, people's morality degrades, leading to an uncivil society.

1.1.3 Human-human moral interactions in public space

Protecting moral standards in public leads to a polite and peaceful environment. Human staff in public spaces play a crucial role in fostering moral standards by executing moral interactions. They provide friendly and polite services to the visitors, and at the same time, they stop visitors' norm-violating behaviour through actions such as admonishment, reminding, and monitoring. Even the presence of a human employee may exert social pressure on people, which can discourage them from engaging in norm-violating behaviours.

However, actions such as admonishing, warning, and instruction giving are considered face-threatening acts which put the listener (i.e., a visitor with low moral behaviour) and speaker (i.e., an employee in a public space) in an uncomfortable state. Visitors may experience resistance [89] towards the threatening messages and the employees who delivers such messages. Sometimes, visitors may react aggressively towards the employees, which could result in a conflict and put the employees at risk. On the other hand, employees may feel stressed about confronting strangers.

1.1.4 Robot ethics, moral competence and moral agency

As robots become more involved in humans' lives, the attention of robot ethics is rising. Current discussions on robot ethics consider two aspects: how a robot could behave ethically towards humans and the ethics of how a robot is designed and used [90].

The current discussions on the morality of the robot are focused on concepts such as moral agency and moral competence. A moral agency is the ability to act according to what is right and wrong and take responsibility for their actions and their consequences [24, 73]. Several requirements have been proposed to consider a robot as a moral agent: autonomous from programmers and operators, able to act intentionally, and in a position of responsibility to other moral agents [91]. Moral competence refers to the capacity to deal with the tasks of moral decision-making and actions. Moral competence consists of several components such as norms and moral language, moral cognition and affect, moral decision-making and action, and moral communication [57].

1.1.5 Robot moral interactions

We define moral interactions for robots as follows: *engagement with people while attempting to maintain a high level of morality in the robot's own and others' behaviours.* Moral interaction capability can be considered a part of moral competence in robots. Robots do not necessarily need to be fully moral agents to possess certain moral competence [57] and, consequently moral interaction capabilities.

In this thesis, our focus is on the moral interactions that aim to prevent or stop people's inappropriate behaviours (in public spaces). We classify such moral interactions into two subcategories. 1) Direct moral interactions: interactions where robots attempt to actively regulate people's behaviours through direct interventions such as admonishing for inappropriate behaviours or offering instructions to prevent inappropriate behaviours in advance. 2) Indirect moral interactions: interactions in which robots attempt to regulate people's behaviours with a less direct approach. For example, exerting social pressure to discourage inappropriate behaviours by its social presence.

1.1.6 Key challenges with designing moral interactions for robots in public space

Designing robots with moral interaction capability in public environments posses several challenges.

1. **People's less compliance with robots:** The low social power of robots and people's lack of respect for them compared to humans may lead people to ignore robots that attempt to regulate their behaviours. Indeed, previous studies show that people are less likely to comply with an admonishment from a robot than from a human [62].

2. **Negative perspectives about robots that attempt to regulate people:** Previous works reveal that participants have negative impressions of the robots that admonish or punish and feel less safe around them [46]. Having such negative perspectives makes it complicated to deploy robots with moral interaction capabilities in public spaces. Robots should be capable of moral interaction while still projecting a positive image of themselves.

3. **Complexity and lack of knowledge in developing reliable robot systems to operate in the real world:** Developing robot systems for real-world operation and interaction with the public is much more complex than developing robots to operate in a controlled environment like a laboratory. As a result, only a few robots work in public environments. The real world consists of new technical challenges and uncontrollable environmental conditions. People's spontaneous behaviours and their interactions with a robot could be hard to predict in advance [48]. Therefore, for robots to function well in public areas, they must be safe, robust to environmental challenges, and able to support a range of user behaviours. Developing such

a system is a challenging task and requires the integration of various technologies and components. Furthermore, knowledge of how to practically develop robot systems to work well in the real world is limited.

4. **Revealing people's perceptions and interactions with robots that execute moral interactions in daily life:** Only a few past studies have investigated people's perceptions and interactions with robots that attempt to regulate their behaviours in a real-life situation [82]. Hence, existing knowledge doesn't provide deep insight into how people will respond to a robot that attempts to regulate them in a public space or whether they consider such robot services acceptable. To reveal people's perceptions and interactions with such robots it is need to do field studies in the public space. However, running a field trial is a complex and expensive task. A field trial demands considerable time (such as for robot system development, logistics, data collection and analysis, etc.), and resources (such as robot, investigators, data collection equipment, etc.)

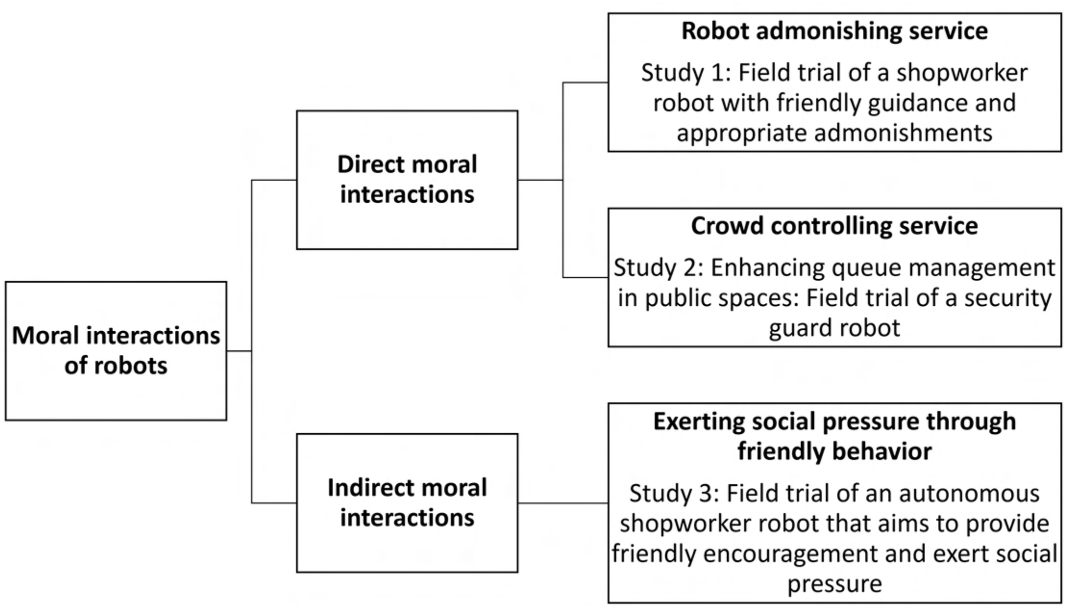


Figure 1.1: Overview of the research

1.2 Contributions of the research

This thesis presents our effort to design moral interaction capabilities for service robots in public environments. We seek solutions to the four issues we pointed out in Section 1.1.6.

Figure 1.1 shows the overview of the research. We carried out three field-oriented studies. We selected two representative public space roles: security guards and shop employees, both of which are common uses for robots and need moral interaction capabilities. We carried out two studies under direct moral interaction and one under indirect moral interactions. Below we briefly introduce our three studies:

Study 1: Field trial of a shopworker robot with friendly guidance and appropriate admonishments

We focused on developing an acceptable admonishing service for a real-world shopworker robot. Applying the admonishing service in a real-world robot is difficult due to the high risk of rejection by society. We wanted to achieve an acceptable admonishing service while simultaneously avoiding the impression of a forceful request from a machine. We proposed a harmonized design that provided friendly and admonishing services. First, we interviewed a shop's staff to learn their strategies for both friendly and admonishing services. From our evaluation of the interview results, we derived three design principles: friendly impressions, zero erroneous admonishments, and polite requests. Based on the design principles, we implemented our harmonized design on a social robot that guides customers to product locations and admonishes those who are not wearing face masks. We conducted a 13-day field trial in a retail shop and interviewed the customers and shopworkers to learn their impressions of our robot. While the opinions of admonished customers couldn't be heard in the interviews, we heard the opinions of both the unadmonished customers and the shop staff. Many of them reported positive impressions of the robot, its admonishing and friendly services, and expressed an intention to use it in the future. However, a few rejected the robot admonishing service and preferred humans' due to the demerits of the robot, which need to be studied in future works.

Study 2: Enhancing Queue Management in Public Spaces: Field Trial of a Security Guard Robot

In this study, we developed a security guard robot that is specifically designed to manage queues of people and conducted a field trial at an actual public event to assess its effectiveness. However, the acceptance of robot instructions or admonishments poses challenges in real-world applications. Our primary objective was to achieve an efficient and socially acceptable queue-management solution. To accomplish this, we took inspiration from human security guards whose role has already been well-received in society. Our robot, whose design embodied the image of a professional security guard, focused on three key aspects: duties, professional behavior, and appearance. To ensure its competence, we interviewed professional security guards to deepen our understanding of the responsibilities associated with queue management. Based on their insights, we incorporated features of ushering, admonishing, announcing, and question answering into the robot's functionality. We also prioritized the modeling of professional ushering behavior. During a 10-day field trial at a children's amusement event. We interviewed both the visitors who interacted with the robot, including a few admonished visitors, and the event staff. The results revealed that visitors generally complied with its ushering and admonishments, indicating a positive reception. Many visitors and event staff expressed a favourable impression of the robot and its queue-management services. While these findings indicate some success with our proposed security guard robot, there are some visitors and staff who reported an unfavourable impression of the robot due to its demerits, such as lack of capability and unnatural behaviour, which need to be addressed in future work.

Study 3: Field trial of an autonomous shopworker robot that aims to provide friendly encouragement and exert social pressure

Our third study focused on achieving acceptable indirect moral interactions. We attempted to exert social pressure on people through the friendly behaviour of a robot. We developed an autonomous hatshop robot for encouraging customers to try on hats by providing comments that appropriately fit their actions, and in such a way also indirectly exerting social pressure. To enable it to offer such a service smoothly in a real shop, we developed a large system (around 150k lines of code with 23 ROS packages) integrated with various technologies, like people tracking, shopping activity recognition and navigation. The robot needed to move in narrow corridors, detect customers, and recognise their shopping activities. We employed an iterative development process, repeating trial-and-error integration with the robot in the actual shop, while also collecting real-world data during field-testing. This process enabled us to improve our shopping activity recognition system by collecting real-world data, and to adapt our software modules to the target shop environment. We report the lessons learnt during our system development process. The results of our 11-day field trial indicate that our robot was able to provide its encouragement based on action recognition reasonably well. Many customers expressed a positive impression of the robot and its services. However, some customers expressed their negative impressions due to several demerits of the robot, including a lack of capability and a sense of being watched by the robot. These limitations of the robot need to be improved in future studies. Furthermore, its capability to exert social pressure needs to be confirmed by long-term data collection.

1.3 Thesis structure

The rest of the thesis is organised as follows: In **Chapter 2**, we present the related works on social robot services in public spaces, and robots that regulate people. In **Chapter 3**, we explain our study of the design and implementation of an acceptable admonishing service for a shopworker robot and our findings from our 13-day field trial at an actual shop. **Chapter 4** describes the design and implementation of an acceptable and effective security guard robot for queue management in public spaces. We also presented the results of our 10-day field study at a public event, including the admonished visitors' opinions of the robot. **Chapter 5** reports our attempt to exert social pressure from the friendly behaviour (i.e., customer's shopping activity detection and giving appropriate encouraging remarks) of a shopworker robot. We also present how to get such a robot to autonomously work in a real shop, as well as the results of our 11-day field trial. **Chapter 6** presents the discussion and future works. Finally, the conclusion of this thesis is given in **Chapter 7**.

CHAPTER 2

Related Works

2.1 Social robot services in public space

Social robot services in public spaces are emerging in a number of sectors, such as commerce, health care, education, and security. They sometimes take on human jobs, including shopworkers, tour guides, and receptionists, and in other cases they complement or support human workers.

Social robots in public spaces often engage in friendly services. One common robot service is guiding and providing information in complex environments like shopping malls, train stations, and museums [43, 79, 85, 86]. Furthermore, due to robots' novelty and ability to provide an enjoyable experience, they attract customers to retail and hospitality facilities, such as shopping malls, stores, restaurants, and hotels. They serve as front-line staff and perform duties like welcoming, entertaining, advertising, and delivering food and other items [20, 64, 69, 83, 84]. However, human workers currently handle the bulk of a shop's workload due to the limited social interaction capabilities of robots. Most existing robots focus on responding to customer requests rather than engaging in perception-based interactions [20, 37].

Moreover, robots are used for security services like patrolling and acting as a telepresence platform for human staff in public environments [12, 95]. They have been occasionally used for regulating visitor's behaviors, for instance, cajoling adherence to social norms [62, 82] and health measures during the COVID-19 pandemic [54].

However, little research has been done to develop robots for controlling visitor behaviour in public spaces, which is an important part of the duty of workers in such places.

2.2 Robots that regulate people

Researchers are showing interest in investigating the potential of social robots that regulate people's behaviors or encourage them to take actions that they are resisting. Previous works have studied the robots potential to regulate people's behavior through direct interventions like admonishing, commanding and punishing etc. For examples, past works explored a robot's capability to force participants in laboratory settings to continue tedious tasks [22], and improve task performance [46]. Several studies applied social robots in public spaces for compelling people to follow social norms [62, 82], and COVID-19 measures [54]. Furthermore, several studies investigated the effect of indirect approaches such as a robot's social presence, and monitoring on human morality. For example previous works examined the robot's presence on humans honesty in exam settings [63] and situation that encourages dishonesty [27, 41],

Robotics research related to regulatory robots focuses on two main factors; people's compliance and the acceptance of the robot (i.e., positive attitude towards robot and intention to receive its service). These two factors seem equally important for a successful design. Psychological studies [23, 92] have shown that controlling attempts like admonishing individuals generates negative emotions such as guilt, and feeling bad about themselves that cause to change their behaviors. On other hand, such a persuasive attempt can be perceived as a threat to one's freedom of acting as desired. Thus, persuasive attempts are considered as a type of face threatening acts (FTAs) that cause to damage the pubic self-image (i.e., face) of a person [14, 32]. Furthermore, a perceived threat to freedom can arise a reactance (i.e. unpleasant motivation state) [89]. Reactance could result counter behaviors such as not complying with the message and being aggressive towards threatening agent to regain the freedom.

Although findings from previous studies revealed the potential of robots to regulate people's behaviors, yet their capability of performing such a role remains obviously inferior to that of humans. People tend to comply less with robots that are attempting to control their behaviors [46]. Forlizzi et al. [27] suggested that when people perceive that they are being monitored by a robot, they tend to evaluate its instrumental capabilities, feeling that it is less capable (such as less intelligent and responding more slowly) and that they can escape from any consequences of wrongdoing. They tend to continue with their bad behaviors. Similarly, Schneider et al. [82] showed that people trivialize an admonishing robot due to its technological immaturity. People seem unwilling to accept robots as social peers who are imbued with the status to judge humans. Hoffman et al. [41] concluded that people feel less guilty after cheating in the presence of a robot than in the presence of a human. These findings emphasize the importance of robot designs that evoke compliance.

Several earlier studies attempted to improve compliance with regulatory robots. Still, people comply less with a robot than with a human. Mizumaru et al. [62] developed an approaching strategy for a robot that admonishes pedestrians who use smartphones by modeling a human security guard's admonishing approach and proved that more people comply when the robot uses their proposed model than with a friendly approaching method. Schneider et al. [82] investigated why people ignore a robot's admonishments and proposed a counter-trivialization strategy to improve compliance. They found that significantly fewer people ignored the robot with their strategy. In addition, several studies attempted to find more effective strategies in influencing people's behavior in other contexts. Furthermore, Ham and Midden [39] revealed that robots become more persuasive when giving negative social feedback. Rea et al. [75] studied the effect of polite and impolite robot encouragement in an exercise context and pointed out that impolite behaviors can encourage people to push more effort. Moreover, factors such as anthropomorphism [49], physical embodiment [47] were found to be favorable in inducing social presence and hence social pressure.

Furthermore, some people have negative attitudes of robots that are trying to control their behaviors which implies a risk of rejecting such kind of robots from the society. For instance, Jois et al. [46] found that participants perceived a punishing robot (verbally or physically) as less-likable and felt less safe around it. Groom et al. [36] revealed that people perceive the robots as less friendly and more belligerent when they blame people.

Although researchers have studied effective strategies to improve the acceptance of robots when doing persuasive acts such as giving advice and feedback in other contexts, little work has been done on robots that try to stop people's inappropriate behaviour. Torrey et al. [93] proposed a communication strategy for a robot's advice-giving task using hedges or discourse markers and found out that robots are seen as more considerate and likable, and less controlling when they use these modifiers. Ghazali et al. [30] investigated how social cues and controlling language of the persuasive robot affect the reactance of people and discovered that the social cues reduce the reactance to the high controlling language. In addition, previous works has discovered acceptable communication strategies that robot can use when they perform other FTAs such as blaming users [36], and rejecting user requests [13] and responses to such robots.

Only a few studies are available related to the robots that prevent people's inappropriate behaviours (i.e., robots that execute moral interactions) in public spaces, especially how to design such robots to perform moral interactions in an acceptable way. Furthermore, the compliance of such robots requires further improvement to provide effective service. Moreover, there is a lack of studies on how different stakeholders in public spaces perceive regulatory robots, such as visitors being regulated or warned by the robots and fellow employees. Also, knowledge is limited on how to develop a robot system for controlling visitors in an actual public environment.

CHAPTER 3

Field Trial of a Shopworker Robot with Friendly Guidance and Appropriate Admonishments

3.1 Introduction

Social robots that serve in public places, such as airports, museums, shopping malls and hospitals are expected to socially interact with people and offer useful services such as guiding, information providing, entertaining, and educating [20, 25, 42, 59, 94]. Such stores and retail shops are the key sectors where social robots can be utilized as assistants. Robots may bring unique value to shops (e.g., attracting more customers) due to their rare existence in the public space. In addition, they are perceived as an alternative to high labor costs [84]. Existing shopping-store robots provide such services as welcoming, leading customers to product locations, carrying shopping carts, etc. [37, 44]. However, the abilities of existing shopworker robots have not yet been developed to the level of humans.

Shopworkers core tasks are providing friendly services and maintaining a shop's safe and courteous atmosphere. For example, shopworkers monitor customers and admonish the one who behaves inappropriately (smoking, littering, vandalizing, and shoplifting). However, monitoring and admonishing strangers are stressful tasks for shopworkers. Furthermore, the COVID-19 outbreak has increased the admonishing work load of shopworkers because they often have to remind customers to wear face masks. If robots can support shopworkers, it will reduce their burden.

With the robot being a social actor, it can support shopworkers' tasks and admonish troublemakers without negatively impacting their impressions. As a shopworker, the robot must be able to perform like a human shopworker who provide friendly services and social pressure when necessary. However, some people might resist being reminded or instructed by a robot because they feel that such machines are unsafe and less likable [46, 66]. People with negative viewpoints about such robots complicate the application of a robot-admonishing service in a real-world shop. A robot should not be perceived as an admonishing machine. We need a robot that has an admonishing functionality but still conveys a positive impression about itself and its admonishing service. We aimed to solve this difficulty by formulating our first research question.

RQ1: How can we design an acceptable admonishing service for a shopworker robot?

One possible acceptable admonishing service design would be a design that includes admonishing function and retains the image of a friendly shopworker. We believed that such kind of acceptable design could be achieved through harmony between friendly and admonishing services. To design the harmonized services, we interviewed several shopworkers and gathered their input and advice about what kind of admonishing and friendly roles they generally expect from a robot as well as the shopworkers' own admonishment strategies. We derived three design principles (i.e., friendly impression, zero erroneous admonishments, polite request) for a harmonized model and implemented friendly and admonishing services in our robot.

The second research question we addressed was:

RQ2: How do customers and shop staff perceive our robot in its harmonized dual services?

To answer this question, we conducted a 13-days field trial in a retail shop that sells souvenirs of a Japanese soccer team and interviewed the customers and the shop staff to learn their impression of our robot. Overall, shop staff and customers had a positive outlook on robot and its admonishing and friendly services. From our field study, we concluded that acceptable admonishing service could be achieved through the harmony between friendly and admonishing service.

In addition, we analyzed the robot's autonomous capability to provide its friendly and admonishing services in the field. Our results show that our robot can provide its services reasonably well with minimum human intervention. We also conducted an evaluation with hired participants to further examine the robot's autonomous mask recognition capability. This additional evaluation was done due to the limitation of the number of customers without masks in the field trial.

3.2 Design considerations

Shopworkers play two roles: 1) a friendly role, which provides a warm service to customers, 2) an admonishing role, which warns those who are failing to maintain a safe and courteous atmosphere by breaking the rules. Concerning these two roles, the shopworkers reacted anxiously to the admonishing task. The COVID-19 outbreak further increased their burden since they have to exert extra effort to monitor and remind customers who are not following safety protocols.

We wanted to support shopworkers by developing a robot that can provide a friendly service and appropriately admonish customers. Our challenge was to include the admonishing functionality to the shopworker robot while simultaneously designing it in more acceptable way for the shop and its customers. We particularly wanted the users to perceive the robot as a friendly shopworker rather than an admonishing machine. We believe a design that harmonized friendly and admonishing services will solve this issue. To identify a way to create such harmony, we interviewed several members of a shop staff. We asked about their expectations with robots for both the friendly and admonishing services as well as their own particular admonishing strategy. Below we describe their perspectives for the dual service and our design principles for a harmonized design.

3.2.1 Understanding the expectations of shop staff

Interview procedure

We conducted semi-structured interviews with three Japanese staff members of a store: a shop manager (male), an assistant manager (male), and a shop assistant (female), all of whom voluntarily agreed to our interview requests. They worked in a shop that sells the clothing, shoes, and sporting equipment of a national soccer team. We chose the staff members from different levels and duties to gather broader knowledge. The shop manager and the assistant manager obtained some prior experience with service robots when they observed an advertising robot that worked at a nearby shop.

The interviews were conducted by one of the authors. All the interviews were audio recorded and later transcribed for analysis. The interview questions were formulated by the authors. For each interview with shop personnel, we asked about their intention to use the following two aspects of the robot services:

Friendly role We asked them whether they were interested in using robots for providing friendly services in their store (e.g., their expectations from the robot). We also asked them to clearly explain their reasons. Furthermore, we inquired what kind of friendly services they expected from the robot.

Admonishment role We asked them whether they wanted to use the robot for admonishing services in their store. We also asked them to describe their own admonishing strategies and situations where admonishment might be deemed appropriate.

We thematically analyzed the interview results of the shop staff to identify their expectations for robot services and their admonishing strategies. This analysis was done by one of the authors.

Expectations for dual service

The shop staff mainly expected the robot to provide friendly services and admonish customers in situations where admonishment is the only choice for addressing inappropriate behaviors. The following are their expectations for each service and admonishing strategy.

Expectation for friendly service Concerning friendly services, all 3 members of the shop staff we interviewed expected the robot to contribute to the shop's interactive services and to create positive customer impressions. When asked about their reasons for using the robot, all 3 expected that using it would make shopping more enjoyable for their customers. The shop manager and the assistant manager believed that the robot's presence would improve the customers' shopping experience and increase traffic flow. All 3 members perceived the robot as a solution for staff shortages at peak hours and evenings. They intended to use the robot for such tasks as greeting customers (shop manager and assistant manager) and providing information (all 3). Furthermore, the shop manager and the shop assistant were intrigued with the idea of using the robot as a mascot to interact with customers.

Expectation for admonishing service All 3 shop staff members were willing to use the robot for situations that require admonishing. When asked about the reasons for their decision, they deemed it stressful and often felt awkward when admonishing or reminding strangers.

Shopworker's admonishing strategies We analyzed the shop staffs' responses about their admonishment strategies. All 3 mentioned that they tried to limit admonishments as much as possible to minimize negative reactions from customers. In other words, the shop staff did not admonish customers for every inappropriate behavior. They refrained from admonishing in situations where the negative impact of an admonishment exceeds the effects of an appropriate customer behaviors. For example, although behaviors such as returning an item to the wrong shelf or children shouting inside the shop might be considered inappropriate, they fail to warrant being admonished. On the other hand, smoking inside a shop is a serious inappropriate behavior where admonishing is permitted.

When asked about strategies for dealing with situations where they cannot comfortably admonish a customer, all 3 said they would discretely monitor the customer by pretending to engage in friendly behavior *(friendly monitoring)*. The assistant manager and the shop assistant said they might move near the customer and pretend to be doing another task, such as arranging items or cleaning shelves while closely monitoring that person's actions. The shop manager stated he would greet such customers.

Summary of interview results

The shop staff members were willing to use the robot for both friendly and admonishing services in their store. From interviews with them we identified the following three critical factors for designing a shopworker robot with an acceptable admonishing service:

1. Requirement I: The shopworker robot must act friendly and create a positive customer impression.
2. Requirement II: The shopworker robot must minimize negative customer impressions of admonishment.
3. Shopworker's admonishing strategy: Admonishments to serious inappropriate behaviors must be limited. Such admonishments and their key features should be communicated with a friendly monitoring strategy.

3.2.2 Design of robot service

We followed an iterative design approach (repeated prototyping and testing) [33] to design our robot. Based on the above interview findings, we created an initial prototype design of our shopworker robot with both friendly and admonishing services. We wanted to create a design that satisfied Requirements I and II listed above. We adopted key features of the shopworkers' admonishing strategies into our robot's behavior. We tested our prototype design in-house and demonstrated it with the other members of our research group. Then we improved our design based on our self-critiques and feedback from others and simultaneously updated its design principles. We repeated this testing and improving process until everyone involved in our project was satisfied with the robot's behaviors. All the authors participated in the design process.

We achieved a harmonized design based on the following principles that met the shop's expectations.

1. **Friendly impression:** We designed the robot to mostly operate in a friendly service mode for interacting with customers and exhibiting the impression of a friendly shopworker. We considered a *Friendly monitoring strategy* of shopworkers to design dual behaviors (Section 3.3.3) for with

which it monitors customers and determines when to admonish. Furthermore, we avoided admonishing as much as possible, limiting admonishments to a serious inappropriate behavior (i.e., shopping without mask). We directly formulated this design principle based on the findings of the interviews with the shop staff members.

2. **Zero erroneous admonishment:** While we tested our prototype, we noted that the robot has a limitation in detecting inappropriate behaviors, leading to erroneous admonishments. We believe the detection of inappropriate behaviors is critical and must be done with absolutely zero error. In other words, at all costs, the robot must avoid admonishing a customer without valid reasons. Furthermore, we thought that people might not accept a robot that determines whether various human behaviors are inappropriate. Therefore, a human operator determined whether the robot appropriately detected behaviors.

3. **Polite request:** We designed the robot's admonishing behavior to avoid creating negative customer impressions by giving it polite, respectful language for the admonishments. The participants of our prototype tests categorized as harsh the robot's admonishment that were too direct: "Please put on a mask". Therefore, we searched the literature to find a proven way of admonishing without upsetting the targets. As previously suggested [14], politeness strategies can be used in human communication to soften the effect of admonishments (i.e., one kind of a face-threatening act) when admonishing is inevitable. Formulating the admonishment as a question is one such strategy. Thus, we created the robot's admonishment as a polite request: "Would you please put on a mask?". After the request, the robot thanked the customers who modified their behaviors and bowed (which is important in Japanese culture).

For our example of inappropriate behavior, we chose entering a shop without a mask to reflect the reality of the COVID-pandemic. The robot identified people without masks and admonished them. As a friendly service, we implemented a simple but essential service that the robot could do on behalf of the human shopworkers: directing customers to product locations. Thus, we implemented greeting and guiding as the robot's main behaviors.

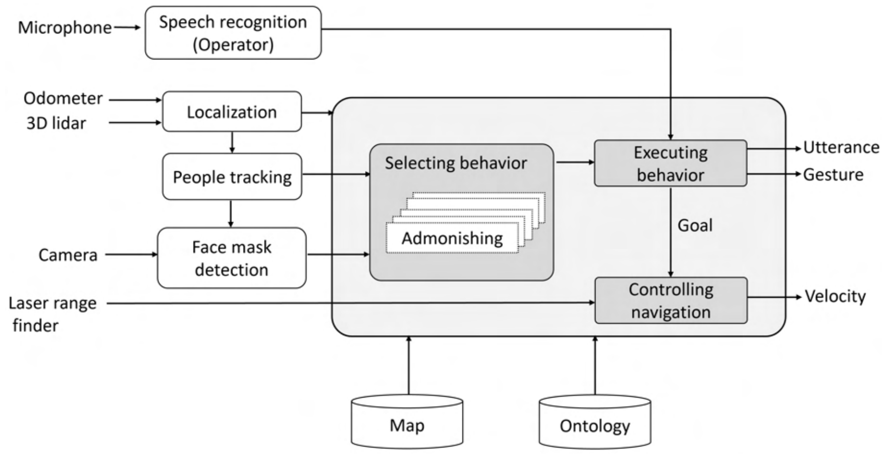


Figure 3.1: System architecture

3.3 System

3.3.1 Architecture

Figure 3.1 illustrates our system's architecture. The robot selects one of its behaviors (Section 3.3.3), based on the information received by the localization (Section 3.3.4), people tracking (Section 3.3.4), and face-mask detection (Section 3.3.4) modules. The robot localizes itself in its environment using the inputs of an odometer, 3D LIDAR, and a multilayered map. This localization information is used by the people tracking-module to identify where the customers are in the store. The face-mask detection module considers the face images of people that obtained by the camera, and their positions that tracked by the people-tracking module, and detects those wearing masks.

Once a behavior is selected to be executed, each behavior reads the real-time sensory data and controls the robot's actuation, such as utterances, gestures, and navigation (Section 3.3.4). If conversation is required with a visitor (such as for giving directions or guiding behaviors), the behaviors used the speech recognition module (Section 3.3.4) operated by the operator. Furthermore, an ontology of products (Section 3.3.4) is used for find product locations.

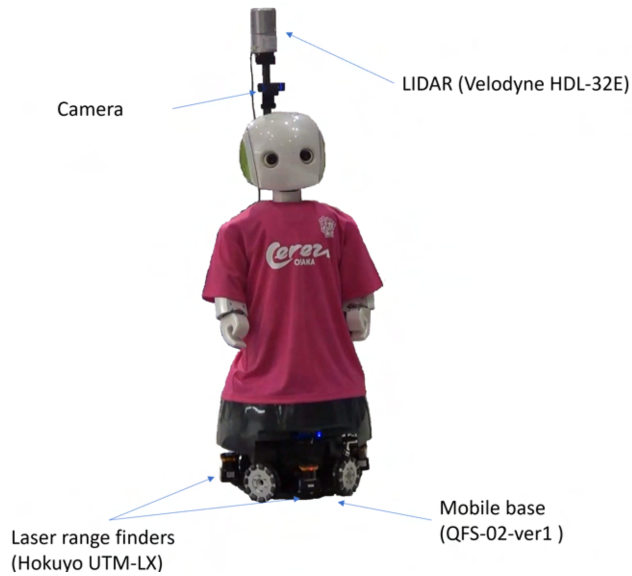


Figure 3.2: Robot

3.3.2 Robot

Our field trial used Robovie-R3 (Figure 3.2), which stand 120 cm tall. It has human-like physical appearance (11 DOFs for its gestures). It was dressed in a soccer team T-shirt to resemble the appearance of a shopworker. The robot used QFS-02-ver1 developed by Qfeeltech for its mobile base. It has omnidirectional wheels that allow it to move in any direction at a maximum speed of 0.8 m/sec. Its maximum angular velocity is 60 degrees/sec. A LIDAR (Velodyne HDL-32E) was attached on a top of a pole with a height of 143 cm on Robovie's back for localization and people-tracking. We also attached four laser range finders (Hokuyo UTM-LX) to its mobile base for obstacle detection for its navigation functionality.

3.3.3 Behaviors

Behavior transition

The behaviors of the robot can be categorized into the following three groups: friendly (giving directions and guiding), dual (roaming and approaching), and admonishing:

- Friendly behaviors: The robot's intention, which is to assist customers, is

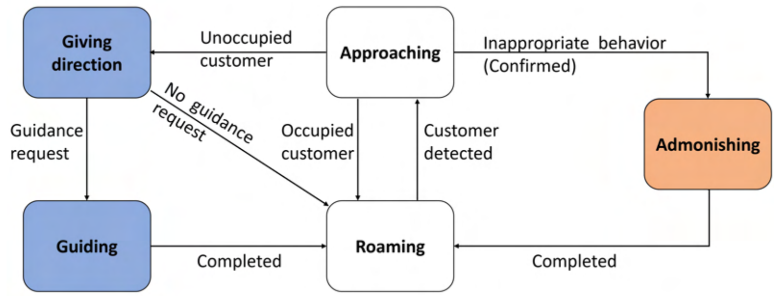


Figure 3.3: Behavior transition of robot

completely friendly and customers are expected to perceive its actions as such.

- Dual behaviors: The robot uses a friendly monitoring strategy to decide whether to assist or admonish customers. The robot's intention is not entirely friendly. However, it tries to make a friendly impression by roaming around the shop, greeting and approaching customers.

- Admonishing behavior: The robot admonishes customers who engage in inappropriate behaviors. They are expected to perceive this behavior as unfriendly.

Figure 3.3 depicts the behavior transition of the robot. It basically roams in the shop and looking for customers. When customers are detected, it approaches them. During its approach, the robot selects a friendly behavior (i.e., giving directions and guiding) or an admonishing behavior depending on the detection of inappropriate actions (i.e., no mask).

If an inappropriate behavior (i.e., no mask) is detected and confirmed by the operator, then the admonishing behavior is triggered. Even if the customer is occupied (this is not the direction giving target), the robot approaches to admonish. After the admonishing behavior is completed, the robot returns to roaming behavior.

If no inappropriate behavior is detected, the robot checks whether the customer is occupied and only initiates friendly interaction with customers who seem unoccupied. If a customer is available for interaction, the direction-giving behavior is triggered. After providing directions, the robot asks whether she would like an

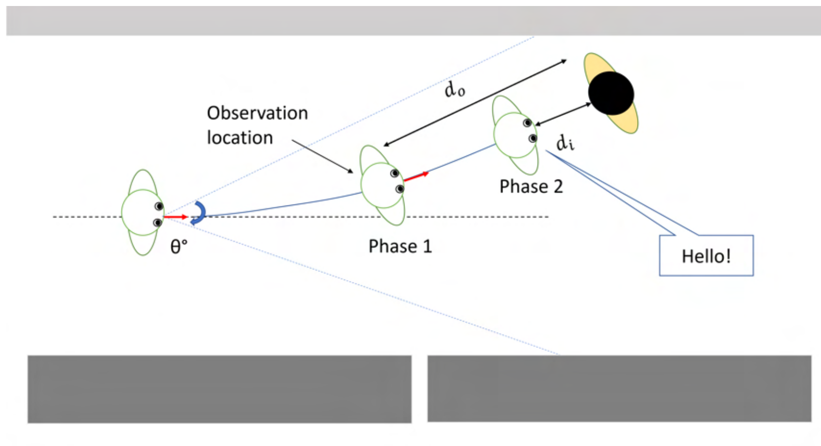


Figure 3.4: Approaching behavior of robot

escort to the target location. If the offer is accepted, the robot starts its guiding. After the guiding is completed, the robot starts roaming around the shop.

Behaviors of robot

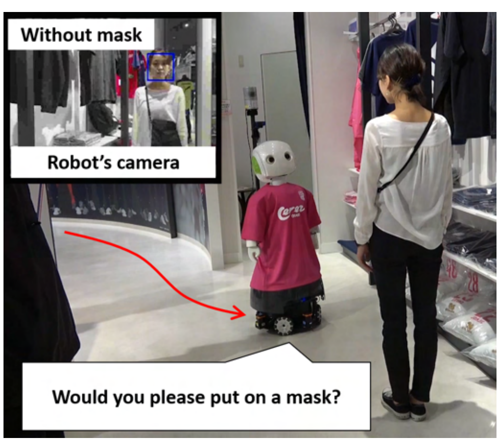
1. Roaming

   The robot's roaming behavior has two roles: creating a friendly impression and monitoring customers. Our robot continuously roams around the shop, enabling customers to easily recognize its presence. Thus, people who want to use it will simply recall its presence and access it easily. To create a friendly impression, we designed the robot to greet customers while roams around the shop. This shop consists of rows of shelves around 1.5-m high and 1-m wide aisles. Thus, a person of average height can see the robot over the shelves. When it passes by customers detected by the people–tracking module (Section 3.3.4), and if they are unapproachable due to the shelves, the robot looks up and greets them with such friendly language as "Welcome" and "Enjoy your shopping." We selected a roaming route that covers most of the shop, including those areas at which the shop staff cannot look frequently. Thus, the roaming route supports the monitoring role and increases the availability of the robot.

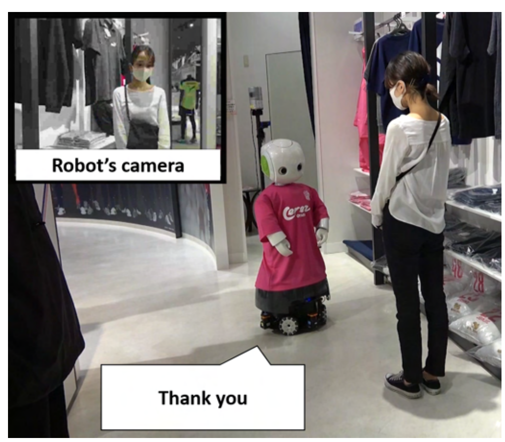
2. Approaching

   In this behavior the robot approaches customers for conversation. It has two phases (Figure 3.4). First, once the robot detects customers using the people-tracking module, it automatically starts to reach those within the $\theta°$ vicinity of its moving direction. Due to the shelves and size of the aisles the robot can only approach people who are in front of it. Therefore, we chose 45° because it is the maximum possible range the robot can approach. Then it stops at d_o (2.5 m), which is the maximum stable distance for detecting the faces of people and monitor them. Then it looks at the person's face and checks whether he is wearing a mask, as described in Section 3.3.4. Then it waits for the operator's confirmation of the mask situation. The operator's confirmation enables the robot to admonish with 100% accuracy, and avoid situations that result in customers being mistakenly admonished. Next, the services are chosen accordingly. In case admonishing is needed, the robot approaches the customers even if they are occupied. On the other hand, for the guiding service, it waits for the operator's confirmation to approach the person. Otherwise, the robot executes its roaming behavior. At the last phase of approaching, the robot moves to the interaction distance d_i of 1.0 m. As it comes closer, the robot looks at the faces of customers and starts addressing them. Its language differs based on the selected service. For the friendly service, it simply says "Hello." When it approaches to admonish, it says "Excuse me."

3. Admonishing



(a) Polite request



(b) Thanking

Figure 3.5: Admonishing behavior

Figure 3.6: Direction-giving behavior

The admonishing behavior of the robot was designed to be polite to avoid negative customer impressions. The robot behaves courteously and uses polite utterances. The robot politely requests the customers: "Would you please put on a mask?" If customers comply with the robot's request, it thanks them and bows. Figure 3.5 shows the admonishing behavior that consists of two phases: polite request and thanking. In the first phase it asks the customer to wear a mask and waits for the operator's confirmation that the customer agreed. Using a human operator ensures zero erroneous admonishment. If the customer obeys the admonishment, the robot executes the thanking phase.

We prepared the following variations of robot responses that anticipate different customer reactions to being admonished. If the customer doesn't immediately comply with the robot's request (or argues), then it repeats the request a maximum of three times. If a customer still refuses to comply, then the robot stops admonishing and resumes roaming in the shop. If the customer leaves without cooperating with the robot, it stops admonishing and starts to roam again. If the robot again sees a customer who failed to comply to its admonishment in a different location of the shop, it approaches again and repeats its admonishment.

4. Giving directions

Figure 3.6 shows the direction-giving behavior, which starts with a self-introduction: "Welcome to our store! I'm Robovie. I'd love to show you

Figure 3.7: Guiding behavior

around." Without this self-introduction, customers might not understand its guiding role [80]. Any confusion might cause customers to overlook the robot's services. Next Robovie asks whether it can help them find anything in particular. If the customers respond with a specific product name, the robot confirms the name by repeating it, finds it on the map using ontology and keywords, and shows the directions by pointing and gazing. Finally, the robot asks the customer if she would like to be escorted to the target location.

5. Guiding

   For guiding behavior, (Figure 3.7) the robot escorts the customer to the product's location and points to it on the shelves. If the target location is relatively far away, the robot makes small talk throughout their walk. Such conversations include shop information and advertisements. To start small talk, the robot calculates the shortest path to the product location. If the length exceeds a pre-defined threshold, it engages in small talk. We set 2 m as the threshold distance for starting small talk. This value was adjusted by trial and error to allow sufficient time for the customer to respond to the robot.

3.3.4 Other modules

Localization

We applied a particle-filter-based method on the LIDAR and odometry inputs and, we conducted map-matching for each particle. The module periodically corrects the robot's location at 10 Hz. The localization module uses a 3-dimensional map prepared in advance, which was created by tele-operating the robot in the environment and applying the 3D Toolkit SLAM library to match consecutive scans (containing LIDAR 3D scans and odometry data) and performing global relaxation [9].

People tracking

We implemented a people-tracking algorithm for the point cloud from LIDAR that consists of three process steps: background subtraction, people detection, and people- tracking. The background subtraction, which is done immediately after the localization, compared the map and the raw point cloud, and removed the entities recorded in the map. After this, the remaining point cloud shows the movable entities. At the people-detection step, clustering is applied and entities that approximately resemble a person's size are detected. Finally, in the people-tracking step, a particle filter is applied to the detection result, so even with occlusion, e.g., passersby, it can continuously track the locations of people. In our setting, the system tracks those who were within 10 m of the robot every 0.1 second.

Face-mask detection

We used a combination of face detection and people-tracking modules to detect people wearing masks. The face detection algorithm considers such features of faces as eyes, nose, and mouth to detect faces. Unfortunately, when a person is wearing a mask, some of these features become invisible. Thus, the system will not be able to detect the face. However, the people-tracking system still detects a person's presence. The combination of these two enables the robot to detect people who are wearing masks. We used OpenCV [2] to implement the face detection algorithm, which was trained with a data set of the faces of people not wearing masks.

Navigation

When a goal is given, the robot checks for obstacles between the goal and itself. If there are none, it directly approaches the goal. Otherwise, it calculates the shortest path to the goal using a topological map (Figure 3.8), which was manually created using a grid map. The robot calculates the shortest path by finding

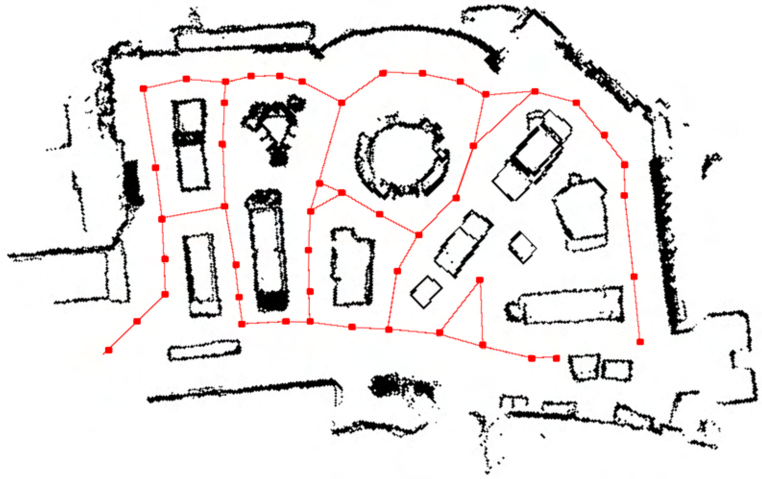


Figure 3.8: Topological map

the closest node to itself and the goal and calculates shortest path to the goal based on the A* algorithm. The robot calculates the shortest path every 100 ms to support the movements of people and reaches the target by following the nodes on the topological map. We used a Dynamic Window Approach (DWA) [29] for collision avoidance. DWA periodically considers short time periods when calculating the next steering command and selects optimum velocities by considering the acceleration and velocity constraints of a system. We applied an extended version of DWA that also considered the side velocities for our omnidirectional robot. We used the ROS DWB library for the implementation [1]. We also implemented a safety module to reduce the risk of collisions when the robot moved closer to obstacles.

Speech recognition

Due to various ambient sounds in the shop (videos of soccer games, shop music, and so on), we gave up using an automatic speech recognition (ASR) and a semi-autonomous approach [31]. In this previous work, one operator controlled up to four robots at the same time. Thus, even with an operator (Section 3.3.5), our system can realistically provide services. Note that in our system, the operator only typed the words spoken by the users without supplementing any knowledge. It means that the operator can be a novice who does not need to know anything about the shopping mall and can be replaced with a more advanced ASR that

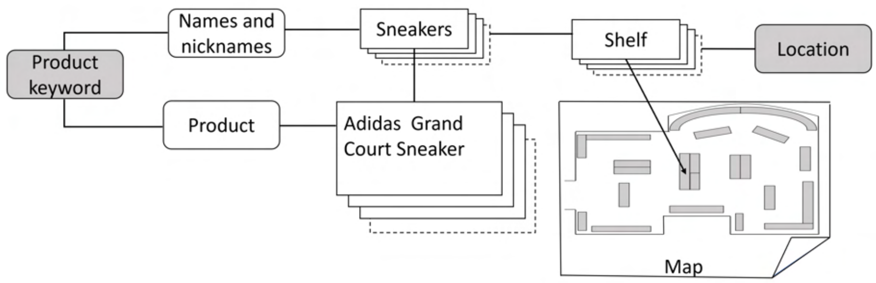


Figure 3.9: Ontology for guiding service

will be developed in the near future.

Ontology for guiding service

Figure 3.9 depicts the ontology used by the robot to find the locations of products during the guiding service. The ontology consists of two classes, product keywords (names, nicknames, and actual products) and locations (shelves) in the shop. It contains 270 products, 4328 nicknames of products, and 50 locations. Figure 3.9 shows an example where "sneakers" is related to the actual product "Adidas Grand Court Sneaker" and the shelf where it sits.

3.3.5 Role of operator

We used a human operator to improve the accuracy of the system. The operator serves like another module and might be replaced with a more sophisticated autonomous module in the future. To investigate the potential of autonomy, we limited the operator's intervention to the following situations where human's assistance is essential for the robot to proceed with its duty.

The operator is involved in four types of control: speech recognition, confirmation of inappropriate behavior detection (i.e., shopping without masks), determining whether customers are occupied or not, and error correction. The determination of being busy is executed right after the mask confirmation (whether a person is wearing a mask). Therefore, the mask confirmation and being busy detection are implemented as one system task. Operator control was achieved using a graphical user interface. The following are the operator's duties:

- Speech recognition: This function was only performed for the direction-giving and guiding services.

- Confirmation of inappropriate behavior detection: The operator verifies inappropriate behavior detected by the system in two situations. First, the robot monitored customers from the observation distance. After its admonishment, it confirmed whether the person complied.

- Determining whether customers are occupied or not: Whether customers are occupied or not is determined when the robot observes customers before offering the guiding service. This detection is entirely done by the operator. We implemented no autonomous modules due to task's complexity.

- Error correction: The operator mainly fixes two types of errors: navigation and localization. During the navigation, the robot might move too close to a wall or a shelf. If the distance between the robot and an obstacle is less than a predefined threshold, its autonomous navigation is stopped by the safety module. Then the operator must fix it and remove the safety lock. Sometimes when the robot's sensor data do not match the localization map, it fails to correctly find itself in the environment. Then the operator is also required to fix the location.

3.4 Field trial

We conducted a field trial to test the proposed harmonized dual service robot in a real shop environment. We wanted to focus on to what degree the robot can autonomously provide services, how customers interact with it, and their impressions of it. The shop staff and the customers were interviewed to explore their impressions of the robot and its admonishing and guiding services, their comparison of the robot with a human shopworker, and their intention to use it in the future.

3.4.1 Procedure

The field trial was conducted at a retail shop (Figure 3.10) located on the ground floor of a large shopping mall. It sells souvenirs of a popular soccer team, such as athletic equipment, clothing, sneakers, bags, and key tags. The shop is approximately 100m^2 in area and consists of 1-m wide corridors that satisfy the

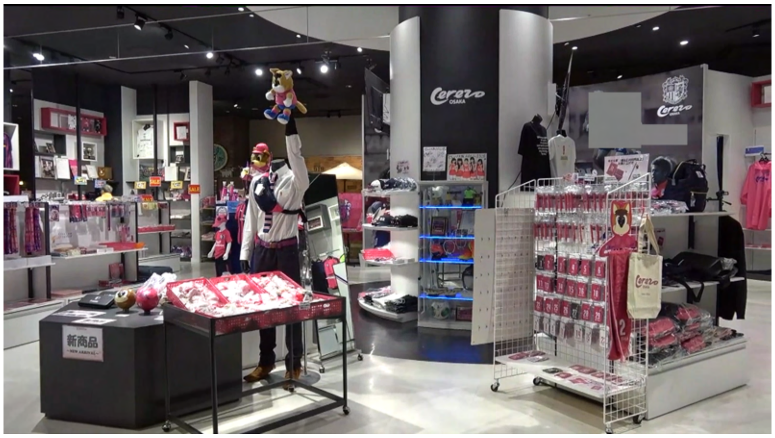


Figure 3.10: Shop environment

robot's minimum space requirements for smooth navigation. The shop was often crowded on weekends, holidays, and year-end sales days. The customers ranged from children to seniors. Families and couples were the most frequent customers.

The robot was tested during 13 days from November 11 to December 26, 2020, three hours per day on weekdays and weekends. This period includes the year-end sales days. The field trial sessions were conducted from 1 to 4 p.m. each day. This time was chosen in accordance with the shop manager who wanted to avoid extremely crowded hours as a COVID-19 precaution and to avoid disturbing the shopping of customers. On average the shop was crowded with 5 to 6 customers on weekdays and 10 to 15 customers on weekends. However, on several days the shop was more crowded than expected. Therefore, we temporarily stopped the field trial session for 20 to 30 minutes until the crowd thinned out.

We used the robot described in Section 3.3.2 that was implemented with the harmonized dual service for our field trial. A human operator sat in a separate room to support the robot's operation when needed. He handled the admonishment confirmation, the speech recognition, and the error handling. We recorded all of his commands and behavior states (including starting and ending times, mask detection results) for evaluating our system. The robot was available to the staff and any customer who visited the shop. We did not provide any prior instructions or explanations about the robot or its functionality to the customers except a notice at the shop's entrance that explained that a field trial of robot services was in progress and videos were recorded for research purposes. Thus, the customers were free to interact with the robot or to ignore it.

We used three video cameras to record the interactions of our field trials: two static cameras and one mobile camera with which one investigator (a camera operator) followed the robot to capture the interactions with the static cameras.

We managed our field trial with three investigators in the shop: an interviewer, a safety monitor, and a camera operator. The interviewer observed the interactions from around 10m distance and approached the customers for interviews. The safety monitor and the camera operator followed the robot without disturbing the interactions. The former, who is responsible for the safety both of the robot and the customers, could stop the robot with a Bluetooth controller when needed, including when rambunctious children pose potential risks. The camera operator captured the interactions using a mobile camera. Note that all the investigators were always located away from the robot and didn't interfere in the interactions.

3.4.2 Data collection

During the field trial we collected data of the system performance records, observations, and interviews to evaluate the robot's ability to provide admonishing and guiding services in an actual shop environment as well as the opinions of the customers and the shop staff about it.

System performance records

We collected three forms of system performance records: 1) system logs (starting and ending times of all five behaviors (roaming, approaching, admonishing, giving directions, guiding) and data related to mask recognition and operator control); 2) behavior logs (number of guiding and admonishing attempts and successful ones); 3) manual records (time taken for such manual operations as map and ontology updates). Based on the above records, we calculated the following five measures to evaluate our system's performance.

1. Total time the robot served and total time being autonomous: We recorded these two values to understand to what degree our robot can work autonomously. We calculated the total operator control time to compute the time that the robot was autonomous We recorded the time spent by the operator to resolve the system calls for operator assistance as well as

the type of control exerted on the system log. Each time period was measured from the point where the system summoned operator assistance to finishing the task. This includes the waiting times for the user responses. Thus, we measured the time taken for four types of control: speech recognition, determination whether customers are occupied or not, confirmation of inappropriate behavior (during monitoring and after admonishment), and error correction. We combined them as the total operator control time and subtracted the autonomous time from total time the robot served. In addition, we calculated the average time between two system calls for operator assistance.

2. Number of ontology, topological, and grid map updating incidents and total time spent: Updating its knowledge is an operation the robot cannot autonomously manage and requires human effort. We were interested in knowing what kind of updates happen in real shop environment, how frequently they happen, and how much time is required for them. These values were counted using our manual records.

3. Number of guiding requests and admonishing attempts and number of successful guiding and admonishing incidents: We use these data to study how frequently each service was provided and how each module worked.

4. Face-mask recognition accuracy: We recorded the face mask recognition data and calculated the accuracy to evaluate the effectiveness of the face-mask detection module.

5. Total time the robot spent engaged in friendly dual and admonishing behaviors: We used these values to measure the portion of its total service time during which the robot was presented in a friendly way.

Observations

All the field trial sessions were video recorded. We used these video recordings to investigate whether the robot smoothly provided dual services and to identify the customers' interactions with it. We note the following types of information: the number of interactive user groups, how interactions were started, the nature of the typical guiding incidents, how customers reacted to being admonished, and the typical reactions of children and adults.

Interviews

We interviewed customers whose interactions with the robot extended beyond superficial greetings as well as the shop staff to learn their impressions of our harmonized dual service robot, its admonishing and friendly services, and the reasons underlying their opinions. We used a semi-structured interview that consisted of open-ended questions. The interviews were conducted by one of the investigators and were both recorded and transcribed.

1. Interviews with customers

   We approached customers who used the guiding service or were admonished after they finish interacting with the robot to participate in interviews based on their experience with the robot. We excluded customers whose interactions were limited to approaches and greetings because such short interactions with the robot were too superficial. We also excluded young children, assuming they would struggle to appropriately answer the questions. We interviewed 30 customers: 15 males and 15 females.

   These 30 customers answered questions under the following topics. In each part, we asked them to explain their responses.

   - Impressions about the robot and their interactions with it, i.e., guiding or admonishing.
   - Impressions about the other robot services (guiding or admonishing) that customer did not experience: There was a possibility that a customer experienced only one of the robot services. Hence, we described to the customers the other available robot services that they didn't experience and asked for their opinions about them. In other words, we asked the customers who received only the guiding service to imagine the admonishing service and vice versa.
   - Comparison with a human shopworkers: Preference for receiving a dual service from a human or a robot.
   - Intention to use the robot in future: Whether they wanted to use it again.

   The shop manager requested that we minimize disturbing the shopping experiences of the customers and to protect their privacy. Therefore, we limited the interview questions to the above topics and avoided asking such personal questions as age.

2. Interviews of shopworkers

   The interviews of shop staff were conducted at the end of the field trial to give them adequate time to observe the robot's performance. We only interviewed those who observed the robot's service on at least one day. After obtaining permission from the shop manager to interview his staff, we interviewed willingly members without paying them. However, except for the shop manager, neither of the previous staff members whom we initially interviewed still worked in the shop a year later when we did our field trial. Thus, we interviewed five new shop personnel: 2 men and 3 women.

   The questions for the second series of staff interviews slightly differed from those of the customers. Such changes reflected the differences in their purpose of using the robot, their interactions, and time period of engagement (i.e., the robot's interaction with customers was rather short compared to the shop staff). The interview questions were formed under the following topics. In each topic, we asked them to explain their answers.

   - The robot and dual service: opinions of the robot and the provided dual service, and their preferences between the dual service robots and those specialized for each service.
   - Guiding service: impressions of the robot's guiding service and comparison with a human shopworker.
   - Admonishing service: opinion of it and comparison with a human shopworker.
   - Expectation for working with robots: degree of interest in working with the dual service robot and their expectations for working style, i.e., robot-only shops or human and robots working together.

Table 3.1: Summary of system related statistics

Measurement	Value
Total days served by robot	13
Total time it served	1611.0 min
Total autonomous time	1515.9 min (94.1%)
Average time period between system calls for operator assistance	3.9 min
Number of ontology, topological, and grid map updating incidents	4
Total time of ontology and map updates	224.0 min
Total time of friendly and dual behaviors	1609.4 min (99.9%)
Total time of admonishing behaviors	1.6 min
Number of monitoring attempts (approaching and checking faces)	194
Number of greeting incidents	161
Number of guiding requests	57
Number of successful guiding attempts	53
Number of admonishing attempts	4
Number of successful admonishing attempts	3

3.5 Results

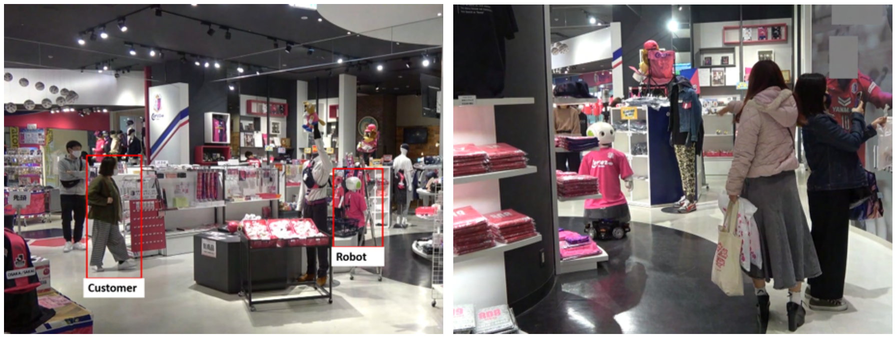
3.5.1 System performance

Table 3.1 presents the system's performance related statistics. The robot served for 1611 min. The operator was with the system during this entire time period to respond if system needed assistance. However, the total time the operator actually worked was 95.1 min. This includes time for speech recognition (70.5 min.), determining whether customers are occupied or not (6.3 min.), mask detection confirmation (15.5 min. during monitoring and 0.9 min. after admonishment), and fixing navigation errors (1.9 min). Thus, the robot was autonomous for 1515.9 min., which is 94.1% of its total operation time. For operator assistance, the operator received 416 system calls, which were categorized into the following three types: I) speech recognition (206); II) mask detection confirmation, and determination whether a customer is occupied (described in Section 3.3.5): (194); III) error correction: (16). The average time between system calls was 3.9 min. In addition, the ontology, topological, and grid maps were updated on 4 occasions due to changes in the products and their locations. These updates required 224 min. Such modifications are unavoidable in real shop environments.

The robot greeted and introduced itself to the customers in 161 incidents. These incidents involved individuals and groups such as families and couples. Even if several people from a same group interacted with the robot, we counted them as one group. It received 57 guiding requests. Others greeted the robot and replied they did not need any assistance. Once the operator performed speech recognition and typed the utterances of the visitors, it autonomously interpreted and successfully fulfilled 53 guiding requests, including both pointing at products and guiding customers. 4 guiding requests could not be completed for several reasons. For example, sometimes the operator could not comprehend the speech of children. Some customers requested sports apparel that was not included in our ontology. In another situation a customer asked for a specific athlete's gear and the operator mistyped the name. Therefore, the robot could not find any products in the ontology. People without masks was rare. We only observed 4 admonishing attempts. In 3 of them, the people complied with the robot's request.

The shop was generally not very crowded. Most of the time the robot roamed in the shop and looked for customers. It spent 72 min. guiding and giving directions in friendly behaviors. It engaged in 1.6 min. of admonishments. The rest of the time it roamed and monitored (i.e., dual behaviors) and presented a seemingly friendly appearance to customers. Thus, the robot acted in a friendly way for 1609.4 min.: 99.9% of its total operating time.

During the field trial 175 people with masks and 4 people without mask were spotted. Among them, the robot successfully detected 152 cases. Thus, the mask-detection accuracy was 86.6%. Due to the limited number of people without masks, we did an additional evaluation (Section 3.6) with hired participants to further analyze our robot's mask detection capability.



(a) Customers approached the robot

(b) Customers beckoned to the robot

Figure 3.11: Customers initiating interactions

3.5.2 Interaction scene

Typical interactions with customers

Interactions typically started in two forms. Half of them were initiated by the robot. In the other half, customers approached the robot by themselves or beckoned to it (Figure 3.11). Families and couples were the most interactive users. Generally, adults interacted with the robot just once; children often repeatedly interacted with it.

After initiating an interaction and the robot explained its guiding capability, over one third of the customers used the guiding service. The following is a fragment of a conversation between a robot and a customer:

Robot: ***Welcome to our store! I'm Robovie. I'd love to show you around. Are you looking for something in particular?***

Customer: Yeah, Kakitani's (a soccer player's) stuff.

Robot: ***His goods are over there.***

Customer: Oh. Thanks!

Robot: ***Would you like me to take you there?***

Customer: please do.

Robot: ***Okay, follow me.***

Figure 3.12 shows a typical guiding incident. Generally, they asked about uniforms and soccer balls that are specific to the shop. When the robot pointed at a target location, the customers looked in that direction. Nearly half of the customers requested the guiding service to check the robot's capability. They

(a) Asking product location (b) Robot explaining the directions (c) Customer following robot (d) Robot showing the product

Figure 3.12: Customer using robot's guiding service

(a) Bowing (b) Greeting (c) Taking pictures

Figure 3.13: Adults' reactions to robot

quizzed it about the locations of products that were close or clearly visible. For example, one child looked around and asked for the location of soccer balls that was directly behind him.

Once the robot explained the directions, a majority of the customers requested the robot to escort them to the product. As they followed it, the robot engaged in small talk and actively engaged most of the customers who seemed to enjoying such interaction. Customers' questions included "Who is your favorite soccer player?" and "Have you ever been to the stadium?" After reaching the required location and finding the product, people often bowed and thanked the robot. A fragment is given below of the small talk between the robot and a customer while they walk to the product locations:

Robot: ***The next world cup will be held in 2022.***

Customer: Oh, wow!

Robot: ***I can't wait.***

Customer: I know.....Who's your favorite player?

During the greeting and guiding services, many customers enjoyed their interactions with the robot. They often smiled or laughed when they were talking with

(a) Running towards robot (b) Looking at it (c) Touching it

Figure 3.14: Reactions of children to robot

the robot. People often bowed and greeted the robot even if they did not use the guiding service (Figure 3.13 (a) and (b)). Some took pictures of the robot (Figure 3.13 (c)) and were excited by its appearance. A few adults were very interested in the robot and interacted many times with it during their time in the shop. We noticed a repeat customer who interacted with it on both days he visited. In addition, we observed a male customer who stroked the robot's head as if he were petting a dog. The enjoyment of the customers who interacted with the robot swayed others to interact themselves. Some customers continued shopping while observing how others used it and eventually requested its assistance.

Children showed more interest in the robot than adults. They exhibited a variety of reactions to it. They often approached it by themselves. Some ran toward it when they first noticed it (Figure 3.14 (a)). Several children insisted that their parents talk to it. Generally, the children repeatedly interacted with the robot and often followed it to another location. They spent time watching it (Figure 3.14 (b)) and how it interacted with others. Some children touched the robot (Figure 3.14 (c)) or petted its head. Others played in front of it, took pictures, etc.

Admonishing incidents

Since most of the customers were wearing masks, we only observed 4 admonishing incidents during the entire field trial. The robot admonished 4 customers, and 3 complied. No arguments or conflicts occurred between the robot and the customers.

Figure 3.15 shows a successful admonishing incident that involved a group of

(a) Robot detected two children without masks (b) Robot admonished them (c) One child put on his mask

Figure 3.15: Successful admonishing incident

mothers and children. Two boys were not wearing masks. The robot noticed them, approached, and asked them to put on masks (Figure 3.15 (a) and (b)). They looked surprisingly at the robot. One boy put his mask on (Figure 3.15 (c)). The robot thanked him. Then the robot asked the other boy again to put on a mask. Finally, his mother took a mask from her bag and put it on him. Another successful admonishing case involved an adult and a toddler. They approached the robot because the toddler was interested in it. The father's mask was on his chin (Figure 3.16 (a)). The robot noticed and asked him to pull it up. Immediately after the admonishment, the adult pulled it up and walked away (Figure 3.16 (b)).

Figure 3.17 shows an unsuccessful admonishing case that involved a young preschool age girl who approached the robot by herself and observed it without any interaction. The robot admonished her for not wearing a mask. She ignored the request and walked away without responding. Robot did not meet her again during its roaming in the shop.

3.5.3 Interview results with customers

30 customers who experienced the guiding service accepted our interview requests. We did not interview any of the 4 (3 children and 1 adult) customers who were admonished due to several reasons. The parents of one child could not be found. The adult and parents of other children rejected our request because they were too busy. Similarly, some customers who used the guiding service refused our request. Thus, we only analyzed the responses of 30 customers.

We analyzed our interview results themselves by applying a qualitative con-

(a) Robot admonished a customer (b) Customer put on his mask

Figure 3.16: Successful admonishing of an adult

Figure 3.17: Unsuccessful admonishing incident with a child

tent analysis [34]. It is a bottom-up approach to define the exclusive main (i.e., opinion) categories and the subcategories (i.e., reason). In other words, the categories were defined by considering the nature of the interview data. We classified a given customer's answer into only one of the opinion categories. If the customer listed several reasons for his/her opinion, then he/she was counted under every applicable reason category. The interview results were translated from Japanese to English.

The opinions of the customers who used the guiding service are under the following four topics: impressions of the robot and the guiding service, impressions of the admonishing service, comparison with a human shopworker, and intention to use in the future.

Table 3.2: Summary of customers' impressions of robot and guiding service

Impression	Reason
Positive (30)	Capability (21/30)
	Robot Specific (15/30)
	Child-like design (10/30)
Negative (0)	-

Impression of robot and guiding service

First, we categorized the overall impressions of a customer into one of mutually exclusive main categories: *positive* or *negative*. Then we subcategorized the reasons for their impressions under the relevant main category.

Table 3.2 summarizes their responses. All the customers who used the robot's service had overall positive impressions about the robot and the guiding service. They also suggested some minor improvements to the functionality: more conversation variety and different speed responses. However, none had a negative attitude towards the robot. We identified three categories: *capability, robot specific,* and *child-like design.*

Capability: 21 out of 30 customers argued for the capability of the robot to do the guiding service. This category also includes the service's usefulness, its naturalness, etc. Customers offered the following comments:

– "Yes, the robot was capable. It was very clever. I think it's necessary. After all, it's more difficult to find a shop clerk and ask for help, so I think it's good that only people who want to use the service can choose to do so."

– "It guided me well, as smoothly as a person."

Robot specific: Half of the 30 customers commented on the merits that are particular to the robot (i.e., differences from human shopworkers) and specifically mentioned such features as *easy to talk* , *good for COVID-19 restrictions* (slows community spread), *good for children, enjoyment*, and *novelty.* They made similar comments:

Table 3.3: Summary of customers' impressions of admonishing service of robot

Opinion	Reason
Accept (27/30)	Robots are more acceptable for customers (than human) (14/27)
	Adequate capability (12/27)
	Easier for robot to do (3/27)
	Child-like design (3/27)
Reject (3/30)	Prefer humans (3/3)

- "I can talk to the robot as easily as a clerk. I don't know what to say, it's better than talking to a clerk directly, because I can talk more easily and be myself." *(easy to talk)*

- "Since COVID-19 is going around now, I think robots like that or non-contact customer service is a good idea" *(good for COVID-19 restrictions)*

Child-like design: 10 out of 30 customers preferred the robot's child-like design (appearance, voice, and so on). They felt it was "cute":

- "The child's voice was really good, because it was kind of cute. It makes me want to listen to the robot. Like being guided by a child."

- "It was like a child, like a person."

Admonishing service

We classified the opinions of the customers into one mutually exclusive main category: *accept* or *reject*. We categorized the customers who commented that the admonishing service was good and appreciated its merits in the *accept* category and those who argued for its demerits into the *reject* category.

Table 3.3 summarizes the customers' impressions of the admonishing service. A large majority (27 out of 30) accepted the robot's admonishing service. The customers who accepted the admonishing service mentioned one or more of the following reasons:

Robots are more acceptable for customers (than humans): 14 out of 27 customers mentioned that using the robot for admonishment is better than a human shopworker. They also pointed out the following merits:

- "I think it's better to be warned by a robot. It's less harmful because robots say things without feelings (just because it has been programmed to say things). If it were human, a person might feel, "Oh, that person doesn't have the right to berate me.""
- "If I were chastised by a person, I'd probably feel bitter, angry. But if I were told by a robot, I wouldn't feel so bad."
- "I think it's better to use a robot because then it doesn't feel like people are spying on you."

Adequate capability: 12 out of 27 customers mentioned the robot's capability to admonish:

- "I would probably wear a mask if a robot asked me."
- "If the robot says, "Please wear a mask," then I'd think, "Oh, I have to wear a mask because that's the rule.""

Easier for robot to do: Just 3 out of 27 customers commented that the admonishing was easier for a robot than a human shopworker. They made the following comments.

- "Well, I think it's (robot admonishing customers) fine. I mean, in this day and age. If it were a human, sometimes a person might find it difficult to say something, but a robot does so mechanically, which is fine. Robots can't react to a particular context or atmosphere like humans, so maybe they are even better for such warnings."

Child-like design: Just 3 out of 27 customers felt that the robot's admonishing service was acceptable because of its child-like design of it:

- "Well, if it has a child's voice, it's tolerable. But a man's voice might feel too harsh."

Table 3.4: Summary of customers' responses for comparison with a human shopworker

Opinion	Reason
Robot is better (16/27)	Robot Specific (9/16)
	Robots are more acceptable for customers (5/16)
Situational (8/27)	Complementary capability (5/8)
	Guide for human and admonishment for robot (3/8)
Human is better (3/27)	Humans are more acceptable for admonishing customers (1/3)
	Human capabilities (1/3)
	Other (1/3)

– "I think people are more likely to listen to a cute robot than to a human."

3 out of 30 customers said that they did not accept the robot's admonishing service. All preferred humans for such a task:

– "That would be a bit of a problem, so I'm not sure. Maybe it's better to be told by an actual person."

– "Well...I think it's a little scary because I'm not familiar with it at first."

Comparison with human shopworker

We studied the answers of the customers related to their preferences between the robot and a human shopworker. We excluded 3 customers from this analysis because the interviewer neglected to ask them every question during their interviews. Thus, we present 27 customer responses and identified three main categories: *robot is better*, *situational*, and *human is better*.

Table 3.4 summarizes the comparison results. 16 out of 27 customers thought that the robot is better, 8 said their preference is situational, and 3 replied that a human is better. A majority of the customers preferred the robot over a human. We identified the following two groups of reasons:

Robot specific: 9 out of 16 preferred the robot because they see merits in the robot that are missing in a human shopworker:

– "It's hard to talk to human clerks, but I think robots are easier to talk to." (Robot specific: easy to talk)

Robots are more acceptable to customers: 5 out of 16 customers said that robot shopworkers are more acceptable than human shopworkers:

– "I think a robot is better at talking to customers. When talking to a human shopworker, I might feel obligated to buy something, so I think robots are more appreciated."

8 out of 27 customers believed that their preference might change depending on the situation or the context. They mainly argued about two aspects.

Complementary capability: A majority (5 out of 8) commented that since humans and robots have different capabilities, both are needed to provide good service:

– "If customers have a specific idea what they want, then a robot is better. But if they're having trouble deciding, then a human is probably better."

– "I think we need both. Humans and robots both have their good points, I think."

Guide for human and admonishment for robot: 3 out of 8 customers specifically commented that humans are suitable for guidance, and the robot is suitable for admonishment because of their specific capabilities:

– "I think the robot should do the negative aspects, such as reminding or pointing out problems, but when you ask for information about a product, I think it's better to ask a person."

Only a tiny minority (3 out of 27) of customers preferred a human shopworker over the robot:

– "I think humans are more flexible, although there are many types of people. I think humans are better when they are considerate and responsible." *(human capabilities: flexibility)*

Table 3.5: Summary of customers' responses for intention to use in future

Response	Reason
Yes (29/30)	Robot specific (20/29)
	Capability (7/29)
	Child-like design (1/29)
No (1/30)	Lack of emotional capability

- "I prefer a human. It's better to be told by a person. If you are told by a robot or a machine, something might go wrong later." *(humans are more acceptable for admonishing customers)*

- "If I had to choose, I'd say a human. But I think a robot is good enough for reminding people to wear masks or to take their temperature." *(other)*

Intention to use in future

When the customers were asked whether they would like to use the robot service again in the future, only 1 of the 30 said *no*. Table 3.5 summarizes their opinions and their reasons.

20 out of 29 of customers commented on such *Robot specific* features as *easy to talk, interesting, good for COVID-19 restrictions, good for children, cheap labor* and *expectation for future tasks*. 7 customers said they wanted to interact with the robot in the future because of its *capability*, and 1 customer commented on its *child-like design*. The following are additional representative comments on why they wanted to use it again:

- "Yes, I'd talk to a robot again. I don't know how it could deal with the steps, but it would be nice if it could move around in various places like in a nursing home." *(robot specific: expectation for future tasks)*

- "I think it would be very convenient if a robot like that could guide you properly. It would be much better than a person with a bad memory. Robots could guide people properly if memories are stored in a computer." *(capability)*

- "It was cute." *(child-like design)*

Table 3.6: Summary of shopworkers' impression on robot and dual service

Impression	Reason
Positive (5/5)	Robot specific (3/5)
	Adequate capability (2/5)
	Reduced shoplifting (2/5)
	Robot is more acceptable for admonishing customers (than human) (2/5)
	Child-like design (2/5)
Negative (0)	-

The customer who didn't want to interact again with it commented on the robot's *Lack of emotional capability*:

– "It's scary. They don't have feelings. People are easier to deal with, especially when you are dealing with customers. Robots have no emotions. They don't have joy, anger, sorrow, or pleasure, so I'd prefer a human guide for customers."

3.5.4 Interview results of shop staff

We studied the responses of the 5 members of the shop staff who observed our robot's services during the field trial. Our goal was to learn how they perceived the services provided by the robot, their intention to work with it in future and their expectation about working style.

We used the same procedure described in Section 6.3 for analyzing the shop staff's interview results. We categorized their opinions into mutually exclusive main categories and their reasons were subcategorized under each opinion category. We categorized their opinions as follows:

Robot and dual service

1. Impressions of the robot and the dual service

   All 5 shopworkers had overall positive impressions of the robot and its dual service. Of course, they did have criticisms, such as a rather limited variety of conversations. "It needs more language options. For example, the only

Table 3.7: Summary of preference of shopworkers for design of service

Opinion	Reason
Dual service (4/5)	Prefer general purpose robots (4/4) Only admonishing machines are not necessary (2/4)
Specialized services (0)	-
Both (1/5)	-

thing it can say when customers come in is, *'Welcome to our store.'* I'm sure some of the customers would get slightly annoyed if it just repeats the same phrase." Unfortunately, developing a sophisticated conversation ability for the robot was beyond the scope of this research. None of the shop staff had a negative impression of the robot or its dual service. Table 3.6 summarizes their impressions and their reasons.

3 out of 5 members of the shop staff mentioned merits specific to the robot *(robot specific)*, such as *good for COVID-19 restrictions, easy to talk, novelty* and *good for children.* 2 out of 5 shopworkers mentioned that the robot has *adequate capability*: "If a customer has a problem, or the staff can't handle something by themselves, the customer can ask the robot. In that way, the robot resembles a staff member." Other 2 out of 5 shopworkers mentioned that the robot is useful for reducing *shoplifting.* "If the robot patrols around the whole store, it's not really surveillance, but more like having eyes on people that might reduce shoplifting." Furthermore, another 2 out of 5 shopworkers mentioned that *the robot is more acceptable for admonishing customers (than humans)*: "I think the mask reminder is great. It's better that Robovie makes that request than a human." 2 out of 5 shopworkers liked the robot because of its *child-like design*: "I like the robot. I think it's cute."

2. Dual service or specialized robots?

   When asked, 4 out of 5 shopworkers preferred robots that could provide a dual service (friendly and admonishing) over robots specialized for each service. Only one shopworker preferred both specialized and dual service robots. Table 3.7 summarizes the responses of the shop staff.

Table 3.8: Summary of shopworkers' impression of admonishing service

Opinion	Reason
Accept (5/5)	Easier for robot to do (2/5)
	Adequate capability (1/5)
	Robot specific(1/5)
	Robots are more acceptable for admonishing customers than human (1/5)
Reject (0)	-

Table 3.9: Summary of shopworkers' preferences for admonishing service (human or robot)

Opinion	Reason
Robot is better (5/5)	Less offensive (3/5)
	Easier for robot to do (3/5)
	Adequate capability (1/5)
Human is better(0)	-

All 4 shopworkers who preferred the dual service design wanted general-purpose robots to handle many tasks rather than many robots for each service: "If possible, I'd prefer a single robot that can handle every task." They also thought that customers would also expect such general robots. "I think that customers will expect a robot to have lots of information. So, I think it's better for it to do many things than just to say one thing." Furthermore, 2 out of 4 shopworkers who preferred the dual service design pointed out that, although the admonishing service was essential, inappropriate behaviors are rather rare. Thus, robots that only provide an admonishing service are not necessary: "It's wasteful if we have a robot just for admonishing."

The shopworker who commented both said that "I think it depends on the size of the store. "I think it would be fine to have specialized robots for each service, or maybe one robot that can do both services."

Admonishing service

1. Impressions of admonishing service

   All 5 shopworkers accepted the robot's admonishing service. None commented on its demerits. Table 3.8 summarizes the shop staff's opinions. 2 out of 5 shopworkers preferred that the robot admonish customers on their behalf because it was *easier for a robot to do* than a human shopworker: "It's quite difficult for us to remind customers. I think it would be helpful if the robot could remind customers for us." 1 out of 5 shopworkers believed that the robot has *adequate capability* for the admonishing task. 2 other shopworkers commented on the *robot specific* features and that *they are more acceptable for admonishing customers than human.*

2. Preference for admonishing service (human or robot)

   All the shopworkers commented that the robot was better for the admonishing service than a human. Table 3.9 presents their preferences. 3 out of 5 shopworkers thought the robot was *less offensive* than a human and customers might feel less uncomfortable.: "I think a robot is better. The request is softened from a robot. When it comes to a human, some people might be offended by a particular person's appearance, tone of voice, and so on. If we had a mechanical robot to give reminders to customers, they might feel more comfortable." 3 out of 5 more workers mentioned it was *easier for robot to do* than a human shopworker. 1 out of 5 shopworker thought that the robot has *adequate capability* for the admonishments: "I think that if a robot says it, people will follow because they will think it's a rule. If a human reminds people, they might say, "What? Why?".

Guiding service

1. Impressions of guiding service

   All 5 shop staff accepted the robot's guiding service. Table 3.10 presents their impressions and reasons. 3 out of 5 of them commented that the robot had *adequate capability* for guiding: "I think it's great. It's good that the robot can guide customers to a product's location." Furthermore, they cited the robot's usefulness: "When we are busy, it would be helpful to have a robot to help us." Another 3 shopworkers commented on its *robot specific*

Table 3.10: Summary of shopworkers' impression on guiding service

Impression	Reason
Positive(5/5)	Adequate capability (3/5)
	Robot specific (3/5)
Negative(0)	-

Table 3.11: Summary of shopworker's preference for guiding service (human or robot)

Opinion	Reason
Robot is better (2/5)	Robot specific (1/2)
	Simple tasks fit robots (1/2)
Human is better (2/5)	Human capabilities (2/2)
Situational (1/5)	Case by case

features. One of them said that robot could approach any person without discomfort or stress and could be used in situations where shopworkers might hesitate to address customers. "There are customers who we think, "Oh, I don't really like this person," or "I don't really want to go talk to this person." So, I'd be happy if a robot would talk to them for us." In addition, they mentioned other *robot specific* features such as *novelty* and *cheap labor*.

2. Preference for the guiding service (human or robot)

   When asked who was better for the guiding service, a human or a robot shopworker, opinions were diverse. 2 out of 5 shopworkers thought that a *robot is better*, and another 2 out of 5 thought that a *human is better*, and 1 out of 5 said it is *situational*. Table 3.11 summarizes their preferences and reasons.

   1 out of 2 shopworkers, who commented that the *robot is better*, mentioned *robot specific* features such as *cheap labor*. Another said that guiding a customer to a product's location is easy, saying that task is a better fit for a robot *(simple tasks fit the robot)*.

   On the other hand, 2 shopworkers who said that a *human is better* cited *human capabilities* like speed and *communication skills* such as ability to

Table 3.12: Summary of intention of shopworkers to work with robot

Response	Reason
Yes (5/5)	Adequate capability (2/5)
	Robot specific (1/5)
	Child-like design (1/5)
No (0)	-

chat with customers. "There are some customers, especially the elderly, who want to have a conversation with us. Especially in this kind of store, some people want to talk about goods and recent games." Furthermore, they pointed out that humans can understand the context and serve customers at appropriate times.

The staff member who mentioned the *situational* aspect said that robots and humans are necessary on a *case-by-case* basis. She added that robots are good for young and children, but humans are better for seniors.

Expectations for working with robots

1. Intention to work with a robot in the future

   All the shopworkers were willing to work with the robot in the future. Table 3.12 presents their intentions and reasons. 2 out of 5 shopworkers wanted to work with it again because it has *adequate capability*. They appreciated its helpfulness and its contribution to improve efficiency. For example, they said, "I also think that people need to work more efficiently, so I think it would be good to have a new normal in store management, including robots." 1 out of 5 shopworkers mentioned such *robot specific* features as novelty. Another shopworker said she would use the robot because of its cute appearance, which is related to its *child-like design*: "I think it's good because of its cute form. It's a robot, but I always think it's cute and I get attached to it."

2. Expectation for working style

   We analyzed the impressions of the shopworkers about future shops with robots. All believed that it is better to have humans and robots working

Table 3.13: Summary of shopworkers' expectation for future working style

Expectation	Reason
Human and robot work together (5/5)	Humans are needed (3/5)
	Complementary capability (2/5)
Robot-only shop (0)	-

together rather than robot-only shops. They believe that even if a shop is mostly operated by robots, human staff must be available in the background to assist customers when necessary. They expect that work will be divided between humans and robots. Table 3.13 summarizes their expectations for working styles and reasons.

3 out of 5 shopworkers pointed out that *humans are needed* for shops. Their reasons included "I'm still a little wary of a store with only robots" and "Some people might say, 'I can't talk to a robot.' Since there are all kinds of people, it's better to have human staff who can respond on a case-by-case basis." Another shopworker expressed the latter opinion, especially concerning senior customers. However, we found no evidence that seniors avoided using our robot. Furthermore, such older customers whom we interviewed seemed satisfied with the robot's service and were willing to use it in the future. In addition, other customers commented that it was easier to talk to the robot.

Moreover, 2 out of 5 shopworkers commented on the *complementary capability* of humans and robots and added that robots have low communication capabilities (Robots might struggle to understand some contexts and can't communicate intelligently) and lack of problem management skills. Furthermore, they added humans are necessary for improving the image of a store.

3.6 Additional evaluation of mask recognition

We wanted to determine the extent to which our robot can autonomously detect people who are not wearing face. Unfortunately, the number of people without masks during the field trial was too small to adequately measure the robot's ability. Therefore, we conducted an additional evaluation that tested its ability to distinguish between people with and without masks when they were performing common shopping activities.

3.6.1 Environment and setup

As our location, we choose the same shop described in Section 3.4. The evaluation was conducted in a relatively less crowded area of the shop. We avoided its busy hours to reduce any possible disturbances to shop activities. We used the same robot from the field trial for this evaluation, which was autonomously done in the shop. An investigator (hidden from the participants) played the role of the operator and was responsible for the navigation and localization-error correction. Two other investigators were assigned to such tasks as managing the participants, recording videos, and maintaining safety during robot navigation.

3.6.2 Procedure

The evaluation was conducted with 15 hired participants (8 males and 7 females), each of whom acted as a customer in three trials with the robot: 45 trials in total. In each trial they performed one of the following three typical shopping activities. These activities reflected our observations during the field trial:

1. entering a shop;
2. shopping by ignoring the robot;
3. shopping and noticing the robot.

Each trial was conducted in two parts and the accuracy of the robot's detection was tested.

Part I: The participant performs the given activity without wearing a face mask (Figure 3.18 (a))

Part II: The participant wears a face mask and continues the given activity (Figure 3.18 (b))

(a) Participant without mask (b) Same participant with mask

Figure 3.18: Evaluation scenes

Table 3.14: Robot's recognition accuracy according to customer's activity

Activity	**Detection accuracy**	
	Face	Face mask
Entering shop	14/46	11/45
Shopping by ignoring robot	7/45	10/45
Shopping and noticing robot	13/45	11/45
Total	34/45	32/45

3.6.3 Results and improvements

Table 3.14 presents the robot's detection accuracy for each customer's activity. The robot successfully detected faces in 34/45 incidents and masks in 32/45 incidents: 73.3% mask-detection accuracy.

Table 3.15 presents the reasons for the robot's 24 incorrect detections and the associated frequencies. 17 of the 24 incorrect detections were caused by the recognition error of our face-recognition algorithm. Hence, the robot's detection accuracy was low when capturing a person's face from the side and with personal differences like wearing glasses. Those issues were probably caused by the lack of

Table 3.15: Reasons for incorrect detections

Reason	Number of incidents
Recognition error of face-recognition algorithm	17/24
Unable to capture person's entire face due to robot's monitoring location	7/24

the diversity of our training dataset. The remaining 7 incorrect detections were caused by the robot's incorrect monitoring location. Sometimes, it monitored people from behind or its observation distance was too close to a person. In both situations, the robot failed to capture the person's entire face, leading to incorrect results.

The accuracy of the robot's face-mask detection can be improved by increasing the diversity of the training dataset of the face-recognition algorithm and improving the robot's monitoring location (i.e., monitoring direction and distance).

3.7 Discussion

3.7.1 Summary of results

The aim of this work was to design an acceptable admonishing service for a shopworker robot. Our first research question focused on this dilemma. "How can we design an acceptable admonishing service for a shopworker robot?" As a solution, we proposed a harmonized design of both friendly and admonishing services to provide a convivial image to customers from the robot while avoiding the negativity of an admonishing machine. From our analysis of the pre-development interview results of the shop staff, we derived three configuration principles for a harmonized design: friendly impressions, zero erroneous admonishments, and polite requests.

Analysis of the field trial results shows that our first and the second design principles (i.e., friendly impressions and zero erroneous admonishments) contributed to achieve an acceptable admonishing service. As the first design principle, we improved the robot's friendly impression by allowing it to mostly provide a friendly service by implementing the dual (i.e., combining friendly and admonishing) behaviors and limiting admonishment to seriously inappropriate behaviors. Thus, 99.9% of its total operating time it was spent in a friendly way. The customers and shop staff thought it was friendly, polite, and fun. Second, designing the robot to admonish with zero error resulted in no incidents where an "innocent" person was admonished. Hence, we received no complaints from the staff or customers about inappropriate robot accusations/behaviors. However, since we could not hear the opinions of those who were admonished, we cannot directly evaluate the effectiveness of our third design principle, "polite requests."

It remains unclear whether implementing polite admonishments actually reduced negative impressions about the robot. At least, we did not observe any arguments between the robot and the admonished customers; nor did we receive any complaints from the shop staff or customers.

The following is our second research question: "How do customers and the shop staff perceive our robot in its harmonized dual service?" Analysis of our interview results of the shopworkers and the customers who used the guiding service revealed that they had positive impressions of the robot and the services that it provided. Furthermore, our design influenced them to positively think about the robot-admonishing service. They commented on the suitability of the robot for this admonishing service. They felt the robot had adequate capability for the admonishing task. A considerable portion of the customers voluntarily compared the robot with a human and said that robots are more acceptable for admonishing customers than humans. The robot's admonishment was seen as less offensive and less uncomfortable for the customers and a strategy for avoiding conflicts. Admonishing is deemed to be an easier task for a robot than a human shopworker. All the shopworkers preferred to place the responsibility for the admonishing services on the robot because they didn't want to perform them. Thus, both the customers who were not admonished and the shopworkers saw the robot-admonishing service as a favorable solution for the difficulties they face. These results suggest that our harmonized design approach works well in a shopworker robot's context. Unfortunately, our interview results do not reveal the opinions of those customers who were actually admonished. The opinions and reactions of this user group are crucial.

3.7.2 Implications

Implication of design of social robots

We believe that our research describes a new design direction for future social robots. Previous robot services were limited to a binary relationship: friendly or unfriendly. For instance, robots that satisfied such roles as receptionist, guide, tutor, and shop assistant provided friendly services; most security and police robots are limited to patrolling and monitoring, which are unfriendly services. However, human professionals who provide friendly services also admonish people when necessary. For example, a receptionist might admonish visitors who act inappropriately and a teacher might criticize students who misbehave. Similarly, such professionals as policemen whose services are generally not considered friendly might act in a friendly way depending on the situation. For example, a police officer will act kindly to a lost child. In that sense, most of the roles in the real world are a combination of friendly and unfriendly services. We believe that our harmonized design approach with dual service suggests future potential in a wide range of applications.

Implication of design of admonishing service

Our research implies that robot-admonishing services have potential for non-critical situations when humans might hesitate to remind others due to their stressful natures. Sometimes even when admonishing is necessary, people tend to avoid it because they feel awkward or fear creating bad impressions. Our analysis of the interview results with shop staff and unadmonished customers revealed they see that a robot can easily perform such admonishing tasks, and its admonishments are deemed less offensive than those from humans. This reaction suggests the potential of applying robots for such situations. Several people commented that when they are admonished by another person, they might take it personally; when a robot admonishes them, they might accept that remark as merely following the rules. This suggests that a robot might be used to announce rules without fanning conflict.

Our results suggest that the robot's appearance and voice contribute to the acceptance of its admonishing service. Previous researches argued that people's perception of a robot varies with its appearance and voice [67, 97]. An admonishment might be offensive or tolerable depending on the appearance and tone of voice of the admonisher. Some people commented that the robot's child-like appearance, voice, and cuteness associated with it soften its admonishment, making it tolerable. They recognized the child-like design as a favorable feature for accepting its admonishing role. Thus, we believe a child-like design might be one successful design approach for an acceptable admonishing service.

3.7.3 Open questions

Our research raises several open questions. One is the design of the future society. If robots with admonishing functions become ubiquitous in the future society and start admonishing people for their inappropriate behaviors, will people accept the robots? What are the potential contexts that robot-admonishing service can be appropriate? Our research answers these questions to a certain extent. Our interview results show that most shopworkers and customers have a positive outlook about robot admonishing service. Therefore, robot-admonishing service can be applied to shops and stores if they agree that it might solve their difficulties. We believe that in addition to our design, the context (i.e., reminders to wear a mask, which is deemed reasonable in Japanese culture) of the admonishing service contributes to such positive outcomes.

When humans are persuaded or prohibited to do certain actions, they naturally tend to see it as a threat to their freedom and experience a reactance (i.e., unpleasant motivational state) [89]. Reactance could lead to unexpected behaviors to restore their freedom, such as not complying with the request, doing exactly opposite, or even being aggressive toward the person who impose the threat [89]. For example, one of the customers expressed following idea “Robot admonishing is better than having a person do it. Well, I would feel sorry for the robot if a bad person told it off and beat it up”. The reactance is affected by various factors such as perceived threat to the freedom, attitude toward the robot’s message and initial motivation to avoid the behavior [21]. Furthermore, people experience an impulsive reactance if the request is illegitimate [87].

The context we applied the robot-admonishing service satisfied the above conditions in a favorable way. First, in Japan refusing to wear a mask in public during the COVID-19 pandemic was deemed to be inappropriate behavior that warrants a reminder. Because the inappropriateness of such behavior is unambiguous, the robot’s request is legitimate since the government requested that the general public wear masks. People were aware of the serious consequence of not wearing mask and majority were willing to follow the restriction. As a result of the legitimacy of the request, people who were admonished might haven’t experience impulsive reactance and did not do any immediate counter actions to restore their freedom. Secondly, our interview result represents the opinions of the people who already followed the restriction. They had a positive attitude toward the robot’s message and initial motivation to wear the mask. Thus, they might have felt the robot’s admonishment was less threatening to their freedom [88] and showed positive impression toward the admonishing service.

On the other hand, if a robot admonishes for more sensitive behaviors that inappropriateness is controversial (E.g. returning a product to a wrong shelf and being noisy inside the shop), then the portion of people that have negative attitude towards the robot's admonishing service would be larger than our study. More people might feel robot's request is illegitimate, or unnecessary. Similarly, a considerable number of people might engage in such controversial inappropriate behaviors and might feel the high degree of threat to their freedom and might do counter actions.

Thus, the context of robot-admonishing service seems affect the people's acceptance and effectiveness of the service. In other word, application of robot-admonishing service in a wrong context could results negative outcomes. Unfortunately, it might be difficult to identify hard and fast rules to determining the context, as the perceived threat to the persons' freedom depends on individual's and cultural beliefs [61]. For example, a mask-reminding service that Japanese culture considers acceptable might be treated as contentious in other cultures. Hence, further research is required to identify the possible context where a robot-admonishing service might be applied without reducing compliance compared to human admonishment and threatening the people's autonomy.

3.7.4 Future role of the operator

The current state-of-the-art technology is insufficient to implement a fully autonomous robot to provide interactive services in real fields. Therefore, we employed a human operator to solve the technical immaturities of our system and to gain greater accuracy. We limited the operator engagement to four types of critical situations: speech recognition, confirmation of inappropriate behavior detection, determining whether the customer is busy, and error correction. Thus, the operator control happened only 5.9% of the robot's total service time. We believe more parts of the system will eventually be automated.

One major task performed by the operator was speech recognition. We made this choice because existing ASR are obviously unable to achieve sufficient degree of accuracy due to the shop's noisy environment. We believe that eventually a robust ASR module will assume such speech recognition. We also believe that the task of determining whether customers are occupied or no will be automated with reasonable accuracy. Then a robot will achieve an even higher level of autonomy.

However, we still believe the operator is needed for inappropriate behavior detection confirmation and handling the system's errors. We are skeptical of the potential of complete automation of inappropriate behavior detection. First, achieving 100% accuracy in real environments will be almost impossible. Second, even if we solve such daunting technical difficulties, people might not be willing to allow AI to determine morality. Some will see AI as a threat to their autonomy. Humans determine morality. This concern might be rather insignificant for such non-critical situations like a reminder to wear a face mask during a pandemic. But people will be more concerned about critical situations such as a police robot that approaches a person on the street to make inquiries. Thus, the operator must confirm the system's inappropriate behavior detection and make the final decisions. An operator is also needed for fixing errors in the system because creating a completely error free system is also nearly impossible. However, the operator's intervention for error correction was minimal (0.6 incidents per hour) compared to the other controls. Perhaps an even more robust system can be developed with a minimum error rate.

Automating most of the parts will further minimize the operator engagement, enabling one operator to simultaneously control multiple robots in the future.

3.7.5 Limitations

The findings of this research cannot be generalized due to several limitations. First, our design principles were derived based on interviews with only three staff members. Thus, there might be other effective admonishing strategies for shopworkers that our study failed to reveal.

Second, since our field trial had almost no admonishing incidents, we are completely unable to predict the general reactions of customers to robot's admonishment.

Third, our data represent the opinions of self-selected customers. Those with negative opinions about the robot might avoid its service or refuse our interview requests. Hence, the results might be biased. However, this is unavoidable in interview-based field studies. Furthermore, we were unable to interview those customers who were admonished. Their impressions of the robot and their opinions about its admonishing function are crucial and remain unknown. Hence, our study failed to reveal whether the robot's admonishing service is acceptable for the customers that were actually admonished. Furthermore, since we only interviewed a limited number of shop staff, our result might not be generalizable to the opinions of all shopworkers.

Nor did we evaluate the effectiveness of the harmonized design through a comparison with a non-harmonized design. However, a non-harmonized design seems less promising for several reasons. Such a non-harmonized design does not combine friendly and admonishing behaviors and operates in either friendly or admonishing behavior. Thus, sometimes it acts as an admonishing machine. Furthermore, the portion of the time the robot operates in a friendly way might be less than the harmonized design and it might be seen as less friendly. Moreover, shops might not allow a less promising design to be tested since it could create negative customer impressions. Hence, such a comparison is impractical. Therefore, we believe that people are positive about the robot, that they accepted its admonishing service and have high intention to use it in the future. These results suggest a successful harmonized design. Thus, the results of our field trial empirically show the effectiveness of our design.

Another limitation is that our admonishing service is limited to one specific inappropriate behavior: shopping without a mask during a pandemic. We chose this behavior based on the topical importance of such reminders during the COVID-19 pandemic. Further research is required when applying the admonishing service to other inappropriate behaviors.

Our research is also limited to one particular shop. The opinions of the shop staffs might be different in other types of stores and this design can't be directly applied to other shops. Since our work was conducted in Japan, worldwide responses are undoubtedly culture specific. Therefore, further research is required to apply this design to other countries.

3.8 Summary

We present our effort to design an acceptable admonishing service for a shopworker robot. We proposed a harmonized design of dual services: friendly and admonishing. Our robot provided guidance about product locations and admonished customers who were not wearing face masks. We conducted a 13-day field trial in a retail shop that sells the apparel and souvenirs of a popular Japanese soccer team and investigated the impressions of people about the robot. Although the opinions of the admonished customers were not disclosed in this study, we heard the opinions of the shop staff and the customers who used the guiding service. Our findings support our idea that an acceptable design of a shopworker robot with an admonishing function can be achieved by harmonizing friendly and admonishing services. Although robots that only admonish are generally rejected by society, our customers had a positive attitude toward our proposed harmonized dual service robot and showed a high intention to use it in the future. Since admonishments from the robot were felt to be less offensive or less harsh than from humans, customers might be more willing to accept them. On the other hand, admonishing was identified as an easier task for the robot than for human shopworkers. Based on the above findings, we believe that a robot-admonishing service with our harmonized design might be a promising solution for the difficulties faced by customers and shopworkers.

CHAPTER 4

Enhancing Queue Management in Public Spaces: Field Trial of a Security Guard Robot

4.1 Introduction

Social robots have been introduced to public or semi-public spaces to work on behalf of humans by leveraging such potential benefits as providing human-like services, enhancing specific atmospheres, and serving as inexpensive labor[69, 71, 84]. Robots are expected to support human workers by undertaking labor-intensive, repetitive, stressful, and dangerous tasks. Researchers have extensively explored the potential services that social robots can offer in public spaces [5, 43, 64, 86].One such service is regulating visitor behaviors. However, few studies have investigated the potential of robots to deliver such services in public settings[62, 82].

Regulating the behavior of visitors in public places is crucial for maintaining smooth operations and ensuring a civil and safe atmosphere. In such places, security guards, police officers, shopworkers, and receptionists play a role in regulating people when necessary. They ensure that visitors adhere to specific rules, such as refraining from using their phones while walking in crowded areas, avoiding smoking where prohibited, and not bringing prohibited items into stadiums. When violations occur, these employees reprimand the involved individuals. Sometimes, the mere presence of staff will discourage inappropriate behavior. However, attempting to regulate the actions of strangers is often stressful and might even put human employees at risk. If robots can assist in regulating visitors on behalf of human employees, the workload of the latter cohort can be significantly eased, leading to an enhancement of their overall work experience.

Applying a robot to regulate people's behavior in public spaces is challenging. Many issues raise doubts about the effectiveness of such robots: their low social power, people's lack of respect toward them [100], and the tendency to disregard their admonishments [62, 82]. Some individuals perceive as less likable and potentially unsafe robots that exhibit controlling behaviors, including admonishing and punishing [46]. This negative perception among people might fuel a public backlash against utilizing robots to regulate individuals in public environments [66]. Consequently, when designing a robot that is intended to regulate people in the real world, researchers must carefully consider both the effectiveness and the social acceptability of their designs.

In this study, our objective was to specifically design a robot for regulating people in public spaces. We chose to focus on managing queues because they present a novel potential application for robot services. Long queues are frequently observed at such public events/settings as concert halls, stadiums, movie theaters, and airports. The staff at these locations must ensure that individuals are properly lined up and remind them to refrain from engaging in inappropriate behaviors that may disrupt the queue or disturb others, such as queue jumping or obstructing forward movement. In Japan, security guards often handle queue-management responsibilities, including guiding visitors to the end of the queue, making announcements, and monitoring/addressing inappropriate conduct. Unfortunately, for human workers, managing queues can be a monotonous and tiresome task.

Our aim is to develop a robot capable of effectively managing queues while simultaneously gaining societal acceptance, resulting in people who will follow its guidance with minimal resistance. To achieve this goal, we seek to identify a design that satisfies these criteria. Hence, our first research question:

RQ1: How can we develop an acceptable and effective robot for regulating people in public spaces?

Our approach involved learning how to design a robot based on the effective and accepted role of a human security guard in society. Security guards possess a high level of social power and legitimacy and garner much greater compliance from the general public compared to generic citizens [8]. Since a crucial aspect of their role is embodied in their professional image, we imbued our robot with the appearance of a professional security guard. We anticipate that such a design will enhance the robot's social power, facilitate people's understanding of its role, and improve the acceptance and compliance to its requests.

To create a professional impression for our robot, we incorporated the following three key features associated with a security guard's image: duties, professional behavior, and professional appearance. We conducted interviews with three guards with experience in queue-management services to gain insights into their duties. Based on our findings, in our robot we implemented ushering, admonishing, question answering, and making announcements services and modeled its ushering behavior on that of a professional guard. We designed a customized guard's uniform for our robot to enhance its professional appearance.

Moreover, we faced uncertainty regarding the acceptance of a regulatory robot's service (i.e., a queue-managing robot) in real-life situations. Unlike robots that provide such friendly and supportive services as guidance, entertainment, and assistance, there is a greater likelihood that people will reject a robot that is attempting to control their behaviors and admonish them for mistakes. The current limited knowledge about regulatory robots does not adequately capture how people perceive them in their everyday lives. It specifically remains unclear how individuals will react if a robot were to admonish them for inappropriate behavior in real-life scenarios and whether such interventions are deemed acceptable. In light of this, we recognized the need to comprehensively investigate how people perceive a robot that is seeking to regulate their behavior in real-world situations. Our aim was to gain deeper insights into the acceptance and reactions of individuals when confronted with a robot's attempts to control their actions. Consequently, we formulated our second research question:

RQ2: How do people in public spaces perceive a robot that is attempting to control their behaviors?

We addressed our second research question by conducting a 10-day field trial at a children's amusement event during which our robot autonomously managed a queue of people. During this trial, we conducted semi-structured interviews with both the event staff and the visitors who interacted with the robot and experienced its ushering and admonishing services. Our primary objective was to gain insights into people's acceptance of the robot, understand their reasons for complying with/disobeying its admonishments, and to compare their perceptions of a robot's admonishment with that from a human. Additionally, we wanted to assess the extent to which our robot could autonomously provide queue-management services in a real-world setting.

4.2 Design considerations

Our approach is to learn an acceptable and effective design for queue-management based the role of a human security guard. Such services are deemed to be acceptable by modern societies. Most people are familiar with their roles and have some understanding about their duties. In Japan, besides general security related tasks, guards also perform queue management in public events and prevent inappropriate actions. Generally, people comply with a request by a security guard without much resistance.

An important design factor is the image of security guards. Social studies show that more people comply with a request from a uniformed security guard, even if he is acting out of his role, than a request by a generic citizen, a result that indicates their social power[8, 18]. If our robot were to possess such a professional image, people might readily accept it and cooperate with its queue-management service.

To create an image of a professional security guard for our robot, we studied the following three key aspects of a human security guard's image:

1. Duties: Security guards are expected to perform certain duties during their queue-management service. Awareness of their responsibilities will improve the robot's service quality.

2. Service behavior: Professional security guards receive special training for their job. Therefore, their service behavior is different from a novice person.

3. Appearance: Professional security guards can be easily recognized among the crowd.

4.2.1 Duties of queue-management service

Queue-managing security guards are expected to perform certain duties. The inability or unwillingness to perform them will lead to a failed queue-management service. Thus, we interviewed professional security guards to deepen our understanding of the duties of queue-management services.

Interview procedure

We interviewed three male professional security guards (ages 41, 59, and 65 years) with over a year of experience doing queue-management service at public events and store openings. Interview questions were written and interviews were conducted by one of the authors. The interviews were video-recorded and transcribed for analysis. We mainly inquired about the following three points:

- Their duties during queue-management service;
- Common inappropriate behaviors of visitors and strategies for handling them;
- Expectations about using a robot for queue-management service.

Interview results

1. Duties of queue-management service

   Avoiding problematic situations is the main goal of queue management. Security guards are assigned to locations where problems are most likely, such as a queue's end, queue gaps (sometimes long queues are interrupted by roads/streets), or a long queue that bends around a corner.

   Security guards perform the following duties during queue-management services: leading newcomers to the end of the queue (ushering), admonishing visitors who are engaging in inappropriate behavior (described bellow), and making announcements. The guards perform ushering and announce queue-end locations with language designed to guarantee that visitors line up properly and to prevent incorrect behavior. For example, sometimes visitors misidentify the end of line and enter its middle. If trouble happens, such as delays, they also announce such information to forestall potential dissatisfaction. The guards mentioned that since making announcements is considered a challenging task by some novice guards, they sometimes fail to make them. In addition, guards answer visitor questions about the event and surrounding area, such as the location of restrooms, shops, and its starting time.

2. Common inappropriate behaviors of visitors and a strategy for handling them

   The common inappropriate behaviors of the visitors in a queue include failing to move forward in the line (e.g., talking without paying attention), queue jumping, lining up in a way that disturbs others (i.e., blocking a space through which pedestrians must pass), and so on.

   The security guards basically admonish such visitors to stop their inappropriate behaviors. They request that the target person politely but firmly obey (if the impression is too soft, they might not comply). A clear explanation (voice) is also important. Security guards use such a polite strategy to minimize bad impressions when they must explain their reason to visitors: "Please make space for others to avoid disturbing their walking." Visitors who perceive an admonishment as "an order" might complain to the management.

3. Expectations of using a robot for queue management

   Security guards believe that ushering and announcing are tedious tasks. As a result, novice security guards often avoid making announcements. They believe that a robot is more suitable for doing tasks that have a monotonous nature than humans.

4.2.2 Modelling professional service behavior

We modeled a human security guard's ushering behavior in our robot to make its service more professional and effective. We especially wanted the visitors to naturally follow its ushering. We conducted a role-play of a queue-management situation with a hired professional security guard and observed his ushering behavior. To understand the nuances in a professional's approach to the job, we compared the behaviors of professional guards and novices.

Case study: professional vs. novice ushering behavior

We modeled the ushering behavior of one professional guard to mimic an effective service behavior instead of making a general behavior model.

1. Participants

   We hired a professional security guard (male, 45 years old) who has experience in ushering, crowd control, managing queues, and customer service at large public events and retail stores. He has been employed as a professional guard for 1 year, and before that, he worked part-time ushering visitors to public events. We also hired four participants (two males and two females) with no prior experience in queue management to represent novices.

2. Procedure

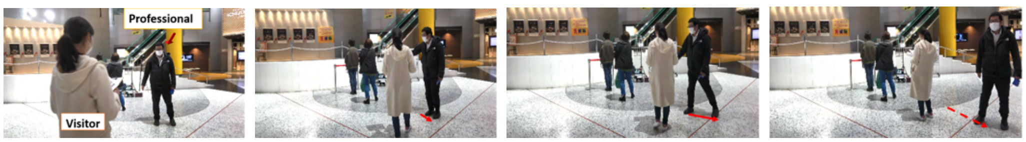
   We set up a queue-management scenario for an imaginary event. Three people were hired as visitors. Two lined up at the entrance, and another acted as a newcomer. We conducted five (i.e., one with the professional and four with the novices) role-play sessions of queue-management services. One session consisted of 30 ushering incidents. In each session, the professional or novice who played the security guard role was asked to stay at the event's entrance and lead a newcomer to the end of the queue. In 30 trials, the newcomer joined the queue by varying his starting point and walking speed. For each session, the person who played the newcomer was changed. The behaviors of the participants were video-recorded.

Observation

The following is the professional's behavior. He stood within 0.5 to 1 m of the last person, almost as if he were in the queue, and waited for newcomers (Fig. 4.1(a)). When a newcomer walked towards the queue, the professional started to usher him in. Professional ushering behavior (Fig. 4.2) consists of three main steps: acknowledging, yielding and pointing, and moving on. The professional acknowledged the approaching newcomer by looking and nodding to her (Fig. 4.2(a)). As newcomers approached closer, the professional yielded his waiting location, pointed to the end of the queue, and said: "Here is the end of the queue" (Fig. 4.2(b)). As newcomers lined up, the professional moved to a new waiting location at the queue's end (Fig. 4.2(c)).

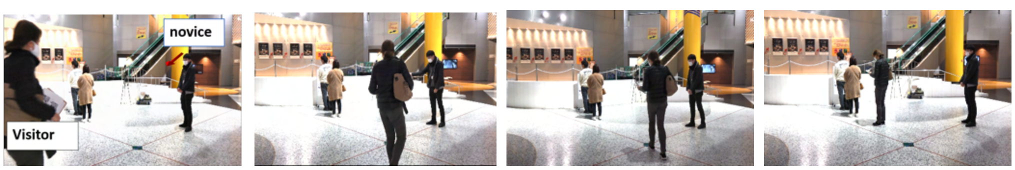
(a) Professional guard (b) Novice

Figure 4.1: Professional's waiting location vs. novice waiting location



(a) Acknowledging (b) Yielding and pointing (c) Moving on

Figure 4.2: Professional ushering behavior



(a) Acknowledging (b) Pointing (c) No change of location

Figure 4.3: Novice ushering behavior

The following is a typical behavior of a novice. Unlike the professionals, three of the four novices waited at a location a relatively large distance (1.5 to 2 m) from the last person in the queue (Fig. 4.1(b)); the other one waited within 1 m. When a newcomer was noticed, the ushering of all four novices resembled the manner shown in Fig. 4.3. A typical ushering behavior of a novice consists of two steps: acknowledging and pointing. They acknowledge newcomers by looking at them (Fig. 4.3(a)). Then they pointed at the queue's end and asked them to get in line (Fig. 4.3(b)). After that, the novices continued waiting at their waiting location for the next visitor (Fig. 4.3(c)).

We identified three differences between the novice and professional ushering behaviors. 1) Waiting location: The professional's waiting location is relatively near the last person (within 1 m) in the queue compared to a novice's waiting location (between 1.5 to 2 m) (Fig. 4.1). 2) Yielding when pointing: The professional yielded to the newcomers when pointing, whereas novices pointed from where they were standing (Figs. 4.2(b) and 4.3(b)). This might be a result of the difference in waiting locations. In the novice's case, a newcomer has enough space to approach the queue's end. Therefore, no yielding is required. 3) Moving on after pointing: The professional moves to a new waiting location (i.e., updating his waiting location according to the newly lined-up visitor) every time a new visitor queues up. But novices don't make this decision. From our observations, we felt that the professional was trying to maintain the end of the queue (Figs. 4.2(c) and 4.3(c)). However, we failed to ask him to explain his behavior, an oversight that is a limitation of our procedure. When we asked the novice participants, they said they weren't maintaining the last position in the queue; rather, they chose a waiting location where they could easily guide visitors from various directions.

In addition to ushering, we observed that when there were no newcomers, the professional kept waving his hand and announcing the event information (Fig.4.1(a)). However, none of the novices made such announcements.

Ushering model

We defined the ushering model as follows:

1. Waiting location: The professional guard's waiting location is less than 1 meter from the last person in the queue and is almost aligned with the queue.

2. Three-step ushering behavior: professional ushering behavior consists of the following three steps:

   (a) Acknowledging: Greeting the approaching visitors by making eye contact with them.

   (b) Yielding and pointing: Yielding to the visitor, pointing to the queue's end, and saying: "Here is the end of the queue."

   (c) Moving on: As the newcomer lined up, the guard moved to a new waiting location at the end of the queue.

4.2.3 Expressing security guard's role by appearance

We dressed our robot in a uniform that resembles one worn by professional security guards to make its role clear to people and give it a competent appearance. An agent's physical appearance evokes his/her role. People's reaction to a request by an individual depends on his or her physical appearance [8]. For instant, when a standardly-dressed person and another wearing a guard's uniform approached people in the street and asked them to pick up a bag, more people complied with the latter person in uniform [8].

Human security guards wear a special type of uniform that makes them look professional and prominent among others even in crowded situations [3]. Such uniforms are associated with a certain degree of legitimacy that influences people to obey their requests [8, 18]. Thus, we believe a uniform is an essential feature upon which to erect a professional image for our robot security guard.

We made a customized uniform design for our robot (Fig. 4.5). We chose a design that resembles a local company's security guards because people are familiar with them. The design was customized based on the needs of our robot. We removed its sleeves and shoulder cord because they might have limited its arm movements. However, we retained such essential features as a hat, which helps people easily recognize that the robot is functioning as a guard.

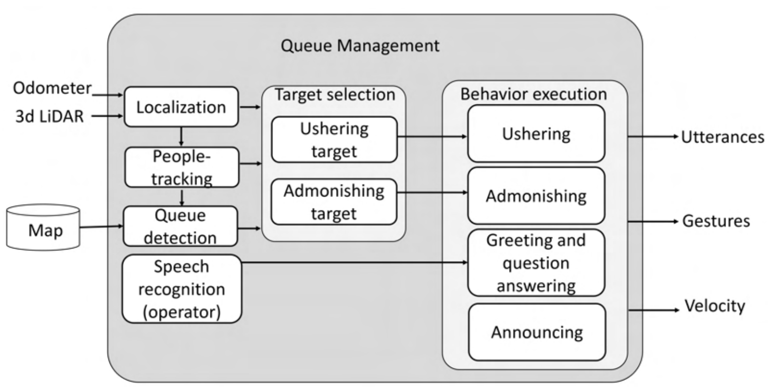


Figure 4.4: System architecture

4.3 Robot system

4.3.1 System architecture

Figure 4.4 depicts the system architecture of our queue-managing robot. Basically, it selects target visitors for its service: approaching visitors to the queue as ushering targets and those who engage in inappropriate behavior as admonishing targets, using the target selection module (Section 4.3.4) and executes the appropriate behavior (Section 4.3.5). The robot localizes (Section 4.3.6) itself in the environment with a multilayered map that includes a pre-defined queue area (i.e., the area where visitors are supposed to line up) and the information received from an odometer and 3D LiDAR. The people-tracking module (Section 4.3.6) maps out the locations and movements of the visitors in the surrounding area by accessing the information in the localization module. The queue-detection module (Section 4.3.3) locates the queued-up people with the people-tracking data. The target selection module (Section 4.3.4) uses the people-tracking data and the queue-detection module to select the ushering and admonishing targets based on the visitor's activities, which are then used to select appropriate behavior for execution. During the execution, each behavior reads the sensory data and controls such robot output as utterances, gestures, and velocity. If the visitors want to talk with the robot, a human operator (Section 4.3.7) performed the speech recognition task on its behalf.

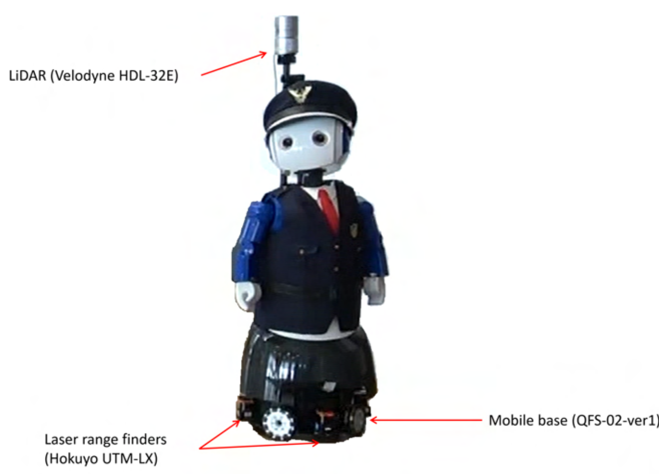


Figure 4.5: Robot

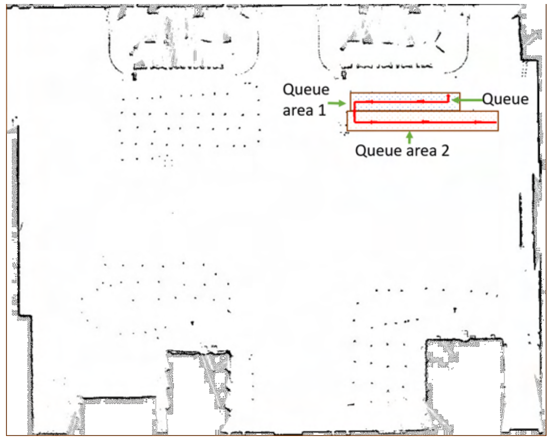


Figure 4.6: Map with pre-defined queue areas

4.3.2 Robot

We implemented the queue-management functionality in a robot named Robovie (Fig. 4.5), which is 120-cm high and has a human-like appearance with 11 degrees of freedom for gestures. It has a QFS-02-ver1 mobile base developed by Qfeeltech for navigation. Its omnidirectional wheels enable it to move in any direction at a maximum speed of 0.8 m/sec and a maximum angular velocity of 60 degrees/sec. We attached four laser range finders (Hokuyo UTM-LX) to its mobile base to detect obstacles during its navigation. A LiDAR (Velodyne HDL-32E) was mounted on top of a pole at 143 cm on Robovie's back for localization and people-tracking.

4.3.3 Queue detection

We implemented a functionality to detect the queued-up people and tracked the last person using the people-tracking data. We tracked the last person in line for two reasons. First, we must determine the robot's waiting location. According to the professional ushering model (Section 4.2.2), the robot should wait within 1 m of the last person. Second, we wanted to support the detection of people who are approaching the queue (i.e., potential ushering targets). We defined a queue area (where people might queue up) in advance (Fig. 4.6). The robot detects queued-up people using their positions in the queue area by a pre-defined distance threshold value (i.e., lined-up distance = 1.5 m) and tracks the last person. If a new person enters the queue area within the distance threshold from the last

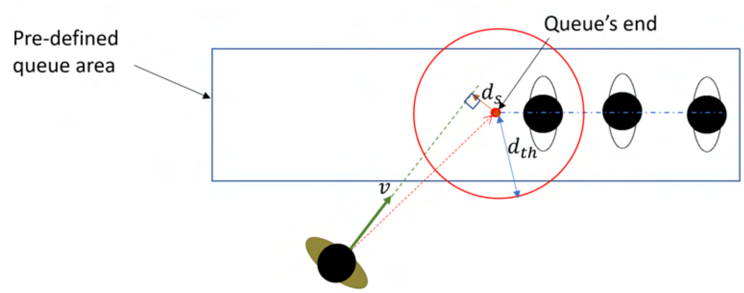


Figure 4.7: Detection of potential ushering targets

person, it updates the newcomer as the last person.

4.3.4 Target selection

We implemented a functionality to select target visitors for ushering and admonishing based on their activities. This module uses people-tracking data and queue-detection modules for activity detection, which is updated every 0.1 s to support the visitor movements. The target selection is done as follows:

1. Ushering target: To select the ushering target, the robot first detects all the people approaching the end of the queue. The potential ushering targets are detected by computing the closest distance (d_s) to a person's walking trajectory and compared with a pre-defined threshold value, d_{th} (2 m) (i.e., if $d_s \leq d_{th}$, then since the person can join the queue, she/he is a potential ushering target). Next the distance from the queue's end to all the potential ushering targets is computed and the closest one is identified as an ushering target (Fig. 4.7).

2. Admonishing targets (i.e., visitors who engage in inappropriate behaviors): For the admonishing target selection, first the robot identified visitors who are making inappropriate behaviors and waits for the operator's confirmation. We added a decision-confirming step to avoid erroneous target selections. Visitors are detected when they are engaged in two types of inappropriate behaviors: failing to move forward in the queue and blocking the queue area because they haven't properly queued up. For identifying people who haven't moved forward in the line, the robot computes

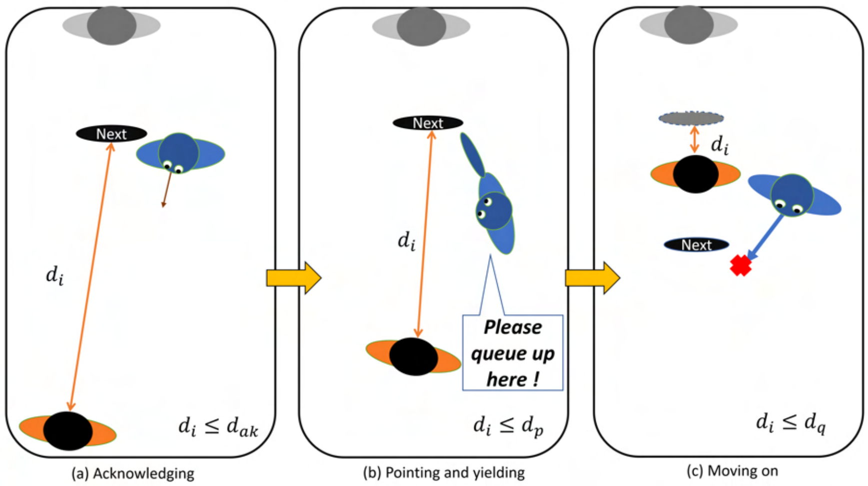


Figure 4.8: Ushering behavior execution

the distance between the adjacent queued-up people, compares it against a threshold value (1.5 m), and detects those whose queued-up distance exceeds the threshold. To distinguish those who are waiting in the queue area without queuing up, it considers all the people waiting in the queue area and those who have already lined up. Then the remainder are identified as not lined up.

4.3.5 Behavior implementation

Ushering behavior

In the ushering behavior the robot guides new visitors to the queue's end. We implemented the professional security guard's ushering model described in Section 4.2.2. Basically, the robot stands in the next spot that a newcomer should fill and it yields that spot to the newcomer (Fig. 4.8). The robot's ushering behavior was implemented with two key elements: ushering target selection and ushering behavior execution. Following the professional guard's waiting location, the robot waited within 1 m of the last person in the queue, giving enough space for visitors to pass through, while watching for newcomers to the queue. It autonomously selects the ushering targets, as described in Section 4.3.4. Next the robot executes its ushering behavior in three steps: acknowledging visitors (Fig. 4.8(a)), pointing out the queue's end and yielding (Fig. 4.8(b)), and moving to the next position

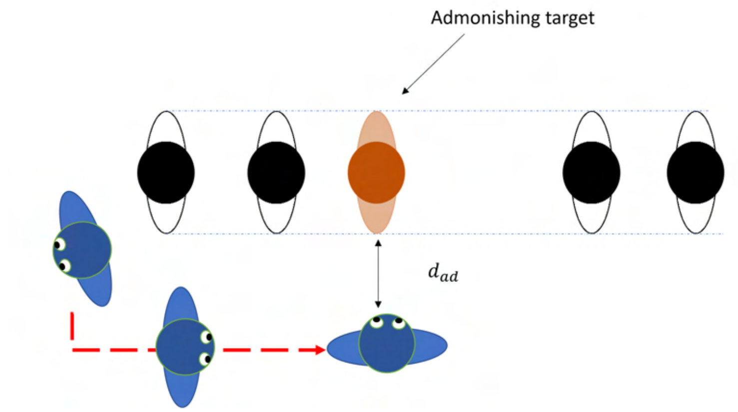


Figure 4.9: Robot approaches to admonishing

(Fig. 4.8(c)). First, when a target person reaches 7.5 m (threshold distance for acknowledgement, d_{ak}) from the next spot in the queue, the robot starts looking at his/her face. Once the person arrives closer to the queue end at a threshold distance of pointing d_p (5.5 m), the robot points to the end of the queue and says, "please queue up here" and allows the newcomer to join the line. While the person is queuing up (i.e. $d_i \leq d_q$), the robot considers him/her the queue's new last person and moves to the new waiting spot. All the threshold values were tuned by trial and error.

Admonishing behavior

In this behavior, the robot admonishes visitors who are engaged in one of two inappropriate behaviors: blocking the queue area without joining the queue and failing to move forward. The admonishing behavior has two elements: admonishing target selection (i.e., a visitor engaged in inappropriate behavior) and execution admonishments.

The selection of admonishing targets is described in Section 4.3.4. After identifying a visitor who is engaged in inappropriate behavior, the robot requests confirmation from a human operator who must grant permission before an admonishment can be executed. We designed this confirmation step to reduce erroneous admonishments from inaccurate recognitions. After the admonishing target is confirmed by the operator, the robot warns the visitor by executing the following behavior sequence: approaching, admonishing, and thanking. In the first phase, the robot approached within 1.2 m of the target person. If the target person is

Figure 4.10: Robot's announcing behavior

in the queue, the robot moves parallel to the queue during its approach (Fig. 4.9), appears next to the person, and makes an appropriate admonishment based on the situation: "Could you please move forward?", and indicates with a hand gesture, or "Excuse me, please queue up along the chain." If person corrects his behavior, then the robot executes its thanking phase and bows to acknowledge the cooperation. It repeats its admonishment up to three times. If the person still hasn't complied, the robot stops admonishing.

Greeting and question-answering behavior

In this behavior, the robot greets the visitors who approached it and answers their simple questions about the event. Once the visitor starts a conversation, the operator interprets the utterance and chooses an appropriate answer from a pool of pre-defined responses. We pre-defined a set of conversations: greetings for children, such answers to common questions as explanations of the event itself, ticket prices, event schedules, starting/closing times, etc. The robot greets the children waiting in front of it and encourages them to line up: "Hello. Welcome to Let's Go Thomas (i.e., event name). If you don't line up properly, you'll miss Thomas," and "Don't be shy! Let's get lined up!"

Announcing behavior

Figure 4.10 shows the robot's announcing behavior, in which it describes the event's location to help visitors find it. The robot makes its announcements when it is not engaging in any of its other behaviors (i.e., ushering, admonishing, and question answering). During its announcement, the robot waits near the end of the queue, looks around for visitors, waves, and occasionally informs them of the facility's location. To minimize annoying the visitors by excessively repeating this announcement, we setup a 35-second interval between two announcements. This behavior was inspired by the professional guard's announcing behavior.

4.3.6 Other modules

Localization

Reliable localization is required in open public environments, e.g., an exhibition hall with crowds of ambulatory visitors. In our implementation, we used a particle-filter-based method [35] with Velodyne LiDAR point cloud data to achieve 6D localization for the robot. It localized itself at 10 Hz on a 3D point cloud map created beforehand by real-time collected 3D point cloud data and their odometry inputs.

Due to the daily change of features (e.g., barriers, signal boards, etc.) and the intensive human flows during the exhibition, the local environment around the robot in the task was always different from the pre-built map, a challenging situation for localization in a large open space. We configured the robot to utilize the point clouds in a 20-m radius range so that those unchanged features in the architecture (e.g. walls, gates, pipes in the exhibition hall) can be perceived to localize the robot more accurately among the crowds. The denser point cloud clusters near the robot were filtered out from calculation to balance the computational cost of localization after increasing the perception range.

People-tracking

For people-tracking, we applied an algorithm to the LiDAR point cloud data that consist of three steps: background subtraction, people-detection, and people-tracking. The background subtraction is done immediately after localization, compares the raw point cloud data with a 3D map of the environment, and re-moves the entities in the map. The remaining point cloud data show the movable entities. To detect people, clustering is applied, and bodies are detected if they approximately resemble a human's size. Finally, at the people-tracking step, we applied a particle filter to the detection results. Even with such occlusions as passersby, it can continuously track locations within 15 m of the robot every 0.1 s.

Speech recognition

We used a semi-autonomous approach [31] for speech recognition instead of automatic speech recognition (ASR) due to such high ambient noise as loud music and the voices of many visitors in event environments. As shown in this previous work, a single operator can simultaneously control several robots. Even with a human operator, our system can provide a realistic service. The human operator typed the visitor utterances to the system without any supplementary information. Thus, even a novice with no prior knowledge about the event can serve as an operator.

4.3.7 Role of human operator

We used a human operator to compensate for the technical limitations of our robot system. The operator worked as another module, which in the future will probably be replaced with sophisticated autonomous modules with technological development. To explore the robot's autonomous operation capability, we limited the operator assistant to the following situations where human intervention is essential for performing its duties. We used a graphical user interface (GUI) to give the operator control:

1. Selecting appropriate queue settings: We used multiple queue area definitions (Section 4.3.3) during the field trial. The operator is responsible for checking the size of the crowd in the queue and switching to a new queue when the current queue area is filled.

2. Confirmation of inappropriate detection: We delegated the task of confirming inappropriate behavior detection to the operator to avoid erroneous identifications by the robot. The operator determined the accuracy of the robot's detection of inappropriate behaviors (not moving forward in the

queue and waiting in the queue area without joining it) by observing such visualizations in its GUI.

3. Error handling: The operator was responsible for recovering localization and navigation errors. In situations where the robot's sensor data don't match the map, it is unable to find its true location on the map. Then operator fixed its location. When the robot moved too close to obstacles, its safety module stopped its autonomous navigation. In such cases, the operator recovered the robot's navigation and removed its safety lock.

4. Speech recognition: We abandoned automatic speech recognition due to its low accuracy in noisy environments. The operator interpreted the people's inquiries and selected a relevant robot-response from a pool of utterances.

4.4 Field trial

We conducted a 10-day field trial to study our robot's ability to manage a queue of people at an actual public event and people's interactions with it. Furthermore, we interviewed visitors as much as possible and the event staff to learn their impressions about our robot and its services.

4.4.1 Environment

We tested our robot at a children's amusement event for ten days from April 29 to May 8, 2022. The event was held in a large indoor space that had several facilities for children. Its visitors were basically families with elementary school

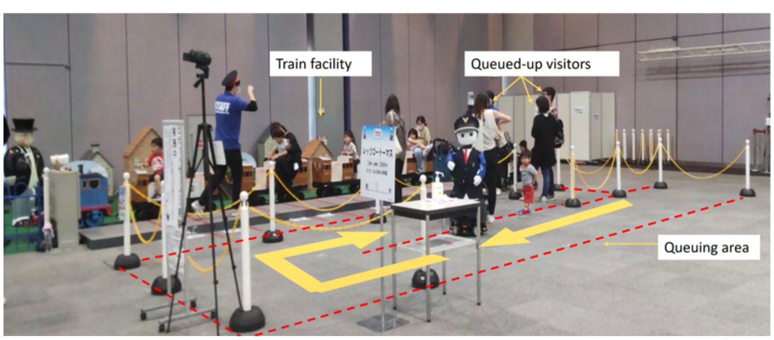


Figure 4.11: Field trial environment

kids. The robot engaged in its queue-management duty at the entrance of one of the amusement facilities where kids and parents were queued up for a train ride (Fig. 4.11).

4.4.2 Procedure

For our field trial, we used the robot (described in Section 4.3.2) that implemented the queue-management functionality. We put it in the queuing area in front of the train facility where it announced event information, ushered new visitors to the queue's end, and admonished visitors who engaged in inappropriate behaviors. Visitors and event staffs could freely interact with the robot. We did not provide any prior description of its functionality or instructions to the visitors, except a simple sign at the entrance of the train facility: "A field trial of robot services is in progress, and videos are being recorded for analysis purposes." We placed a human operator in a separate room who assisted our robot's operation when needed. He updated queue area settings, did inappropriate behavior confirmation, and dealt with errors. Generally, the robot provided its queue-management service 2.6 hrs. a day.

We conducted our field trial with five other investigators: a safety operator, two interviewers, a camera operator, and a coordinator. All stayed in non-disturbing locations, 3 to 4 m from the queue area. The safety operator ensured the security of the robot and the visitors. He could stop it with a Bluetooth controller in emergency situations, such as running children. Two interviewers stood near an exit of the train facility, observed the customer's interactions with the robot, and approached them for interviews after they finished the train ride. The camera operator captured the field trial sessions. The coordinator ensured smooth operation in the field trial. She observed the field study, communicated with other investigators, and made any necessary decisions.

4.4.3 Data collection

Since we wanted to understand our robot's autonomous working capability, its robustness in a real environment, and the visitors and event staffs' impressions of it, during our field trial we collected the following three forms of data: system records, observations and interviews.

System records

To understand our robot's autonomous working capability, we collected system logs, which recorded the following information related to incidents in which the operator assisted the system: changing queue area settings, resolving navigation and localization errors, and speech recognition. We recorded the type of task and the times that the operator started and finished each assisting task. From those data, we calculated the total time that the robot was controlled by the operator and the total time during which it was autonomous.

Observations

To learn about the visitor's interactions with our security guard robot, we recorded the field trials using three static videos cameras and a handheld camera. We subsequently analyzed these recordings to understand the visitor's reactions to the robot's ushering and admonishing services and their typical interactions with the robot.

Interviews

We conducted semi-structured interviews with the queued-up visitors and the event staff to learn their impressions about our robot and its queue-management service. In each question we asked them to elaborate on their answers. The interviews were voice-recorded and transcribed for analysis.

- Visitor interviews

  We approached the visitors who were queued-up and had received the robot's service (ushering and admonishing) for interviews while they were waiting in the queue or after they had finished the train ride. We omitted the children because they were too young to properly answer. The visitors answered the following questions based on their experience with the robot.

  1. Impression of the robot and ushering service:
     What did you think about the robot and its ushering services?
  2. Ushering service quality: To understand the effectiveness and quality of the ushering service, we asked them the following questions:
     (a) How did you interpret the robot's behavior?

   (b) Did you obey (or disobey) the robot's instructions?
   (c) Did you feel that the robot's ushering behavior was natural or unnatural?

3. Admonishing service: We heard the opinions of visitors regardless whether they had been admonished or not. Visitors who weren't admonished were asked to imagine engaging in an inappropriate behavior and being subsequently admonished by the robot. We asked them the following questions:
   (a) Did you comply/will comply with the robot's admonishment?
   (b) How did the human's admonishment feel compared with the robot's?
   (c) What was your impression of the robot that admonished people?
4. Comparison of suitability:

   Which is better for a queue-management service: a robot or a human?

- Staff interviews

  Interviews with the event staff members were done on the last day of the field trial to allow them enough time to get familiar with the robot. The questions for the staff interviews were slightly different from those for the visitors based on the different purposes for using the robot. We asked them the following questions:

  1. Impression of the robot

     What was your opinion of the robot security guard?
  2. Impression of overall service
     (a) How did you feel about the overall service provided by the robot?
     (b) Was its service useful?
  3. Ushering service
     (a) What did you think about the robot security guard's ushering service?
     (b) Was its ushering service natural?
  4. Admonishing service
     (a) What did you think of the robot-admonishing service?

   (b) Who provides a better admonishing service: a robot or a human security guard?

5. Comparison of suitability for queue-management

   Which is better for a queue-management service: a robot or a human?

6. Intention to use in future

   Would you like to interact with a robot security guard's service in future events?

   In addition, we gathered such background information of the staff as initial expectations of the robot as well as both their working experience and prior experience with robots.

4.5 Result

4.5.1 System statistics

The performance statistics of our robot are shown in Table 4.1. It worked ten days at the event. Its total queue-management service time was 1539.2 minutes. Among them, 1494.7 were autonomous service time minutes: 97.1% of its total working time. The human operator was on standby for the robot during its entire service. However, he actually served only 44.5 minutes, including 4.8 minutes of updating the queue area settings, 6.3 of resolving localization errors, 30.9 of admonishing-target confirmation, and 2.5 of speech recognition. The system requested operator assistance for 265 incidents: 143 occasions of updating queue area settings, 18 events of resolving localization errors, 101 occasions of admonishing-target confirmation, and three speech recognition incidents when visitors wanted information about events. Among the 101 requests for admonishing-target confirmation, the operator identified 62 incidents as inappropriate behaviors and the remaining 39 as false detections. Thus, the robot admonished visitors in 62 incidents. The average time between operator intervention incidents was 5.8 minutes.

The robot served 2486 visitors during its service time. It spent 1508.3 minutes ushering, announcing, and question answering and 30.9 minutes admonishing. That means, the robot only spent 2.0% of its working time admonishing visitors.

Table 4.1: System statistics

Measurement	Value
Total days of service	10
Total number of visitors served by robot	2486
Total service time	1539.2 min
Autonomous service time	1494.7 min
Operator service time	44.5 min
Average time period between two incidents of operator assistance	5.8 min
Total admonishing time	30.9 min
Total ushering, announcing, and question answering time	1508.3 min
Number of admonishing incidents	62

4.5.2 Interaction scenes

Typical interactions

Families with pre- or elementary-school children were the primary visitors to the event. When they approached the train facility the robot ushered them in. Fig. 4.12 shows a typical ushering incident. After the robot pointed to the end of the queue and asked visitors to join it, most obeyed. Some responded to the robot's request by nodding, saying they understood, or thanking it. However, around 10% of the visitors didn't join the queue after the first request from the robot. They seemed curious about the robot, especially the children. They stopped in front of it and observed its behavior for a moment and then joined the line. Children often did not voluntarily follow the robot's request. Instead, their parents explained its request and encouraged them to comply. During its non-peak time, the queue generally had between 2 to 12 people and from 10 to 30 during its peak time.

(a) Acknowledging (b) Pointing (c) Yielding (d) Move on

Figure 4.12: Robot's ushering behavior

Figure 4.13: Robot managing a queue during peak time

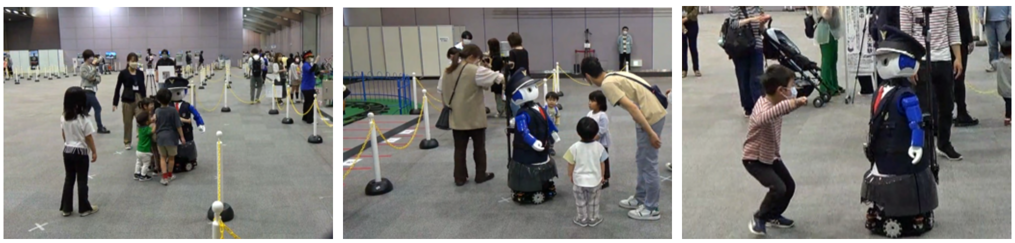


Figure 4.14: Children's interactions with robot

The peak time lasted for about 90 minutes (usually between 10:30 a.m. to 12:00 p.m.). Fig. 4.13 shows the robot's queue-management service during peak time.

A considerable number of the visitors approached the robot to talk when they had free time. Some of them were not necessarily aiming to line up for the train ride but were attracted by its presence. The majority only attempted friendly conversation. They usually greeted the robot, asked its name, and wished him good luck with his duty. A few visitors asked questions related to the train facility, such as ticket prices. They seem impressed when the robot was able to answer their questions. Most visitors took pictures of their children with the robot and said "goodbye."

Children exhibited various reactions to the robot. Most were interested in it. Many who came to use the train facility or were heading elsewhere approached the robot. Some ran toward it after noticing it before their parents arrived; others approached with their parents. Parents encouraged their children to interact with the robot and sometimes held toddlers in front of its face. They observed the robot, touched it, held its hand, talked to it, and hugged it (Fig. 4.14). On the other hand, some children especially toddlers seem scared and tried to avoid it.

(a) Robot noticed disorganized visitors (b) Robot admonished (c) Visitors complied (d) Robot thanked them

Figure 4.15: Successful admonishing incident

(a) 1st attempt (b) 2nd attempt (c) 3rd attempt (d) Staff approaching (e) Visitors queuing up

Figure 4.16: Failed admonishing incident

Admonishing incidents

The robot admonished visitors who didn't move up in the queue, were waiting in the queue in a disorganized fashion, or were waiting near its end without joining it. We analyzed the admonishing incidents to understand how visitors obeyed the robot. The robot admonished visitors in 62 incidents. However, we removed eight admonishing incidents from our analysis because closer evaluation identified them as actually not examples of disobedience. For example, five visitors corrected their behavior just before the robot admonished them, and sometimes human staff influenced the visitors' behavior. In two incidents, staff approached visitors who were waiting in front of the robot as their children aggressively touched it just before it admonished them to line up, and the operator wrongly judged the visitor's behavior. In one incident, even though the visitors looked as if they were engaged in inappropriate behavior, when the robot approached them closer and admonished them, the operator realized they were "innocent" and stopped further admonishments. Thus, we identified only 54 valid admonishing attempts with which we judged the visitor's obedience to the robot.

In 52 of the 54 admonishing attempts, visitors corrected their behavior after hearing the robot's admonishment. In two of them, visitors repeatedly ignored the robot's admonishments, and human staff were forced to intervene. A majority of the visitors who initially ignored the robot corrected themselves after hearing its admonishment, and others complied with the second or third admonishment. Interestingly, several visitors seem to be amazed by the robot's admonishing behavior and laughed. We didn't observe any aggressive reactions or arguments between the robot and the visitors.

Figure 4.15 shows an example of a successful admonishing incident that involved two mothers and their children. They were waiting in line as a group, which made the line look disorganized (Fig. 4.15(a)). After noticing their behavior, the robot approached and asked them to lineup along the chain (Fig. 4.15(b)). They immediately complied (Fig 4.15(c). The robot thanked them for their cooperation (Fig. 4.15(d)). They seemed impressed by its behavior.

Figure 4.16 shows an unsuccessful admonishing incident, which involved a mother and her two children who came for a train ride. First, they stood in the queue in a disorganized way. The robot noticed and admonished them to line up along the chain (Fig. 4.16(a)). But they ignored the robot and sat on the ground near the queue's end. The robot admonished them two more times (Figs. 4.16(b) and (c)). Despite the fact that the mother appeared to have heard the robot, she continued to ignore it and remain preoccupied with talking to her children. The robot abandoned its admonishment attempts. A staff member observed the incident (Fig. 4.16(c)) and approached the group (Fig. 4.16(d)) because they completely ignored the robot. As she approached, the mother finished her task and with her children joined the queue (Fig. 4.16(e)).

4.5.3 Interview results of visitors

During the field trial we conducted semi-structured interviews with 87 visitors (including the six people who were admonished by the robot) to learn their impressions of it and its queue-management service. We did not interview any children.

We analyzed our interviews with the visitors with a qualitative content analysis method to identify common opinions and the reasons behind them [34]. We used a bottom-up approach to form exclusive top categories (i.e., opinions) and subcategories (reasons). Thus, the category labels are defined based on the interview data. We classified a given answer to one of the top categories (i.e., opinions)

Table 4.2: Summary of visitor's impressions of robot and its ushering service

Impression	Reason
Positive (60/87)	Robot has specific merits (39/60)
	Capable of queue management/ushering (32/60)
Neutral (21/87)	Merits and demerits (19/21)
	No specific impression (2/21)
Negative (6/87)	Less capable of queue management (6)

and the given reasons for having such an opinion to the applicable subcategories under the top category. The category labels were defined by the authors, and the interviews were classified collaboratively with external coders.

We analyzed the visitor interviews under four topics: impressions about the robot and its ushering service, ushering service quality, admonishing service, and a comparison of the suitability for the queue-management role between the robot and humans. Note that the number of interviews for some topics is less than 87 since the interviewers didn't have a chance to question every person due to time limitations and human errors. The analysis results are presented below.

Impressions of robot security guard and ushering service

We analyzed the answers of 87 visitors to learn their impressions about our robot and its ushering service. 60 had *positive* impressions, 21 had *neutral* impressions, and six had *negative* impressions. Their opinions are summarized in Table 4.2.

The 60 visitors who had *positive* impressions gave the following merits of the robot and its ushering service.

Robot specific merits: 39 of 60 visitors commented on merits unique to the robot: being cute, its novelty, good for children, solution to labor shortages, and a good non-contact method during the COVID-19 outbreak.

- "I thought it was cute, especially being dressed like a policeman or a security guard" *(robot specific: cute).*
- "Kids like that kind of thing, and they'll enjoy seeing it" *(robot specific: good for children).*

Capability of ushering and queue-management: 32 of 60 visitors felt robots are capable of ushering and queue-management. They commented on the robot's ability to sense visitors and usher them to the queue's end. Some added that the robot's ushering was easy to understand and human-like, and it grasped situations and navigated smoothly without colliding into people.

– "It was so smooth that it was almost like being guided by a person, I thought it was amazing."

– "I thought it was wonderful. It watched people's movements and quickly moved out of the way so as not to disturb them, guided them precisely, and identified the end of the line for them."

Twenty-one of 87 visitors had a *neutral* impression about the robot and its ushering service.

Merits and demerits: Most (19 of 21) provided both merits and demerits. For the former, they mainly mentioned capability of ushering (8 of 19) and its specific merits (8 of 19). As demerits, they pointed out its low communication capabilities (insufficient variety in its conversations and facial expressions) (6 of 19) , scary (especially to very young children) (5 of 19) low ushering ability (3 of 19), and anxious about safety around a robot (2 of 19).

– "I thought it was cute, although I felt that it had less impact, was harder to understand, and a little different from what humans would do" *(robot specific merit (cute), less capable of ushering).*

– "I think it should have a few more friendly words for kids. But, overall I think he did a great job and guided us properly" *(low communication capability, capable of ushering).*

No specific impression: only 2 of 21 visitors didn't have any specific impressions about the robot and its ushering service.

Only six of 87 visitors expressed a *negative* impression about the robot and its ushering service. They thought that the robot lacked queue management capability.

Table 4.3: Visitor opinions about effectiveness of ushering service

Opinion	Reason
Adequate for following (66/74)	Capable of ushering (43/66)
	Easy to understand (16/66)
	Understand robot's role (4/66)
	Robot's specific merits (3/66)
	Same impression as humans (2/66)
Inadequate for following (8/74)	Less capable (4/8)
	Hard to understand (4/8)

Less capable of queue management: Visitors felt that the robot was not able to perform its ushering duties due to such limitations as its soft voice, mismatched instructions, not as capable as humans, and its machine-like voice was less impressive than that of humans:

– "I thought it was slightly less impressive because it had a machine-like voice, and unlike a human voice, it didn't grab my attention as much."

Ushering service quality

We analyzed the visitors' opinions about the effectiveness and naturalness of the robot's ushering behavior.

1. **Effectiveness of ushering service**

   We analyzed the visitor responses about the understandability of its ushering service and their compliance to determine whether the robot's ushering was actually effective. We identified two opinion categories from the visitors' answers: *adequate to follow* and *inadequate to follow*. We labeled the visitors' comments that described the robot's ushering service as useful for queueing up and its merits as *adequate to follow*. On the other hand, those who thought the robot's ushering was not useful for lining up due to its demerits (so they lined up by themselves) were classified in the *inadequate to follow* category.

   Sixty-six of 74 visitors said the robot's ushering service was *adequate to follow*, and only eight said it was *inadequate to follow*. Table 4.3 summarizes our analysis of their opinions and justifications.

The visitors who said the robot's ushering was *adequate to follow* gave the following reasons:

Capability of ushering: 43 of 66 said that robot has adequate capability for ushering. They described the good features of its behavior, such as a clear voice, effective utterances and gestures, prompt ushering, etc.

– "He led me by holding out his hand. I thought, Oh, I should go this way. I was simply amazed that a robot could go this far!"

Easy to understand: 16 of 66 visitors particularly mentioned that following the robot's ushering behavior was simple.

– "It was easy to understand because it told me exactly where to line up."

Understanding robot's role: Four of 66 people said because they understood the robot's role (due to its uniform and its appearance), they decided to follow its ushering:

– "Well, I guess I felt like I had to follow the robot because he was dressed like a security guard."

Robot specific merits: Three of 66 visitors pointed out merits particular to the robot, such as novelty and its suitability to educate and provide services to children.

– "A cute stationmaster like a robot was guiding us. I said to my children, 'Let's follow what Mr. Robot is saying.' It is a good chance to educate them, and I will follow the robot's request with my children. " *(robot specific: suitable for educating children).*

Same impression as humans: two of 66 visitors stated the robot gave them the same impression as a human:

– "I don't really care whether a person or a robot tells me where to line up, I guess it's the same thing."

Eight visitors, who believed that the robot's ushering was *inadequate for following*, mentioned the following limitations of its ushering service.

Less capable: Four of eight visitors complained that the robot was less capable of ushering because it responded too slowly, its instructions didn't match the context, and its voice was too soft:

– "The robot told me to get in line after I was already in line, so I thought, Oh, yeah, whatever" (less capable: too late ushering).

Hard to understand: Another four visitors said it was hard to understand the robot's instructions and behavior:

– "I couldn't understand the robot. He said something about following a line, but I was wondering if he meant the line that resembled a batten. It was a little confusing."

2. **Naturalness**

We analyzed 83 visitor impressions about the naturalness of the robot's ushering behavior. Most based their answers on a comparison of robot and human behaviors. We identified three different opinions: *natural* (51/83), *robotic but acceptable* (19/83), and *unnatural* (13/83). Table 4.4 summarizes the visitor impressions and reasons.

Visitors who said that the robot's behavior was *natural* gave the following reasons:

Appropriate gestures: 15 of 51 visitors described the robot's gestures as appropriate, including hand gestures, eye contact, and body orientations during its ushering behavior. They thought they were natural:

– "We made brief eye contact, which felt natural."

Table 4.4: Visitors' impression about naturalness of robot's ushering behavior

Opinions	Reason
Natural (51/83)	Appropriate gestures (15/51)
	Smoothness (15/51)
	No unnatural aspects (10/51)
	Timely reactions (5/51)
	Others (good qualities, cute) (2/51)
Robotic but acceptable (19/83)	Positively accept robot-like behavior (11/19)
	Less natural than humans but adequate for a robot (8/19)
Unnatural (13/83)	Lack of communication capability (5/13)
	Rough movements (6/13)
	Others: many unnatural elements,robotic appearance (2/13)

Smoothness: Another 15 of 51 visitors felt the robot's behavior was natural due to its smooth body movements and navigation:

– "Well, I think its movements were natural. The waving of its hands and movements were not so jerky and soft."

No unnatural aspects: 10 of 51 said they didn't notice anything unnatural about the robot's behavior:

– "Well, I didn't feel anything unnatural."

Timely reactions: Five of 51 visitors described the robot's ushering behavior as natural due to its timely reactions to human behaviors:

– "It gave me sound guidance the moment I arrived, and it felt very natural!"

Other: Only 2 of 51 visitors noted other reasons, including the robot's cuteness and quality behaviors:

– "It acts so natural, it's just very well made."

The 19 visitors who described it as *robotic but acceptable* gave the following reasons:

Positively accepted robotic behavior: 11 of 19 positively accepted and even preferred the robot's behavior. They explained that robots and humans are different entities, and the robot's current behavior fits itself:

– "Well, isn't robotic behavior good? The neck and hand movements are awkward like a bunraku puppet, although that gives a robotic or puppet-like impression."

Less natural than humans but adequate for a robot: Eight of 19 visitors described the robot's behavior as unnatural/less natural compared to a human but adequate for a robot:

– "It was a bit unnatural, although it didn't feel strange since he is actually a robot, not a human."

People who described the robot's behavior as *unnatural* pointed out following issues:

Unsmooth movements: Six of 13 visitors said they felt the robot's behavior was unnatural due to its jerky body movements:

– "I think some of its parts are unnatural. I didn't think that it was smooth enough, often choppy."

Low communication capability: Five of 13 visitors commented on the limitations in the robot's communication, such as a lack of eye contact, incorrect body orientation, and a lack of language skills. These drawbacks led to them to describe its behavior as unnatural:

– "If it is a security guard robot, I think it is necessary to have two-way face-to-face communication, but I don't think its two-way communication is perfect yet."

Table 4.5: Summary of interview of admonished visitors about compliance to robot's admonishment

Obedience	Reason
Obeyed (6)	Admitted fault (4/6)
	Polite and courteous (1/6)
	Similar to human admonishing (1/6)
Disobeyed (0)	-

Other: Two other visitors pointed out other reasons, such as everything about the robot's ushering behavior being unnatural and its robotic appearance (due to visible wheels) making it unnatural:

- "Oh, it's not natural. Nothing."

Admonishing service

We studied the visitors' (i.e., admonished and unadmonished) impressions about the robot's admonishment service under the following topics:

1. **Obedience to robot's admonishments**

   We analyzed the intentions of 79 (six admonished and 73 unadmonished) visitors to *obey/disobey* a robot's admonishment and the reasons for them.

   (a) Admonished visitors

   All the admonished visitors we interviewed obeyed the robot's admonition. Table 4.5 summarizes our interview analysis. They mentioned the following reasons for their obedience.

   Admitted their mistake: Four of six of the admonished visitors said they obeyed the robot because they realized their mistake after it admonished them. One visitor who was warned for waiting in the queue in an unorganized fashion stated, "Oh, I understood, I should follow this line."

Table 4.6: Summary of analysis of intention of unadmonished visitor to comply with robot's admonishment

Intention	Reason
I will obey (66/73)	Similar to human-admonishing (30/66)
	Adequate capability (11/66)
	Merits unique to robot-admonishing (11/66)
	Others observing (6/66)
Obedience depends on situation (6/73)	Uncertain of robot's capabilities (4/6)
	Factors independent from type of admonisher (2/6)
I will not obey (1/73)	Because it's a robot

Polite and courteous: One of six visitors complied with the robot because its admonishing behavior was polite and kind: "Yes. I think I'd probably comply because it is polite and its voice sounds good with a nice quality."

Similar to human admonishing: Another one of 6 visitors said the robot and a human admonishment felt the same: "I don't think there's much difference between being told by a human or by a robot." She added that "I agreed that I was in the wrong, so I didn't mind which corrected me, a robot or human."

(b) Unadmonished visitors

We analyzed the unadmonished visitors' intentions to obey if they received one. A large majority (66/73) stated they would *obey*. Another six said their obedience would *depend on the situation*; only one visitor said he/she would *not obey*. Table 4.6 shows the analysis result.

Sixty-six visitors who said they would *obey* a robot's admonishment gave the following reasons for their intentions.

Similar to human admonishing: 30/66 visitors stated the features shared by both the human and robot admonishing services. They pointed out that the robot's admonishment would help them recognize and accept their own mistakes (admit a fault), give them a sense of being monitored, cause similar embarrassment from a human's admonishment, and make a similar impression as a human staff member:

- "If I were unconsciously doing bad behavior, I'd thank you for giving me a chance to fix it" *(admitting a mistake).*
- "He's watching me closely, and I should not do anything wrong" *(feeling of monitoring).*
- "Well, I think it's just saying it on behalf of a person, so I think it's the same as a person, and so in my opinion, I'd stop that bad behavior, if it told me" *(feel same as a human staff).*

Adequate capability: 11 of 66 visitors felt the robot had sufficient capability to judge people's behaviors and admonish them:

- "Well, I think that robots recognize and judge queues properly, and I think they are probably smart for making such requests. So, I'd obey."

Merits unique to robot-admonishing: As the reasons for their intentions to obey a robot's admonishing, 11 of 66 visitors described merits unique to a robot-admonishing service: i.e., easier to accept than a human's admonishment, less offensive, nice, cute and childlike, and effective with children etc.

- "There's something less sarcastic about it" *(less offensive).*
- "I think it's easier for explaining to children. Since Mr. Robot says, let's line up properly or Let's listen to Mr. Robot. Children might listen more to a robot than to an adult or a store employee *(effective with children).*

Others watching: Six of 66 visitors said they would obey a robot because others in the vicinity were observing the incidents. Most stated that they would comply with the robot just because they are with their children and want to set a good example for them. Others claimed they complied because of the human operator or others in the vicinity:

– "One reason to follow the robot's admonishment is that I have children. If I were single, the robot's admonishment would annoy me. But since I'm a mother, I want to avoid doing bad things in front of the children. So I follow the robot's admonishment in front of the children" *(setting a good example for children).*

6/73 visitors said their obedience would *depend on the situation.* We identified the following two reasons for their opinions:

Uncertainty about robot's capabilities: Four of six visitors expressed skepticism about the robot's capability to judge the situation and admonish. Furthermore, one pointed out that a robot should use non-offensive words for its admonishment. Thus, their compliance would change based on their own judgment at the moment of the robot's request:

– "Depending on the situation, but I don't know. I might think that the robot was making a mistake, I don't know if it is correct or not."

Factors independent from the type of admonisher: Two of six visitors said that, similar to a human's admonishing situation, their compliance with the robot's admonishment would depend on such factors as the time and the current situation:

– "If a robot warned me, I don't think my response would depend on the robot, but rather on the situation around me at the time."

Only one visitor said she would *not obey* a robot's admonishment:

– "No, I don't think I'd obey it, probably just because it is a robot."

2. **Feelings when receiving a robot's admonishment vs. a human's**

We analyzed the answers of the six admonished and 73 unadmonished visitors to the question whether they felt the same or different when they were admonished by a human or a robot. Our findings are presented below.

(a) Admonished visitors

Admonished visitors gave the following four types of opinions about their feelings when comparing a robot's admonishment and a human's

Table 4.7: Summary of analysis of admonished visitors' feelings when they are admonished by a robot or a human

Impression	Reason
Human's and robot's admonishment feel identical (2/6)	Identical level of persuasiveness (2/2)
Robot's admonishment is easier to accept than human's (2/6)	Robot admonishment is emotionless (1/2) No emotional reaction to robot's admonishment (1/2)
Impression depends on situation (1/6)	Depends on mental state
Robot's admonishment is more uncomfortable than human's (1/6)	Scary

admonishment: *An admonishment from a human and a robot feel the same* (2/6), *a robot's admonishment is easier to accept than that from a human* (2/6), *the feelings depend on the situation* (1/6), and *a robot's admonishment is more uncomfortable than a human's* (1/6). Table 4.7 summarizes their opinions and reasons.

Two visitors who said *human and robot admonishments feel the same* stated that a robot's admonishment has the same persuasive power as from a human. A person who was admonished for not moving forward explained: "Ah, I will probably follow the robot's admonishment and move forward. It is the same feeling for humans."

A pair of visitors who believed that *a robot's admonishment was easier to accept than a human's* gave the following reasons. One said that a robot's admonishment was less annoying than a human's because it didn't contain any emotion: "When we are admonished by another person, the utterance generally contains some emotion, and that is annoying. Our emotional utterances cannot annoy a robot. Since it is just explaining facts without emotion, it's less annoying." The other preferred the robot-admonishing service: "I'd rather be corrected by a robot than by a person. My impression is different based on how a person says things or from his tone of voice. If a person is soft-spoken, that's fine, but if a person has a harsh tone, I might struggle to follow his request, even though I know I should. But if a robot says it, it's like, oh, yes, I see."

The person who stated that his *feelings would depend on the situation* mentioned that it would also depend on his own mental state at the moment: "Ah, if I'm feeling relaxed, then I don't feel any bad impressions."

The visitor who believed that *a robot's admonishment is more uncomfortable than a human's* described that the robot's lifeless impression and/or the unpredictability of its intentions made him scared. He explained: "I felt like I was slightly being pressured in front of the robot, something like the impression of an inorganic object. I had an impression what it is, and I felt scared or something like that. When I'm talking with a robot, I can't imagine what it will say next. But with a person, I can get the message that I'm standing in the wrong location, before it tells me where to line up. With a robot, I might feel anxious because I can't anticipate what it might say."

(b) Unadmonished visitors

We studied the opinions of 73 unadmonished visitors about how they would compare their feelings about a robot's admonishment vs. or a human's. We identified five different opinions: *a robot's admonishment is easier to accept than a human's* (43/73), *the admonishments of a human and a robot feel the same* (17/73), *a human's admonishment is more powerful than a robot's* (6/73), *a robot's admonishment is more uncomfortable than a human's* (3/73) and *other* (4/73). Table 4.8 summarizes our analysis.

43 of 73 visitors said *a robot's admonishment would be easier to accept than a human's*. They commented on the merits of a robot's admonishment, such as being less uncomfortable or offensive (22/43) and emotionless (i.e., unlike humans, robots don't have emotions) (15/43). Furthermore, contrary to the human admonishment cases, they said they would not react emotionally to a robot's admonishment (4/43). In addition, four of the 43 visitors noted that a cute robot's admonishment would be easier to accept (4/43):

Table 4.8: Summary of analysis of unadmonished visitors' feelings when they are admonished by a robot or a human

Feeling	Reason
Robot's admonishment is easier to accept than human's (43/73)	Less uncomfortable/less offensive (22/43) Robot's admonishment is emotionless (15/43) No emotional reactions to robot's admonishments (4/43) Robot is cute (4/43)
Admonishments of humans and robots feel identical (17/73)	Same level of persuasiveness (12/17) No particular bad impression (4/17)
Human's admonishment is more powerful than a robot's (6/73)	Human is more persuasive (4/6) Human's admonishment is emotional (3/6)
Robot's admonishment is more uncomfortable than a human's (3/73)	More embarrassing than from a human (2/3) Doubt about capability (1/3)
Other (4/73)	Difficult to imagine the feelings (3/4) Robot is just a machine (1/4)

– "I think robots consider many things, such as ways of talking or expressing admonishment to avoid uncomfortable representation, so I don't think it gives a bad impression" *(less offensive).*
– "There are no unnecessary emotions, so I can follow it smoothly because I'm just following the rules (of this location)" *(robot's admonishment is emotionless).*

Seventeen of 73 visitors stated that a human's admonishment and *a robot's would feel the same*. 12 mentioned that a robot has the same level of persuasiveness as a human. Another four noted that they have no particular bad impressions about a robot's admonishment:

– "I just feel like, oh, I must've made a mistake in the row, or something like that. My impressions of the admonishments of the robot and the human are the same. Um, the robot and the person are making the same utterance and the same message, so

Table 4.9: Summary of impressions of admonished visitors about robot that admonishes people

Impression	Reason
Positive (5/5)	No particular resistance (3/5) Robot's admonishment is easier to accept than a human's (1/5)
Negative (0)	-
Neutral (0)	-

I understand" *(identical level of persuasiveness).*

Six of 73 visitors said they feel *a human's admonishment is more powerful than a robot's* due to the characteristics of the former. Four described humans as more persuasive and harder to ignore. Three others described human admonishments as being emotional and hence more powerful:

– "A human's admonishment is more forceful" *(humans are more persuasive).*

Three of 73 visitors thought *a robot's admonishment would be more uncomfortable than a human's* for the following reasons. Two mentioned that being admonished by a robot would be more embarrassing than similar treatment from a human. Another felt doubt about the robot's ability to judge the situation.

– "I might feel more embarrassed if a robot chastised me than if a person did. . . . " (a robot's admonishment causes more feelings of embarrassment than an admonishment from a human).

Four of 73 visitors had *other* opinions. Three said they *couldn't imagine how to compare being* admonished by a robot and a human. Other visitor dismissed the robot because it was just a machine.

3. **Impressions about robot that admonished people**

   We analyzed the opinions of 80 visitors (five admonished and 75 not) about robots that admonish people. Our analysis results are presented below.

Table 4.10: Summary of impressions of unadmonished visitors about robot admonishing people

Impression	Reason
Positive (65/75)	Merits specific to robot-admonishing service (40/65)
	Similar to human-admonishing service (25/65)
Neutral (8/75)	Uncertainty about effectiveness (5/8)
	Depends on robot's admonishing language (2/8)
	Effective but more embarrassing than human admonishment (1/8)
Negative (2/75)	Prefer humans (2/2)

(a) Admonished visitors

We analyzed five admonished visitors' impressions about our robot-admonishing service (Table 4.9). All had *positive* impressions. Three of five visitors said they had *no particular resistance* to a robot-admonishing service. One of five visitors believed that *a robot's admonishment is easier to accept than a human's*: "Well, such warnings are good, because we don't have to apologize, and since it is a machine, it's easy to accept its request. For the human-human case, a person might get angry and cause trouble. However with a robot, I just think, Okay, I see." Unfortunately, we didn't hear the reason from the remaining visitor who also had such positive impressions due to our interview limitations.

(b) Unadmonished visitors

Table 4.10 summarizes our analysis of the opinions of the unadmonished visitors about a robot that admonishes people. A majority (65/75) had a *positive* impression of such a service. They gave the following reasons for their positive impressions.

Merits specific to robot-admonishing service: 40/65 mentioned positives specific to robot-admonishing services that are absent in human-admonishing services, such as admonishing is easier for a robot than a human, a robot's admonishment is easier to accept than a human's, impressed with its admonishing capability, avoids conflicts, effective with children, and cute.

- "It's easier to accept a request from a robot" *(robot-specific: a robot's admonishment is easier to accept than a human's).*
- "It's good because the robot can say things that are harder to accept from people" *(robot specific: admonishing is easier for a robot than a human).*

Similar to human-admonishing service: 25/65 of visitors felt the robot-admonishing service resembles a human-admonishing service. They explained that they have no particular resistance to the former because a robot is a good substitute for a human, and robots provide a feeling of security:

- "I don't feel any differently between a human or a security guard robot, because both are just doing their jobs" *(similar to human-admonishing service: no resistance).*
- "Oh, a robot gives the impression and a sense of security, and I know that they are looking out for me" *(similar to human-admonishing service: feeling of security).*

8/75 Unadmonished visitors expressed a *neutral* impression about robot-admonishing service for the following reasons:

Uncertainty about effectiveness: Five of eight visitors were uncertain about the effectiveness of a robot-admonishment service. Since they were not directly warned by the robot, they tended to make assumptions about how other people might behave and express broad opinions. They stated obedience would depend on the person being admonished. People who intentionally engage in inappropriate behavior would probably refuse to comply. One wondered whether children could understand and comply with a robot's admonishment.

- "I think that those who unconsciously make mistakes will think, oh, I'm sorry, but those who are acting intentionally will probably just dismiss such admonishments as nagging."

Table 4.11: Summary of visitor's opinion for comparison of suitability for queue management roles: robots vs. humans

Opinion	Reasons
Robot is better 23/72	Robots are more acceptable to people (10/23) Robot's specific merits (9/23) Reduces human work load (1/23)
Human is better 19/72	Human capabilities (16/19) Other (3/19)
Neutral 30/72	Complimentary merits and capabilities (20/30) Either is fine (10/30)

Depends on the admonishing language: Two of eight visitors said their impression would depend on how the robots admonish, whether they are impolite or not. If the robot's admonishment is not rude, they would have a positive impression:

– "Well, it's okay if the robot's language is polite."

Effective but more embarrassing than a human's admonishment: One of eight visitors who had a neutral opinion said that although a robot's admonishment is effective, it is more embarrassing than being admonished by a person.

– "Oh, being admonished by a robot was more embarrassing than by a human. But after being admonished by it, I realized the robot was right."

Only two of 75 visitors had *negative* impressions about the robot-admonishing service. Both preferred humans for such services. They thought that people will resist being admonished by a machine and that a robot's admonishment draws too much public attention, which increases the intensity of being embarrassed in the receiver.

– "I don't think people probably want to be told what to do by a robot. People won't be accept being admonished by a machine."

Comparison of suitability for queue-management role: robot vs. human

We analyzed 72 visitors' opinions about the suitability of a human vs. a robot for queue management. We identified a variety of views and three types of opinions: *a robot is better* (23/72), *a human is better* (19/72), and *no difference* (30/72). Furthermore, we identified the reasons for their opinions. Table 4.11 summarizes our analysis.

Twenty-three of 72 visitors stated *a robot is better* for queue-management services than a human for the following reasons:

Robots are more acceptable for people: Ten of 23 visitors said robots will be more accepted by people due to such merits as being less rude and easier to accept, etc.

- "I think robots are better. They are easier to accept. With a human, there might be trouble, but not with a robot."

Robot's specific merits: 9/23 visitors described merits specific to robots: being cute, cheap labor, good for children, and wide sensing capability.

- "I think a human guard has a bit of a large blind spot. But a robot would have better ability to check out the whole environment and notice something. It has cameras and can make judgements from their information" *(robot specific: wide sensing capability).*

Reduces human's workload: Only one of 23 visitors said a robot would reduce human's work load.

Nineteen of 72 visitors believed that *humans are better suited* for queue-management services for the following reasons:

Human's capabilities: A majority (16/19) of visitors believe that humans are better due to such human capabilities to act based on specific situations, better judgement, less susceptible to being deceived, fast responses, communication capability, and easier to understand.

- "I think that a human would be able to see a person and make better judgments."

Other: 3/16 visitors mentioned additional reasons, such as robots have machine-like impressions, humans are more conspicuous due to size, and humans need jobs.

- "I think a human guard is better. You know, a robot looks like a machine" (Other: robots give a machine-like impression).

Thirty of 72 visitors expressed a *neutral* opinion about which is better for queue-management services. They pointed out the following two reasons:

Complimentary merits and capabilities: According to 20/30 visitors, since humans and robots have distinct advantages and skill sets, either one or the other may be required, depending on the situation, to maximize each group's unique advantages. They believe that robots are better for children's events because they are cute and will attract their attention. They also pointed out that some children might be scared when there are too many adults. On the other hand, some visitors stated that robots are less effective and irrelevant for adult-only events and humans are more suitable: robots for children's events and humans for adults' events. They added that humans are better in crowded, complex, or dangerous situations that require accuracy, fast responses, and intricate communication capabilities; robots are good for simple and repetitive tasks or as an attraction.

- "If children are present, such as at this event, they will be interested in the robot. When there are only adults, I think the robot service would be more difficult" *(complementary merits and capabilities: robot for children's events humans for adults' events).*

- "Oh, I think both humans and robots are necessary. It would be better to have one person and five robots. Since admonishments sometimes cause troubles, or are done during odd situations, the robot can't possibly do everything. But for standard operations, like repeating the same action like checking tickets, a robot fits the situation better, I think" *(complementary merits and capabilities: humans for complex tasks robots for simple and repetitive tasks).*

Either is fine: Ten of 30 visitors said since there is no difference between the services provided by robots or humans, thus either is fine. They believed the robot also has adequate capability for queue management:

Table 4.12: Summary of staff's impression about robot security guard

Impression	Reason
Positive (3/4)	Complements human staff (1/3)
	Ushering capability (1/3)
	Good for children (1/3)
Neutral (1/4)	Interesting to some children; scary to others
Negative (0)	-

– "Perhaps either is fine. I don't think there is that much of a difference."

4.5.4 Staff interview results

We interviewed four members of the event staff (2 males and 2 females) whose means and standard deviations of ages were 23.75 and 2.75 years. All had 1-2 years of experience working at public events. Only two had prior experience with a robot (i.e., Pepper).

We analyzed their interviews to learn their opinions of our robot and its services. We used the same qualitative analysis approach described in Section 6.3. Their opinions were categorized into exclusive main categories and their reasons as subcategories.

Initial expectations of robot

Two of four members had no expectations for the robot. They said they were unfamiliar with them. The remaining two members expected the robot to record the event with its camera to provide proper evidence (1/4) and interact with children (1/4).

Impressions about robot security guard

When the staff members were asked about their impressions of robot security guards, three of four expressed a *positive* impression, and the remaining member gave a *neutral* impression. Table 4.12 summarizes the analysis.

The three members with *positive* impressions provided the following reasons. One said that the robot worked as a *complement to the staff* (1/3) "Another member of the staff who cares about what people can't do. It was talking to

Table 4.13: summary of staff impressions about overall service of robot

Impression	Reason
Positive (2/4)	Complements human staff (1/2) Queue-management capability (1/2)
Neutral (2/4)	Merits and demerits (2/2)
Negative (0)	-

people who were waiting in line separately or who didn't know where to stand in line." Another commented on the robot's *ushering capability*: "I think the robot was actually guiding the people. After hearing the robot's utterance, something like "don't be shy", a customer follows the robot's request, so I thought that it was working properly." Another described the robot as *good for children*: "it was easy to tend to children because it looks friendly, so they can come around and watch the robot. They were curious about it."

The staff member with a *neutral* impression described the robot as *interesting for some children while scary for others*: "On the positive side, it captured the children's attention and I thought they were slightly interested in approaching it, but on the other hand, many children were scared and crying."

Impression about robot's service

1. **Impression about overall service**

   Two of four members had *positive* impressions of the overall service provided by the robot, and the remaining two had *neutral* impressions. The impression of the visitors and their reasons are listed in Table 4.13.

   The two members who had *positive* impressions thought that a robot's work could *complement the human staff*: "it's not just people, it's convenient to have someone do it. It is useful that the robot checks (and handles) the end of the queue since I was unable to do so today." Here is her comment about the robot's *capability of queue management*: "The good thing is that it told them to get in line like a human and answered questions, which I thought was great."

   The two staff members who had *neutral* opinions commented on both the robot's *merits and demerits*. One mentioned that even although the robot

Table 4.14: Staff opinions about usefulness of robot's service

Impression	Reason
Useful (3/4)	Complements human staff (2/3)
	Reduces work load (1/3)
	Good for children (1/3)
Useless (0)	-
Neutral (1/4)	Good as an attraction but less capable of ushering

had sufficient capability for ushering, it scared some children. Another described it as a good attraction, but slightly criticized its ushering capability due to its low voice.

2. **Usefulness of service**

   When we asked the staff whether the robot's service was useful, three said it was, and one gave a neutral opinion. Their answers are summarized in Table 4.14. The three staff members who said the robot service was *useful* described such merits as the *robot's work complements the human staff* because it *reduced their work load* ("It was a good service for this event because it lowered the work we had to do"), and *good for children* ("it got along easily with children").

   The following is a *neutral* opinion of a staff member: "I feel like it's just another attraction. Not so many people interact with robots on a daily basis, so they can just enjoy a new experience. But in terms of guidance, many of its services aren't good enough yet."

Ushering service

1. **Impression about ushering service**

   Table 4.15 summarizes the impressions of the event staff members of the robot's ushering service. Three of them gave *positive* impressions. One expressed a *negative* impression.

   All three members who had *positive* impressions cited the robot's *adequate capability* for ushering as their reason for being impressed: "I was amazed that it could guide people properly." They added that the robot's standing

Table 4.15: Summary of staff's impression about ushering service

Impression	Reason
Positive (3/4)	Adequate capability (3/3)
Negative (1/4)	Less capable

Table 4.16: Summary of staff's impression of naturalness of robot's ushering behavior

Impression	Reason
Natural (3/4)	Natural enough for a robot (1/3) Smoothness (1/3) No unnatural aspects (1/3)
Unnatural	-
Difficult to judge (1/4)	Not familiar with guiding robots

location made it conspicuous to new visitors. "Because it's more visible at the end of the line than at the front, it got the attention of new customers."

The staff member who gave a *negative* impression thought the robot was *less capable* of ushering due to such faults in its robot's ushering behavior as a low voice and using an ineffective ushering strategy. She noticed that some visitors who waited in front of the robot continued to interact with it for a long time without joining the queue: "The robot sometimes said please form a line, but the visitors didn't obey. They didn't seem to understand the queue and lined up incorrectly in it. I don't think the visitors could hear it." She suggested that "the robot should accompany newcomers to the end of the line."

2. **Naturalness of ushering behavior**

   We asked the event staff whether they felt the robot's ushering behavior was natural or unnatural. Most (3) said it was *natural*, although one staff member said *judging its naturalness was difficult* (Table 4.16).

   The staff members who felt the robot's behavior was *natural* gave the following reasons. One thought that even though its ushering behavior was not on the same level as that of humans, it was *natural enough for a robot*. "It recognized people, although of course not as smoothly as a human. But

Table 4.17: Summary of staff's impression about robot's admonishing service

Impression	Reason
Positive (3/4)	Fewer conflicts (1/3)
	Effective (1/3)
	Complements human staff (1/3)
Neutral (1/4)	Merits and demerits
Negative (0)	-

I think it did recognize people and effectively guided them." Another felt the robot's behavior was *smooth*: "I thought it would talk slowly, but it talked quite smoothly. It also moved well." Another member stated there were *no unnatural aspects* about the robot's behavior: "Nothing bothered me. It felt like it was working as part of our team."

The staff member who said *judging the robot's behavior was difficult* gave the following reason: "Since I have no experience with guiding robots, I don't feel qualified to comment on that aspect."

Admonishing service

We analyzed the staff's impressions about the robot's admonishing service under the following two topics:

1. **Impression about admonishing service**

   Table 4.17 summarizes the impressions of the event staff about the robot-admonishing service. Three of four members expressed *positive* impressions about it; one gave a *neutral* impression.

   One of the three members who expressed a *positive* impression commented that unlike human admonishments, the robot's admonishments caused *fewer conflicts*. "I think some people got offended by being admonished, but you can't argue much with a robot." Another staff member described the robot's admonishment as *effective*: "The robot spoke clearly, so the parents seemed to understand its request. They carefully looked at their children and admonished them when they goofed off." Other staff members said they struggled to focus on the visitors in the queue because they were

Table 4.18: Staff's opinions about suitability for admonishing service (robot vs. human)

Opinion	Reason
Robot is better (2/4)	Robot's admonishment is easier to accept than human's (1/2)
	Reduced mental burden on staff (1/2)
Depends on situation (1/4)	Complementary merits
Difficult to judge (1/4)	Merits and demerits

busy with visitors inside the train facility. Thus, robots handling (and admonishing) those in the queue compensated for the staff's lack of ability *(complementing human staff).*

The staff member who had a *neutral* opinion commented on the *merits and demerits* of the robot's admonishing services. She pointed out that although its admonishment might be successful with adults, it would probably be less effective with children.

2. **Suitability for admonishing service (robot vs human staff)**

   When asked whether a human or a robot is better suited for admonishment service, the staff had divergent answers. Two of four said the *robot is better*, one said that the *suitability depends on the situations*, and the remaining staff member thought it was too *difficult to judge*. Their opinions and reasons are summarized in Table 4.18.

   The two staff members who thought a *robot would be better* stated the merits of its admonishing service. One pointed out that *a robot's admonishment is easier for visitors to accept than a human's*. "I think people will listen to robots more readily because they don't have any emotions." Another staff member said placing the responsibility of admonishing on robots *reduced their own mental burden.*

   The one who stated a suitable person would *depend on the situation* commented on the merits of being a human (i.e., human capabilities and a loud voice) and robot (its admonishment is easy to accept because it's emotionless). Thus, either could be used, depending on the requirement: "I think

Table 4.19: Staff's opinions about suitability for queue-management service of robots and humans

Opinion	Reason
Robot is better (0)	-
Human is better (0)	-
Depends on situation (4/4)	Complementary merits (2/4) Depends on robot's capabilities (1/4) Depends on scale of event (1/4)

a robot would be fine inside a room, but if it is noisy or outside, a human might be more effective."

The staff member who *couldn't decide which was more suitable* commented on the following *merits and demerits* of a robot's admonishment. As a demerit she stated that a robot's admonishment is less effective than a human's due to the former's low capability: "I think that customers are more likely to listen to a human. There are some things like eye contact, When I (a human) admonish customers, they understand my gaze and think I'm saying something to them. But I think it's still a little difficult for the robot." On the other hand, she added that human capacity is also limited, and so the robot's admonishment is also helpful to compensate for the limitations of human resources.

Suitability for queue-management service robot vs human

We analyzed the event staff's opinions about who is more suitable for a queue-management service, a robot or a human. All said a *suitable person depends on the situation*. Table 4.19 summarizes our analysis.

Two of four staff members commented on the *complementary merits* of humans and robots. They pointed out the merits of humans, such as their capabilities and the ability to handle unexpected situations and such merits of robots as attractiveness and fulfilling a lack of human staff. "I think a robot can help reduce the number of staff when we do a certain type of work or guide people around. But when children are running around at an event like this, or when something unexpected happens, a robot alone is not enough." One staff member said the suitability of a robot *depends on its capability*." I think either is fine, but it

Table 4.20: Staff's intention to use robot in future events

Answer	Reason
Yes (3/4)	Interesting (2/3) Reduce workload (1/3) Expecting robot's capabilities will improve further in future (1/3)
No (0)	-
Depends on situation (1/4)	Depends on robot's appearance

depends on the robot's level of speech recognition and capability of answering." Another said that the more suitable person *depends on the scale of the event*. He explained that a robot is suitable for less crowded events, and humans are more suitable for more crowded events: "If the event were less crowded, I think robots are helpful, but when are too many people, then a robot would struggle to organize lines instead of a human."

Intention to use robot in future

When we asked about the staff's intentions to use the robot for future events, three of four said they *would like to use it*, and one said her decision would *depend on the situation*. Their answers and reasons are presented in Table 4.20.

Two of three members who were *willing to use* the robot commented that it is *interesting*. "I think it would be fun to have a lot of robots." One member stated that robot would *reduce their workload*: "it's also hard for us to take a break if not enough people are working, but robots can always work, so that might help us feel better." Another was willing to use the robot due to the *expectation that its capabilities will improve in the future*: "Since I expect that the technology will improve as we conduct more experiments like this in the future, I think it will be good if robots can be more flexible and do more work."

The staff member who said her decision would *depend on the situation* pointed out that she would use the robot if it looked friendlier: "I think its face is scary. It should be changed to look friendlier."

4.6 Discussion

4.6.1 Revisiting research questions

The objective of this study was to develop a robot security guard that can manage queues in public spaces. It is challenging to use a robot to control people's behavior in the actual world because of human reluctance to comply with a robot [62, 82] and the unfavorable perceptions some possess about such robots [46]. To overcome these challenges, we formulated our first research question: "How can we develop an acceptable and effective robot for regulating people in public spaces?" We proposed a design that mimicked a human security guard's role, expecting our design to help people easily understand its role and improve their compliance with and their acceptance of the robot. Our field-trial results showed that it persuaded individuals to comply with its admonishments and requests by acting like a professional security guard and received their acceptance. Although the self-reported number of visitors is limited, the visitors recognized the robot's role as a security guard or a member of staff due to its uniform and appearance which motivated them to comply with it. Further, our interview analysis suggests that visitors cooperated with the robot because they perceived the features of a professional guard in it, such as having sufficient capability for queue management and that its admonishment resembled a human's admonishment. Thus, imbuing a professional image in a robot is an effective and acceptable design for a regulatory robot.

Our second research question looked into "How do people in public spaces perceive a robot that attempts to control their behaviors?" Most visitors accepted this queue-managing robot that wanted to manage their behaviors in real life, and its requests and admonishments were convincing enough to follow. Their opinion of the robot was influenced by such factors as its capacity to provide a service, the clarity and reasonability of its requests or admonishments, and its attitude. Furthermore, even though some visitors disobeyed it, our result demonstrates that being caught and admonished by a robot in public did not motivate them to confront it or act aggressively. Thus, despite the limited number of interviews with admonished visitors, our field-trial results suggest that people will welcome a regulatory robot service in society.

4.6.2 Implications

Implications for design of robots that regulate people

When robots assume authoritative positions in society, they will be required to control the behaviors of others like human professionals do. However, people typically dislike robots that merely attempt to control them through admonishments and punishments [46]. Such an attitude complicates integrating regulatory robots into society. Our study shows one successful solution to this problem.

Our approach is to exhibit a professional image in the robot, implement admonishing as one functionality among several others, and use admonishments sparingly in unavoidable situations. This design enabled our robot to regulate a crowd in a public space reasonably well where it still received people's acceptance even though it performed its admonishing functionality. We believe this design created a perception in the people that a regulatory robot provides a reasonable service instead of merely an admonishing machine. We expect that the "exhibiting a professional image" design concept is applicable to contexts where a robot has to perform roles that require a professional image where admonishing is part of its services, such as police officers, managers, teachers, and exam invigilators.

Our research also emphasizes the importance of minimizing admonishing situations and discovering non-confrontational alternatives. Since admonishing creates negative feelings in people and bad impressions of robots, it should be the last option considered by regulatory robots. Robots should try to lower the likelihood of inappropriate behaviors in the first place by clearly and understandably providing its instructions. Our interview findings showed that most visitors are willing to cooperate if they clearly understand the robot's instructions. On the other hand, confusing instructions increase non-compliance. Another reason for cooperation is predicated on people understanding the robot's role. Its appearance and behaviors must be designed in a way that makes its role obvious.

Finally, our results imply the potential of deploying robots for regulating people in public spaces. A robot's unique capabilities, such as its wide sensing ability, its ability to talk to anyone without experiencing social anxiety, and its ability to work long hours will be helpful for its role.

Implications for design of a robot-admonishing functionality

Our results suggest that a robot's admonishment might be effective and acceptable to reduce inappropriate behaviors. This finding implies the potential of using a robot's admonishments to lower inappropriate behaviors in society, especially for less serious or unintentional behaviors. However, we believe a robot should minimize its use of admonishments since it runs a high risk of fomenting negative impressions.

Furthermore, since an admonishment from a robot is perceived as being easy to accept and less offensive compared to that of a human, robot admonishments could minimize the negative feelings of receivers and such confrontations as arguments and violence that sometimes arise in admonishment scenarios. Therefore, robot admonishments seem especially fruitful for commercial settings like restaurants, shopping centers, and events that are concerned with customer impressions but still need to curb inappropriate behaviors.

Moreover, our interview results showed that a polite and courteous robot is one reason for compliance with and acceptance of its admonishments. People are concerned about the verbal attitude of an admonishing robot, just as in human-human communication. Therefore, a robot with a polite attitude (e.g., using respectful language and a friendly tone of voice) could be a successful approach to achieve an effective and acceptable admonishing service.

Admonished vs unadmonished visitor's opinions about a robot admonishing service

In our field trial we experienced the rare opportunity to listen to the opinions of some visitors who were admonished by our robot. We roughly compared the opinions of the admonished and unadmonished visitors to gain insight about how being admonished by the robot affected their opinions and the validity of the unadmonished visitors' expectation in actual admonishing situations. Across all three interview topics about the admonishing service, i.e., obedience, comparisons of feelings, and impressions, the dominant opinions of both groups are similar, with a slight difference in their reasons. Nevertheless, compared to the admonished visitors, more neutral opinions appeared among the unadmonished visitor results due to their lack of familiarity with its admonishing behavior. The following are the details of our comparison for each topic.

Concerning obedience, the majority of unadmonished visitors intended to comply with a robot's admonishment, consistent with the fact that all the interviewed admonished visitors did obey the robot. Their reasons for obedience included that the admonished visitors tended to talk more about their own actions: "admitting their own mistakes." Unadmonished visitors equally commented on their intention of admitting a mistake as well as such external influences as the robot's capability and merits and the presence of others. Furthermore, based on their experiences, the admonished visitors said the robots politely warned them, an outcome that the unadmonished visitors could not imagine due to their lack of exposure to the robot's admonishing.

In comparing their feelings of receiving a robot's admonishment with a human's, unadmonished visitors expressed more positive expectations about a robot admonishing service. A large majority stated that a robot's admonishment would be easier to accept than a human's. However, such a trend is not clear in the results from the admonished visitors. Instead, two dominant opinions emerged: "a robot's admonishment is easier to accept than a human's" and "human and robot admonishments feel the same." It's unclear whether this result reflects the small number (i.e., 6) of admonished visitors in our study or their experiences with a robot's admonishment. Furthermore, unadmonished visitors expected a human's admonishment to be more powerful than a robot's, although none of the admonished visitors gave this opinion. Perhaps the unadmonished visitors imagined a robot's admonishment for various inappropriate behavior situations, including more serious ones. However, the admonished visitors might have considered their own experiences and felt that such admonishments were powerful enough.

A majority of the unadmonished visitors reported a positive impression of the visitors' acceptance of the robot's admonishing service. All the interviewed admonished visitors reported a positive impression of it. Considering their reasons, most of the admonished visitors appeared to believe that a robot-admonishing service resembles a human-admonishing service and claimed to have no particular resistance toward it. The majority of unadmonished visitors commented on the robot's specific merits.

Based on the above comparison, similar to the majority of unadmonished visitors, the admonished visitors we interviewed had positive impressions of the robot-admonishing service, despite being admonished by a robot. Thus, a robot's admonishment didn't lead to any particular negative impressions from the visitors.

4.6.3 Open questions

Ethical concerns of regulatory robots

One remaining important open question is the ethical concern of applying regulatory robot services in our future societies. First, it's unclear whether allowing a robot or a machine to judge human behavior is socially acceptable. In our study, a human operator confirmed the robot's detection of inappropriate behaviors and gave it permission to make an admonishment. While some might believe that robots have adequate capability for such tasks and can even do them more fairly than humans, a portion is resistance to allowing robots to judge human behaviors. Considering issues of responsibility, we personally believe such decision-making processes should be done by humans or under their supervision.

Second, it is unclear who should take the responsibility for any adverse effects on people due to the controlling behaviors of robots. Our findings show that some people were intimidated and embarrassed when admonished by a robot. If a robot mistakenly admonishes a visitor who did not engage in any inappropriate behavior and if any mental anguish/pain were caused, someone must take responsibility and compensate the injured person. The question of who bears responsibility—robot developers, employers, or another party—remains unresolved.

For which contexts are regulatory robots suitable?

Our findings reveal that the services of regulatory robots are suitable for children's events attended by families with young school-aged children. It is an open question in which other context robots can perform regulatory tasks on behalf of humans. A robot's suitability for a particular context depends on many factors, including its effectiveness, its social acceptance, and its value in a specific location.

A robot's effectiveness in a particular context depends on many aspects, including the task complexity and the nature of the people in the context. We believe a robot will be less effective in situations that demand fast responses, intricate communication skills, and where inappropriate behaviors are likely due to technical immaturities and less powerful admonishment skills compared to humans. Furthermore, such visitor characteristics as their intention to cooperate and the ability to understand a robot's requests will influence its effectiveness. In our case, according to the visitor opinions, it is plausible that parents behaved well around their children as role models, and therefore they complied with the robot's guidance. On the other hand, if only adults were present, incidents of ignoring the robot would undoubtedly increase [82]. Similarly, a robot will be less effective in environments without any adults because children generally show less compliance [16] unless they are guided by adults.

It's also crucial to consider whether using a robot for regulatory services in a certain situation is socially acceptable. Since social acceptance is a complex concept, it is preferable to conduct a detailed investigation of potential users' opinions before deploying a robot in a specific context and only applying it if it is accepted.

In addition, a robot's value in a particular context determines its suitability. For instance, robots will have a higher value in locations with a majority of children who manifest great interest in them. Furthermore, viewing a robot under a positive light is good for interacting with children because it implies a potential use for robots in such contexts.

For which inappropriate behaviors is a robot's admonishment effective?

Our results showed that a simple admonishment from a robot is effective for situations featuring less serious or unintentional inappropriate behaviors. However, it remains unclear what other kinds of inappropriate behaviors robot admonishment can effectively reduce. Compliance with a robot's admonishment depends on the nature of the inappropriate behavior being prohibited. When people are admonished to act in a certain way, they could feel their freedom to act as they desire is threatened and experience an unpleasant motivational state (i.e., psychological reactance). Such reactance can motivate them to act to restore their freedom through such actions as refusing to comply or to behave in an aggressive way toward those who pose a threat [89]. The importance of threats to freedom [11] is one factor that determines the amount of reactance. In other words, how badly do they want to do the prohibited action? In our situation, urging visitors to move ahead and lining up properly were not seen as restrictions on crucial freedom. Thus, they might feel less resistant to complying with a robot's admonishment. If the importance of the threatening behavior is high, for instance, admonishing a visitor who is simultaneously walking and using a smartphone, perhaps he/she will ignore the robot.

Furthermore, in our field trial, most of the people who made inappropriate behaviors did so unintentionally. Therefore a warning from the robot helped them realize their mistake and led to corrections. On the other hand, people who intentionally engage in inappropriate behavior tend to trivialize the robot [82]. We anticipate that a robot's admonishment will not be forceful enough to prevent those who intentionally engage in serious inappropriate behaviors, such as smuggling prohibited items into a stadium, situations even human security guards struggle to resolve.

4.6.4 Future role of operator

We used a human operator to compensate for the technical limitations of our robot. We believe that with future technological advancements, most of the operator's duties will become fully autonomous or their performance will be significantly improved. The operator's effort on one robot will be significantly reduced, enabling him to simultaneously control multiple robots. However, we don't expect operators to be completely eliminated due to ethical considerations. Currently, the operator performs four types of duties: updating queue area settings, resolving system errors, confirming admonishing targets, and speech recognition.

We expect that the selection of queue area settings will be automated with reasonable accuracy, and speech recognition tasks can be delegated to a robust ASR system. Choosing appropriate queue area settings based on the crowd conditions is currently a primary task of the operator. Although we did not emphasize the automation of this task because resolving such technical difficulties was outside the main thrust of our study, we believe that such functionality can be implemented in robots to update the queue area by detecting the crowd's condition. Furthermore, speech recognition was entirely carried out by the operator due to poor ASR accuracy in the highly noisy environments of public events. Future ASR systems might perform much better in such noisy environments.

Considering the practical limitations, we believe an operator will still be needed to confirm inappropriate behavior detection and handle errors. First, the goal of admonishing target detection should be absolutely no errors because a robot that admonishes a person without a legitimate reason might lead to a conflict. However, a detection algorithm that achieves 100% accuracy seems impossible in real environments. Even if we could achieve accuracy, some people might not accept the idea of allowing AI to judge human morality. A human operator might still need to make the final judgement. Second, an operator assistance may be required to fix any system errors since we cannot anticipate an error-free system. Even with our slightly current "crude" technology, the operator spent minimal time on error correction. We believe that based on the future development of technologies, systems will become more robust, which will further reduce the number of operator interventions.

4.6.5 Limitations

Our study has several limitations. First, we modeled the ushering behavior of only one professional guard. Perhaps other effective strategies could have been incorporated into our study.

Second, our interview results might be positively biased since we only interviewed self-selected visitors. Visitors with a negative impression of the robot were more likely to reject our interview requests. Unfortunately, such situations are unavoidable in field studies. Furthermore, we didn't learn the opinions of most of the admonished visitors (including those who disobeyed) for such reasons as declining our interview requests or the interviewers were preoccupied with other visitors. If we could gather such opinions, our interview results might be different or even consist of more negative opinions.

Third, our interview results might not accurately represent the general public's opinions because we only tested our robot at a children's event with families. The response of other groups to our robot is unknown. Similarly, our interview results are limited to the staff members of one particular event. Thus, their opinions cannot be generalized to staff that serve at different types of events.

Finally, our findings cannot be directly applied to other countries with different cultures. People's reactions to the robot and their opinions are highly biased by their own cultural backgrounds. Their expectations about a security robot align with a human security guard's role. We conducted this study in Japan where human security guards are unarmed, play a friendlier role, and are also engaged in customer service. People are familiar with such services and cooperate with a guard's request. Therefore, some people might comply with a robot in the same way that they would with a human guard. On the other hand, in many countries, security guards do not play such a friendly role. They are equipped with weapons and are limited to security-related tasks. In such places, applying our robot (unarmed and friendly-looking) for queue management or crowd handling might be much less effective because people might easily ignore its requests. Therefore, to apply a queue-managing robot in other countries, we must modify its design based on the cultural context and people's expectations.

4.7 Summary

Our study developed an effective and acceptable robot for managing a queue of people in public spaces. We proposed a design that mimicked the role of Japanese security guards who usually provide a queue-management service. Our design concept created an image of a professional security guard in our robot by implementing three features of human guards: their duties, their professional behavior, and their professional appearance. The robot led visitors to the queue's end, admonished those who engaged in inappropriate behaviors, answered questions, and made announcements. We conducted a 10-day field trial at a children's amusement event to investigate how people perceived a robot that regulated their daily behaviors. Our robot interacted with 2486 visitors and during 52 of 54 incidents, visitors complied with its admonishments. We listened to the opinions of visitors, including both those who were ushered and admonished by the robot as well as the event staff. By exhibiting the image of a professional security guard, our findings suggest that our robot can indeed regulate visitors in a queue reasonably well and still receive their acceptance. Unfortunately, we didn't interview nearly enough admonished visitors. Our limited interviews suggest they had a positive attitude about the robot, despite being admonished by it. Further, unadmonished visitors showed a higher intention to comply with a robot's admonishment in the future. Thus, we believe that "creating a professional image" is one successful design approach for a robot that is supposed to fill authoritative roles in future societies.

CHAPTER 5

Field Trial of an Autonomous Shopworker Robot that Aims to Provide Friendly Encouragement and Exert Social Pressure

5.1 Introduction

Some countries are experiencing labour shortages [99], which affect the operation of numerous industries, including retail and shopping stores. Small stores with limited budgets suffer more from a lack of workers due to rising labour costs.

A front-line shopworker has two major roles: one is interacting with customers in a friendly way and providing good service. They assist customers in finding products by offering relevant information. In stores that sell clothes, hats, and jewellery, they encourage customers to try products on and provide feedback. Their other role is to maintain a civil atmosphere in shops. Some customers may engage in such norm-violating behaviours as mistreating valuable items. Shopworkers are vigilant about customers' actions, and their presence exerts social

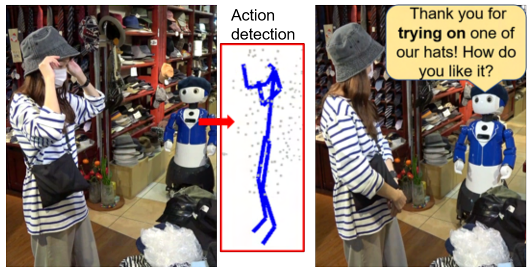


Figure 5.1: The shopworker robot detects the customer's action and starts to encourage them.

pressure on customers that discourages them from inappropriate actions [4]. In addition, shopworkers do back-end duties like inventory management and keeping accounts. To reduce their burden, a viable solution is relinquishing part of their workload to robots.

While shop managers identify the potential benefits of using robots as front-line workers [68, 84], few robots are actually working in stores today and offering limited services. One reason is the numerous real-world technical difficulties that must be overcome throughout the process of creating new robot services [70]. A robot that works well in a lab may fail in the real world. Developers face novel and unexpected problems that do not exist in lab settings. The actual user behaviours and interactions with robots often differ from the scientific imagination [48]. For example, the gait of a real pedestrian could be different from that of a developer's acting.

Based on the above discussion, we formulated the following research question:

RQ: How can we develop an autonomous shopworker robot for customer service that also exerts social pressure in a real-world shop?

As our robot's main service, we chose the encouragement of customers to try on headwear, a typical duty of workers in a hat shop. We designed the robot to recognise customers' shopping activities and provide timely encouragement and flattering feedback (Fig. 5.1). We believe the robot's ability to recognise customers' activities enables it to provide enjoyable customer service; at the same time, remarks on the customer's action convey its ability to understand what they are doing, which can be experienced as social pressure. To achieve a reliable and robust service, we used a field-oriented development process, collecting data while deploying a prototype system and iteratively improving the modules.

5.2 Current state of human activity recognition and datasets

Human action recognition progressed significantly in recent years due to the improvements in recognition algorithms. For example, in skeleton-based recognition, which we use in this work, methods based on graph convolutional networks, such as ST-GCN [101], have shown very good performance in recognising actions from sequences of skeleton measurements.

A large boost to the advances in action recognition came from the availability of datasets, which provided a way to evaluate and compare recognition methods. Prominent examples for skeleton action recognition include the NTU RGB+D-120 [55], the Kinetics-skeleton [19, 101], and the Skeletics-152 [38], all of which contain more than 100 action classes with many sequences for each class.

Yet the majority of the current datasets were collected in artificial environments and/or with hired participants role-playing the actions. They also typically use static sensors and are thus qualitatively different from sensor data from a moving robot. The dataset in [74] is a recent example addressing the lack of realistic in-the-wild datasets for robots, but such datasets remain scarce.

5.3 Design of a shopworker robot

5.3.1 Understanding service requirements

We conducted a semi-structured interview with the owner of a hat shop and observed shopworkers' customer-encouraging behaviour to identify effective encouragement strategies for a robot and ways of exerting social pressure.

Shop owner's expectations

He expected the robot to provide the following services:

- Talking to customers and encouraging them to try products to increase their interest in purchasing: He expected that the robot's positive comments would increase their enjoyment.

- Indirect pressure on customers: He expected the robot's presence and interactions may deter such norm-violating behaviours as roughly handling products or entering the shop with food or drink, especially when workers are busy or not present (e.g., taking a break).

- Advertising in front of the store and greeting the customers to increase their enjoyment.

Shopworkers' customer-encouraging strategy.

The key idea is motivating customers to gradually engage more with products to increase their interest in buying. Shopworkers believe that the more a customer interacts with a product, the more likely he is to purchase it. They encourage customers in a step-wise manner to move through the stages of the purchasing process: visiting the shop to looking at hats, holding one in their hands and examining it, and putting it on. They also provide friendly comments that might help customers find a suitable hat.

Shopworkers' strategy to prevent norm-violating behaviours

They try to prevent customers' norm-violating behaviour by indirectly exerting social pressure. When they notice a customer who might exhibit such behaviour, they don't directly address them to avoid creating bad impressions. Instead, they discourage the person by indirect social pressure through such friendly actions as approaching and greeting them. The shopworkers believe that the customers' perception that the shopworkers are aware of their actions (social pressure) might discourage inappropriate actions.

5.3.2 Design choices

From the above observations, we made the following design choices:

1. The **ability to recognise customer shopping activities** is a key to achieving an effective encouraging service and exerting social pressure. Activity recognition needs to be reasonably **accurate** to ensure correct responses.

2. The robot's responses should be designed to **convey that it is aware of what customers** are doing to exert social pressure. It should provide **friendly** responses to create positive customer impressions.

In addition, we chose a human-like robot to implement our services to improve its social pressure [49].

5.4 System development methodology

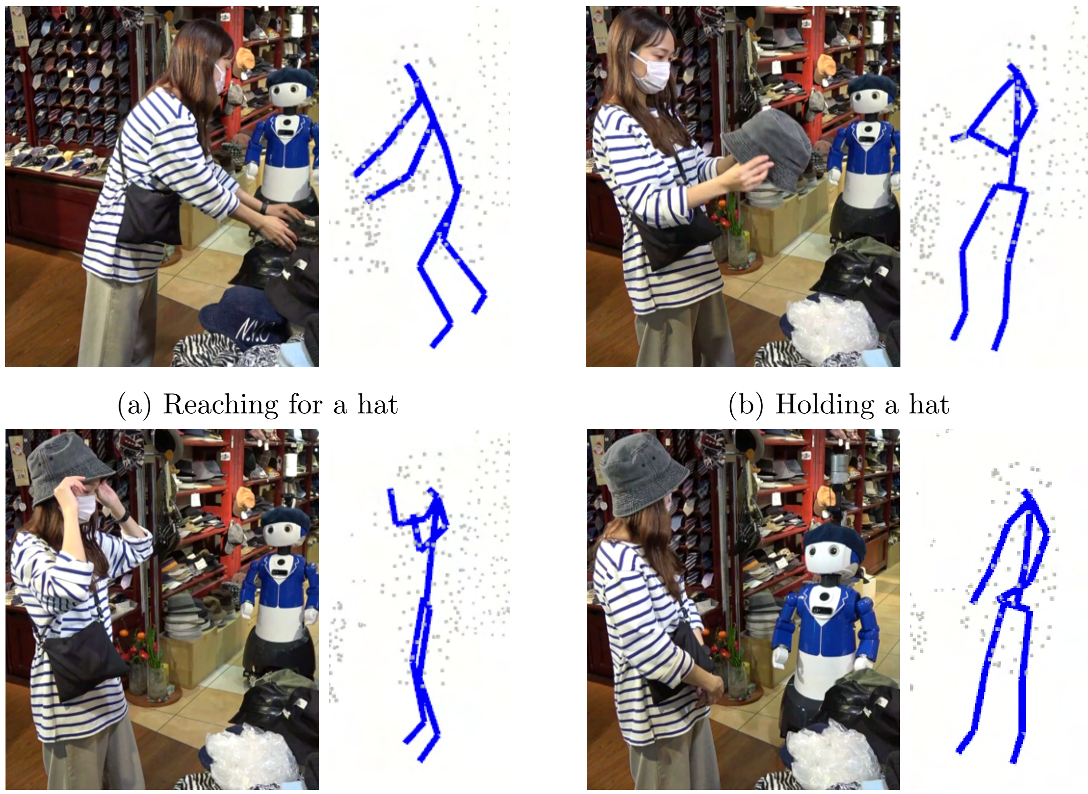
We used a field-oriented testing strategy in which we repeated trial-and-error integration with a real robot. This also enabled us to continually collect data for activity recognition from actual customer behaviours. The realism of behaviours in the training dataset is critical for activity recognition. However, it is difficult to collect truly realistic data by imitating customers' behaviours in a lab, so the best way to collect real data is by actually letting the robot serve real customers in field tests.

After each field test, we performed debugging and improvements of our system, in which the following two functions were helpful:

- **Replaying problematic situations**: Debugging in actual fields is difficult. We may sometimes overlook critical factors that cause problems and cannot constantly check the status of every system part. To handle that, we recorded as much data and the program's internal states (such as system logs) as possible. We recorded the robot's sensor data (odometry, laser range finder, Kinect point cloud, and skeleton) as well as extra audio and video data to later be used for visualisation to improve the situation understanding. This allowed us to subsequently replay problematic situations. We also used the replaying of sensor data to easily test the updated programs on problematic situations.

- **Adding labels simplifies revisiting important scenes that need repeated checking**: For system integration, we repeatedly reviewed the problematic situations to identify the causes and test our updated programs. To improve the activity recognition, we repeatedly needed to check the misrecognition cases. Thus, the ability to add labels to important scenes and easily change them was invaluable.

We ran the development process for 6 months, conducted 33 field tests, and recorded 430 GB of data, through which we improved the accuracy of shopping-activity recognition (Sec. 5) and learned important lessons on various modules in our system (Sec. 5.6).



(a) Reaching for a hat

(b) Holding a hat

(c) Putting a hat on

(d) Idle state

Figure 5.2: Shopping-related actions in hat store: example scenes and corresponding skeleton measurements.

5.5 Shopping-activity recognition

5.5.1 Basic approach

We identified four typical shopping-related actions (Fig. 5.2) that people engaged in at our targeted hat store: (1) selecting a hat from a shelf, (2) holding it in their hands and looking at it, (3) putting it on, (4) doing something else (idle state).

To recognise the actions, we used people's skeletons obtained from a Kinect sensor on the robot's chest. The 3D positions of the skeleton points were used as classifier inputs. While skeleton-based action detection approaches typically use sequences of poses [55, 101], this strategy introduces undesirable recognition delays. Since all four shopping-related actions have characteristic poses (Fig.

5.2), our classifications were based on single skeletons.

We tested a range of standard classifiers including support vector machines (SVM), random forest (RF), XGBoost, and several neural network architectures. All the classifiers gave similar performance, so for brevity, we present only the results obtained with the RF classifier, which consistently performed well in the tests. We used RF with a maximum depth of 10, trained on data that were balanced using under-sampling. As instabilities in real-world skeleton data affected the result, for a more stable detection we additionally applied a Bayesian filter to the classification result (taken from [15], with parameter α set to 0.9).

5.5.2 Training dataset collection

Laboratory dataset

As we initially had no way to record the in-store behaviour data, we created a dataset in the lab for training the classifiers. Ten participants stood in front of a robot and performed the four shopping actions. This resulted in stable skeleton data with a relatively good balance among the action classes; most samples belonged to the idle action, whereas the three non-idle classes had between 2400 and 3800 samples. Yet when we trained the classifiers on this dataset and tested them in the store, their performances were unsatisfactory (results in Section 5.5.3).

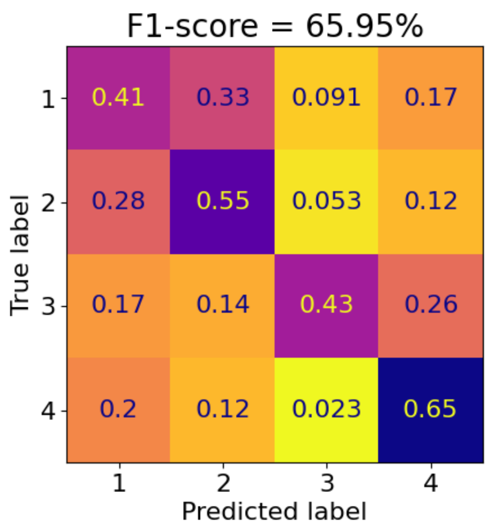
Real store dataset

We next collected data by deploying a prototype version of the robot in the hat store while the robot was serving customers. Data collection was done over 11 days during about 28 hours of operation. The final labelled dataset contains about 24,000 samples, with slightly more than half belonging to the idle state class and the other three classes having between 1100 and 3600 samples. We have also made this dataset freely available *.

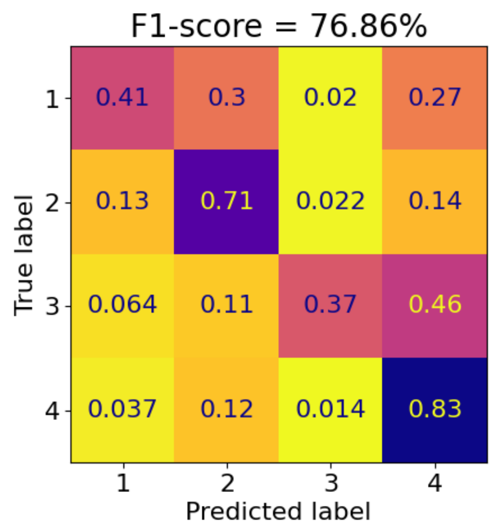
5.5.3 Evaluation

We evaluated our classifiers with F1-scores calculated using weight averaging, a variety of macro-averaging that also accounts for class imbalance. Our initial

*https://dil.atr.jp/ISL/sets/hatshop_dataset

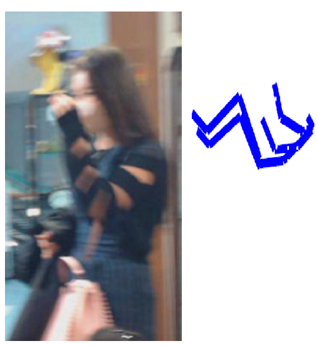


(a) Initial: training on lab dataset w/o Bayesian filtering



(b) Final: training on store data w/ Bayesian filtering.

Figure 5.3: Shopping action recognition F1-scores and confusion matrices: Labels 1 to 4 denote selecting a hat, holding a hat, putting a hat on, and idle.



(a) Distortion during motion

(b) Holding a child

(c) Fixing hair

Figure 5.4: Examples of complicated store situations for activity recognition that did not appear in lab data.

RF classifier trained on the lab data, when evaluated on the store data gives an F1-score of 65.95%. In our development process we added Bayesian filtering only after we started to collect the store dataset; nevertheless, for the sake of comparison, if we add Bayesian filtering for this classifier trained with lab data, it gave us a somewhat improved performance, with an F1-score of 69.23%. Finally,

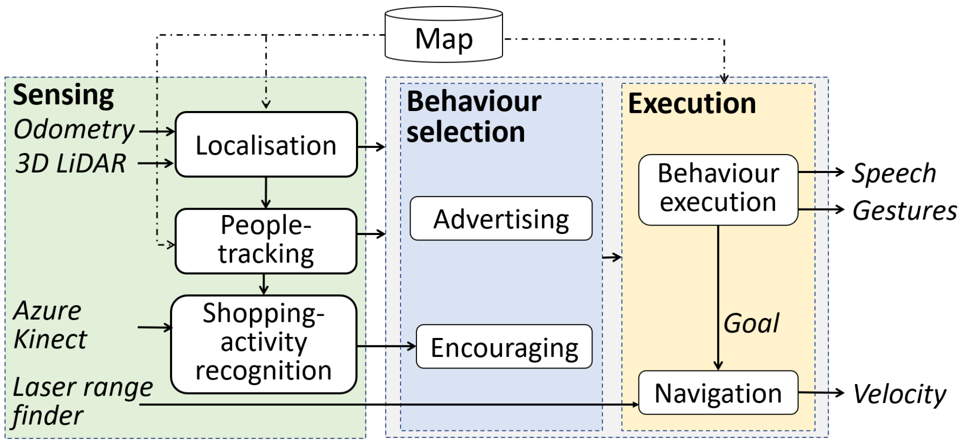


Figure 5.5: System architecture.

once we collected the store dataset we were able to get a further improvement. The final RF classifier with Bayesian filtering trained on the store data gives a score of 76.86% (evaluated using 10-fold cross-validation). Figure 5.3 compares the confusion matrices for our initial and final classifiers.

The store dataset contained a greater variety of data (Fig. 5.4). It includes not only the number of people detected but also variations in how they performed actions, the types of clothing and carry-on items they wore, the context (e.g., shopping in groups, interacting with others), the robot's location and movement, and even influence from surrounding objects due to occlusions, all of which might affect the skeleton detection. This emphasises the importance of data collection in a real setting, even though it typically requires an actual deployment of the system. A bootstrapping deployment process is needed, which we indeed conducted.

5.6 Robot system

5.6.1 Architecture

Figure 5.5 shows our robot's system architecture. The robot selects encouraging or in-front-of-store advertising depending on the presence of new customers. The shopping-activity recognition module (Sec. 5.5) uses a customer's position and the Kinect skeleton data to identify her/his activities. This detection is used to select suitable comments during encouraging behaviour. The robot localises itself

(Sec. 5.6.4) in the shop using a map, an odometer, and 3D LiDAR data. Based on the localisation, the people-tracking module (Sec. 5.6.5) monitors the locations of the customers. After selecting an appropriate behaviour to execute, each behaviour reads the real-time sensor data and controls its utterances, gestures, and navigation (Sec. 5.6.6) Overall, our system consists of around 150k line of code over 23 ROS packages. Note that the robot does not handle voice inputs due to excessive environmental noise. We initially considered the feasibility of autonomous speech recognition, but we abandoned the idea due to loud music and mall announcements.

5.6.2 Robot

We used Robovie-R3, a 120-cm tall, human-like robot (Fig. 5.1) that has a child-like, gender-neutral voice. We customised its appearance for its role by painting a suit on its body and giving it a hat. An Azure Kinect sensor was mounted on its chest at 83 cm and tilted up at about 26^o from the horizontal. The robot was equipped with a LiDAR at 143 cm for localisation and people-tracking and 4 laser range finders for obstacle detection during its navigation. The mobile base with omnidirectional wheels allowed it to move in any direction with a maximum velocity of 0.8 m/sec and angular velocity of 60 degrees/sec.

5.6.3 Behaviour implementation

Behaviour transition:

The robot at first advertised in front of the shop. When new customers entered, it followed them and encouraged them to try on a hat. Once there were no more customers to serve, it resumed its advertising outside.

Encouraging behaviour

The goal of this behaviour is to approach the nearest customer to share encouraging utterances, and it consists of two steps: approaching and encouraging.

Step 1: Approaching Every 100 msec the robot detects the closest person and approaches them using the shortest path. If a different person becomes closer during the approach, it switches to approaching the new person. Upon reaching a talking distance of 2.0 m (empirically tuned during field testing), it stops and rotates to face the customer; if they move away, it approaches them again.

Step 2: Encouraging Upon approaching a customer, it starts to make encouraging utterances based on the results of the shopping activity recognition. We moderated the errors of the shopping-activity recognition by applying the following strategy:

- Rely on recognition only when both the person and the robot are stationary to avoid distortion due to movement (Fig. 5.4(a)).
- Make the same encouraging utterance for "reaching for a hat" and "holding a hat" due to classification difficulty (30% of "reaching" cases were wrongly classified as "holding", and 14% of "holding" cases as "reaching").
- Ignore the "idle states" due to the high ratio of false-positives.

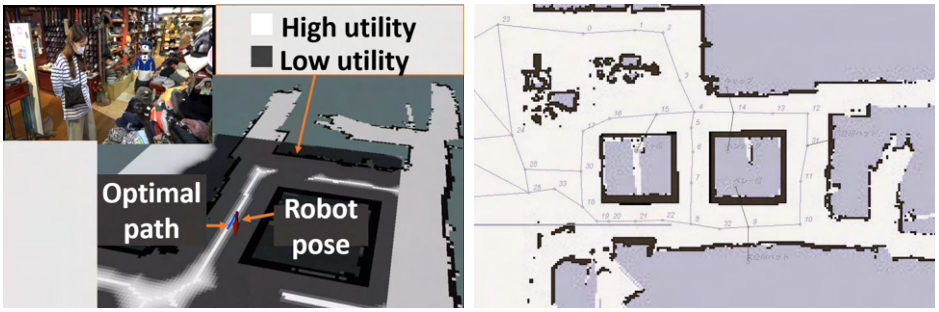
If a customer reaches for or holds a hat, the robot praises the choice: "Oh, that hat looks nice", and encourages them to try it on. If a customer puts a hat on, it gives flattering feedback to encourage buying: "The hat looks great on you." To avoid becoming annoying, the robot waits 5 seconds before giving more encouragement. After 3 encouragement utterances, it bids farewell to the customer and goes back to advertising behaviour. The utterances and gestures for each behaviour were fixed and pre-programmed.

Advertising behaviour

The robot stands at its pre-defined location next to the shop entrance to invite potential customers. When they appear within an advertising distance of 3.0 m (empirically tuned during field testing), the robot rotates towards them and invites them to the shop. After a customer enters, the robot says "Hello" and starts its encouraging behaviour.

5.6.4 Localisation

For navigating in a narrow shop, precise and robust localisation is essential. We applied a particle filter-based method [35] on LiDAR point-cloud and odometry



(a) Prioritising corridor centre (b) Topological map

Figure 5.6: Navigation in narrow and slippery spaces by following the corridor centre.

and conducted map matching. We estimated the robot's pose at 10 Hz on a 3D map prepared in advance.

To improve the localisation accuracy, we reduced the grid size of the 3D occupancy map, i.e., to 5 cm.

5.6.5 People-tracking

The people-tracking method used the 3D LiDAR point cloud. The background part was subtracted based on the 3D map, and clustering was applied to the remaining points to detect human-sized entities. We then applied a particle filter for tracking.

The shop's mirrors reflecting lasers sometimes led to false detections of humans. To solve that, we marked the positions of the mirrors on the map and continuously filtered out the incorrect point-cloud clusters caused by reflections.

5.6.6 Navigation

We used a standard local planner with a dynamic window approach [28], which used an obstacle costmap based on the LiDAR data. However, the robot often slipped on the shop's uneven marble floors, causing a risk of colliding with the shelves in the about 0.88 m wide corridors. To address this, we improved the navigation so that the robot follows the corridor centre (Fig. 5.6). The complicated shapes of the mannequins and shelves complicated the correct detection of the distances the robot must pass through, so we prepared an additional obstacle map to describe these objects. Finally, we integrated the idea of the human-inspired motion planner from [50] for natural and predictable rotation during navigation.

5.7 Field trial

5.7.1 Environment and procedure

We conducted an 11-day field trial in the same hat shop at which we initially developed our system to investigate the robot's ability to autonomously provide its encouraging service and exert social pressure. This shop was generally more crowded at weekends and holidays than on weekdays.

Our robot served 4 hours a day. No prior instructions were given to the customers, who were free to interact with the robot. We only put a notice in front of the shop explaining that a field study was being conducted and that videos would be recorded. While the robot mostly operated autonomously, as a way to handle possible faults and avoid incidents such as property damage, a human operator remotely monitored the system to resolve critical errors and compensate for disruptive interactions (e.g., disturbing of shop staff). We also assigned a local safety person.

We collected 3 types of data on customers who received the encouraging service: system performance records, observations, and interviews. This protocol was approved by our IRB.

5.7.2 System performance

Table 5.1 shows the system-related statistics of the shopworker robot, which generally worked well and autonomously. During the 11 days its total service time was 1750 minutes, during which it tried approaching 196 customers and provided encouraging services to 96 of them. Failed encouragements happened because the robot couldn't reach the customer (98 cases) or due to errors in the recognition system (2 cases). Its autonomous working time was 1742 minutes: 99.5% of its total service time. The human operator intervened in 34 incidents, which comprised just 8 minutes. Most of these cases involved stopping the robot from disturbing the shop staff. The mean time between the incidents that required the operator's intervention was 51.5 min. Due to the shopkeeper's changing of the

Table 5.1: System-related statistics of the field trial

Measurement	Value
Total time it served (encouraging +advertising)	1750 min
Number of approached customers	196
Number of encouraged customers	96
Total autonomous time	1742 min
Number of operator-assisted situations	34 (8 min)
Map-updating incidents	4 (23 min)

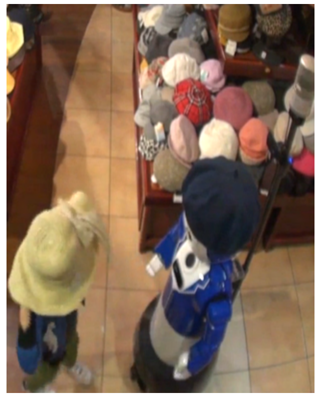
shop arrangement, we also had to manually update maps 4 times, which took 23 minutes in total. In a field trial, such stakeholders' unpredictable behaviours can not be avoided.

5.7.3 Customer interactions

Typically, an interaction started when the robot approached a customer who was looking for a product. When the robot asked them to select a hat and try it on, about half of responses were positive: smiling, nodding, or thanking it. The other half ignored it. When a person chose a hat, the robot encouraged him/her to wear it. If the customer put on a hat, the robot thanked them and asked, "How does it look?" Some customers offered their impressions of the hat. They seemed to appreciate the robot's positive comments: "That hat you just chose looks good on you." They laughed at the robot's flattery (Fig. 5.7(a)), and sometimes people from the customer's group repeated the comment. Children appeared more interested in the robot itself. They touched or talked to it, and even tested its reactions by wearing a hat (Fig. 5.7(b)). A few adults also checked the robot's functionality by putting on a hat (Fig. 5.7(c)).

The robot misidentified customer actions and made unsuitable utterances around 30% of the time. In 2/3 of these cases, customers seemed not to notice or did not react to the mistakes. Interestingly, the remaining 1/3 reacted positively (Fig. 5.8). In the case in Fig. 5.8(a), the robot mistakenly recognised a woman as wearing a hat, to which she laughed, saying "I'm not wearing a hat!" (Fig. 5.8(b)). Similarly, customers often seemed to accept the limitations of the robot's recognition capability and enjoy these errors.

(a) Laughing at its comments



(b) Testing it by wearing a hat

(c) Checking its feedback

Figure 5.7: Customer reactions to robot.

(a) Robot made an erroneous utterance

(b) Customer noticed and responded

Figure 5.8: Customer reaction to a misrecognition

We observed two particular cases in which customers bought hats after being encouraged by the robot. In one such case, a woman entered the shop after hearing the robot's advertisement (Fig. 5.9(a)). After a while, she was about to leave when she heard the robot praising how a hat looked on her (Fig. 5.9(b)), which seemingly motivated her to try it on again (Fig. 5.9(c)), and finally buy it (Fig. 5.9(d)).

(a) Looking at hats (b) Hearing encouragement (c) Rechecking hat (d) Purchasing it

Figure 5.9: Customer buying a hat after hearing the robot's encouragement.

5.7.4 Customers' interview results

We interviewed 42 customer groups who received the robot's encouragement. We conducted a qualitative content analysis [34] on the interview results. We derived exclusive main categories (i.e., opinions) and subcategories (reasons) using a bottom-up approach.

Impressions of shopworker robot

Table 5.2 summarises the customers' opinions about the shopworker robot. 28 of the 42 customer groups had *positive* opinions. One leading reason were its *capabilities*, including recognising customer actions, offering positive encouragement, and providing friendly service. For example:

– "My experience was good! I went inside and looked at lots of different hats, but couldn't find one I liked. Then the robot suggested that I try one on, so I looked around and found a nice one. I immediately bought it." *(capability)*.

Another reason for *positive* impressions were the robot's special merits over a human *(robot-specific)*, such as cuteness, novelty, and entertainment of children. 13 of the 42 groups had a *neutral* opinion. Some cited both its *merits and demerits*. They mentioned as merits the capability of recognising actions, cuteness, and attractiveness, whereas demerits included being scary, not polite enough, and a feeling of uneasiness to interact with it due to unfamiliarity. The remaining groups said they were *surprised* and *other* reasons. One group with a *negative* impression admitted that "My child was scared... I felt like we were being watched."

Table 5.2: Customer impressions of shopworker robot

Opinion	Reason
Positive (28/42)	Capability (16/28) Robot specific merits (16/28)
Neutral (13/42)	Merits and demerits (5/13) Surprised (3/13) Other (5/13)
Negative (1/42)	Scary to children (1) Sense of being watched (1)

Table 5.3: Customer impressions of robot's activity recognition and encouraging behaviour

Opinion	Reasons
Positive (27/40)	Capability (15/27) Robot specific merits (13/27) Other (2/27)
Neutral (8/40)	Merits and demerits (4/8) Other (4/8)
Negative (5/40)	Less capable (2/5) Feeling of being watched (2/5) Dislike of uninvited talk (2/5)

Impression of robot's activity recognition and encouraging behaviour

Table 5.3 summarises the customer opinions. A majority (27/40) expressed *positive* opinions. Over half were impressed by such *capabilities* as recognising customer actions and providing good customer service. Some described its behaviour as human-like:

– "I got the impression that the robot was very good at dealing with situations. It's better than a bad store clerk" *(capability)*.

The next common reason was such *robot-specific merits* as cuteness, being interesting, entertaining children, and creating less discomfort than a human store clerk. 8 of the 40 gave *neutral* opinions. Half cited its *merits and demerits* as their

Table 5.4: Customer impressions of robot's ability to prevent norm-violating behaviours

Opinion	Reason
Can prevent (37/41)	Feeling of being watched (22/37) Feeling of being recorded by its cameras (13/37) Robot's distractive conversation (9/37) It might report/react to suspicious customers (4/37)
Cannot (4/41)	Less capable (4)

reason. They thought that its merits included its action recognition capability and cuteness, and its demerits were its lack of capability (misrecognition of actions, bland talk), feelings of being watched, and unfamiliarity. Another half mentioned *other* reasons like being surprised and no particular impression. Only 5 of the 40 groups expressed a *negative* opinion: the robot *wasn't capable enough* (reflecting its limited variety of utterances and inability to give honest feedback), they *felt like they were being monitored*, and they *disliked the uninvited talk from the store clerk (either human or robot).*

Impression of robot's ability to prevent norm-violating behaviours

Table 5.4 summarises the customer opinions of the robot's ability to discourage norm-violating actions. A huge majority (37 of 41) believed that it *can* prevent such norm-violating actions. Many *felt like the robot was watching* them and cited as reasons for that its gazes, approaching, and ability to recognise their actions:

– "It's not that someone is watching you, but it gives you the same impression" *(feeling of being watched).*

The second common reason was that the *robot's camera* captures evidence of crimes. Other reasons include that a robot that *starts conversations with customers* will prevent norm-violating behaviours by distracting them and drawing the attention of others. Their expectations are that a *robot can recognise suspicious customers and report them to shop staff* and *cause different reactions.*

Only 4 of the 41 groups believed that the robot *can't* prevent norm-violating behaviours. They argued that its cute appearance fails to convey any impression

Table 5.5: Customer impressions of robot's ability to make shopping more enjoyable

opinion	Reason
It can (26/42)	Robot specific merits (16/26) Joy of conversation (6/26) Quality of speech (2/26)
Neutral (9/42)	Merits and demerits (7/9) Surprised/curious (2/9)
It cannot (7/42)	Lack of useful services (2/7) Feeling of being watched (2/7) Burdensome (2/7)

of policing such behaviours as well as its slow reactions and a weak monitoring impression.

Impressions of potential to make shopping more enjoyable

Table 5.5 summarises the customer opinions. 26 of the 42 groups stated that a robot *can* increase shopping's enjoyment. Most referred to *robot-specific merits* as the reason. Other reasons included the *joy of talking with it* and the *pleasing quality of its speech*. 9 of the 42 groups had a *neutral* opinion. Most mentioned its *merits and demerits*: it might be entertaining for families with kids, but much less so for adults shopping alone. It might have other merits, although talking to it is rather embarrassing. Others just felt *curious* or *surprised*. 7 of the 42 groups *didn't think it could* make shopping enjoyable for such reasons as a *lack of useful services* like guiding, the pervasive *feeling of being watched*, and the *burden of talking*.

5.8 Discussion

5.8.1 Implications

Implications for system development methodology

We newly confirmed the importance of the real-world data collected by the robot during test deployment. The recorded data included a varied range of customer behaviours, which proved useful for improving the system performance, such as the accuracy of activity recognition. We also learned how to improve the system modules from the recorded data. We believe our system development methodology would also be useful for other HRI systems.

Ethical implications for surveillance and policing robots

Using robots to make people feel observed is ethically complex. Deploying such robots in a society where privacy and autonomy are highly valued may lead to conflicts. Furthermore, such technology can be misused. Stores could overly rely on robots, which are not always accurate, in sensitive tasks like detecting and approaching suspicious customers. Presently, we are seeing the consequences of some stores' unfair reliance on facial surveillance to identify suspicious consumers [76]. Moreover, an observing robot could intentionally be created to discriminate against certain populations or machine learning-based recognition of a robot could be unconsciously biassed by the datasets [98], resulting in targeting certain populations.

5.8.2 Influence of activity recognition errors

Around 30% of the time, our activity recognition system misrecognized actions, resulting in unsuitable utterances (Fig. 5.8). Robots' service errors have been found to have negative effects on satisfaction and perceptions of them [53]. Yet the customers did not report negative impressions about the robot's mistakes. From our observations, at least 12 of the 42 interviewed customers experienced the robot's unsuitable utterances. Still, the impressions reported in the interviews exhibited a similar trend as those who did not encounter such unsuitable utterances. Why didn't the robot's errors make the impression about it more negative? Perhaps some customers just did not report their complaints, or might not have noticed them as they were focused on shopping. Yet, it is also likely that the robot's errors did not negatively affect their impression. If so, why not?

One possibility is that people have low expectations of robots. One customer was impressed by the robot's capability even though she experienced unsuitable utterances. She thought that due to using a motion recognition system such misrecognitions are reasonable. Other possible reasons include its cute child-like design, as pointed out by some customers. Cuteness increases tolerance of service failures [56], and some customers indeed still described the robot as cute even after experiencing its mistaken utterances. Or, perhaps occasional mistakes could have a positive effect, as some errors are known to increase human-likeness and likeability [77]. In fact, we occasionally observed that customers laughed and were amused by the robot's unsuitable utterances.

Although customers currently tolerate a robot's mistakes, the high failure rate could become problematic in the long term once the novelty wears off. Thus, to ensure the robot's efficacy, activity recognition accuracy would need to be further enhanced.

5.8.3 Limitations

Our interview results may be biased due to several reasons. Firstly, they come from self-selected customers, which is unavoidable in a field trial. People who have a negative impression are much more likely to refuse interview requests. Secondly, the robot offered them encouragement, so they were likely to have a preconceived favourable impression of the robot. Furthermore, our study did not provide direct evidence that the robot's presence actually prevented someone who intended to engage in norm-violating behaviour from doing so, as we did not observe any such situations.

5.9 Summary

We presented the development process, deployment, and evaluation of an autonomous shopworker robot system with shopping activity recognition capability. The robot's behaviours based on recognised actions can be used to encourage customers. However, proving the capability of exerting social pressure requires future work with long-term deployment. Our study also demonstrated the necessity of iterative and bootstrapping development process. For instance, collecting real-world data during test deployment significantly improved recognition performance. We shared the lessons we learned throughout our development process.

CHAPTER 6

Discussion and Future Work

We attempted to design moral interaction capabilities for the service robots in public spaces. We proposed design concepts to achieve acceptable moral interactions and gain visitors' compliance. Furthermore, we demonstrated the development of a robot system with moral interaction capability for a real-world application. We also revealed important knowledge of people's interactions and impressions of such robots in real-life situations. However, successfully deploying robots that can execute moral interaction in public spaces is certainly a big goal. This thesis is one step towards such a future. There are several remaining issues that need to be addressed in future works.

1. **General architecture of executing moral interactions**

   To provide some insight into developing future robot systems with moral interaction capabilities, we present a potential idea for a general architecture (figure 6.1) for a robot to execute both direct and indirect moral interactions. Future research should focus on improving and developing this architecture, as well as investigating its effectiveness.

   The key concept behind the general architecture for moral interactions is preventing (or stopping) visitors' norm-violating behaviours while minimizing negative impressions of the robot. We expect the following design considerations could be helpful in achieving such a robot system:

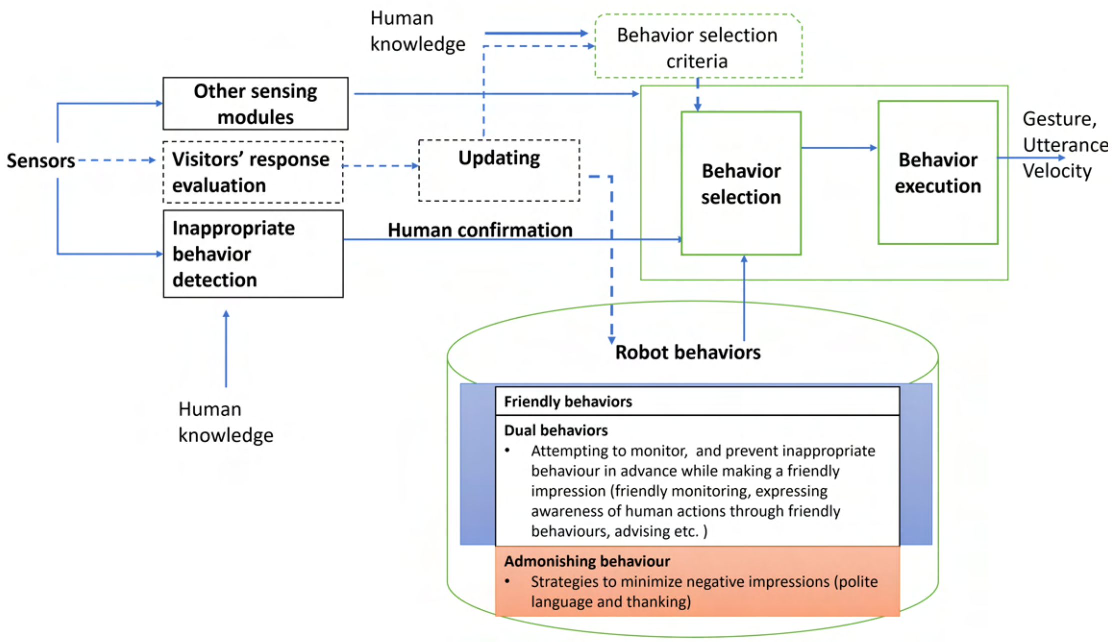


Figure 6.1: General system architecture for moral interactions

- The robot should not be designed solely for admonishing and policing people. Instead, admonishment should be designed as one service among other friendly services to make a friendly impression.
- The robot should use admonishments only when they are the only option to stop a human's inappropriate behaviour. Instead, it should use non-confrontational alternatives (E.g., try to prevent inappropriate behaviours in advance through indirect moral interactions and advising.).
- Judging the appropriateness of human behaviour should be under human control.
- The robot's admonishing behaviour should be designed to minimize negative impressions.

Figure 6.1 shows the potential general architecture for executing moral interactions. The robot selects a behaviour to execute from a repository of behaviours depending on the detection of visitors' inappropriate behaviour. The inappropriate behaviour detection module detects the visitors' norm-violating actions using sensor data (such as skeleton and RGB image) and human-provided knowledge of morality (for instance, by annotating the behaviour datasets for training a machine learning-based inappropriate behaviour detection module). Once the robot detects inappropriate behaviour, it needs human confirmation to proceed. The behaviour selection module selects an appropriate behaviour referring to the human-defined behaviour selection criteria, detection results of inappropriate behaviour, and inputs from other sensing modules (e.g., speech detection, localization, people tracking). Once a behaviour is selected, each behaviour reads the real-time sensor data and generates actuation such as gesture, utterance, and velocity.

The robot's behaviour repository consists of several kinds of behaviours to facilitate the execution of direct and indirect moral interactions while minimizing negative impressions: friendly behaviours (i.e., those in which the robot's intention is entirely friendly, aiming to assist visitors), dual behaviours (i.e., those in which it attempts to monitor and prevent inappropriate behaviours in advance by expressing a friendly impression), and admonishing behaviours.

To facilitate the improvement of moral interaction capability over time, it will be useful to evaluate visitors' responses (such as compliance, emotions, and utterances) to moral interactions using a multi-modal approach. Based on such evaluation, the robot will be able to rate the appropriateness of a selected behaviour and update the behaviour selection criteria and behaviours.

2. **Improving low moral behaviour and norm-violating behaviour detection**

   Future work should consider improving the robots' capability of inappropriate behaviour detection. For the robot to execute moral interaction, it is essential to precisely detect those behaviours. However, little work [26] has been conducted related to that, and existing robots cannot recognize inappropriate behaviours with high accuracy. The algorithms we developed in this research also couldn't achieve human-like recognition accuracy and require human judgment.

   Especially in a crowded public space (with uncontrollable conditions such as varying light conditions, occlusion, and movements of people and the robot), detection of such behaviours is challenging. Using a multi-model recognition system could lead to increased accuracy. Additionally, sensor networks may aid in more accurate detection than sensors mounted on robots. However, this approach may not be practical for large public spaces.

Furthermore, since inappropriate behaviours are relatively rare compared to other behaviours, it requires an extended period to collect real-world data for training machine learning algorithms. As a solution, past works have artificially collected data in the laboratory [26]. It is necessary to confirm their accuracy in real-world settings, as we observed in our studies that algorithms trained with lab data have low performance in the real world.

3. **Improving the capability to engage in moral conversation**

   The robots have limited capability to engage in a moral conversation and use vocabulary related to moral concepts. Future work should consider improving such capabilities. There could be incidents where the visitor who engaged in inappropriate behaviour may provide a reason for their actions or argue with the robot. Sometimes, people unintentionally engage in inappropriate behaviour due to a lack of understanding and require more information, or someone may intentionally engage in inappropriate behaviour and provide a counterargument. Therefore, the robot should be able to understand the visitor's utterances, judge their reasonability, and provide a suitable response with moral vocabulary. Furthermore, robots should be able to personalise admonishments according to the nature of the listener. For example, the level of explanation, word usage, and tone of an admonishment for young children may be different from those of adults. Such personalisation might also be helpful to improve compliance.

4. **Other applications of robot moral interactions**

   To better use robots with moral interaction capabilities in society, it is necessary to further investigate the context where they are effective and acceptable in regulating people's behaviours. We showed that robots are effective and acceptable in preventing visitors' less serious and unintentional inappropriate behaviours and regulating crowds at events for families with young children. Future works should consider putting the robots in challenging situations such as stopping serious inappropriate behaviours (e.g. illegal entering and smuggling unauthorized items to stadiums) and crowd handling in locations where there are only adults. While we can imagine that such situations are harder for robots, it would be worth investigating. If robots could handle those tasks, it would greatly reduce the stressful and dangerous work of human employees.

5. **Ethical studies**

   Ethical studies should be conducted in future to ensure the appropriate use of robots with moral interaction capabilities in society. Robots that attempt to regulate people's behaviours result in ethical concerns about their effect on people's freedom, autonomy and privacy. Furthermore, there is a risk that such robots are misused or unintentionally or intentionally include biased features to discriminate against people. In the future, such issues will be more prominent when the services of robots expand in society. In-depth studies should be conducted to learn the ethical perspective of stakeholders (e.g., the public, employers, policymakers, social and legal experts) on robots with moral interaction capabilities.

6. **Trust in robots with moral interaction capabilities**

   For the robot with moral interactions to successfully serve in society people's correct level of trust is important. An inappropriate level of trust in artificial intelligence may lead to abuse, misuse, or not use of the technology [45]. This phenomenon could be expected for robots with moral interaction capabilities.

   Overtrusting or undertrusting a robot with moral interaction capability may result from people's lack of knowledge of the capabilities of the robot, the developers, and the development process behind the robot system. To establish a correct level of trust, it may be important to disclose information about the developers and the algorithms in the robot system, including the possibility of errors, and create and adhere to standards for the robot development process.[96].

7. **Long-term moral interaction study**

   To better understand the effectiveness of the findings of this research, long-term deployment of robots with moral interaction capabilities in the public environment is needed. Past works also stressed the importance of long-term investigations [82]. Firstly, norm-violating behaviour incidents are rare. It would be ideal to collect data over a long period to gain a more accurate evaluation of the robots' effectiveness in preventing such behaviours. Secondly, robots with moral interaction capabilities are still a novel experience for people. Thus, the novelty affects their reactions to the robots and their impression of them. People's perception of the robots may change (Will they normalize the robots' service, treating them similarly to human employees, or will they become frustrated and start ignoring them?) when they become more familiar with it and perhaps new challenges could appear that cannot be revealed in short term studies.

8. **Cross-cultural study**

   It would be interesting to do a cross-cultural study and understand the effectiveness of proposed design concepts and people's interactions with the robot across cultures. We believe the culture could have a considerable influence on people's perception of the robot. All of the field studies in this thesis were conducted in Japan. Hence, the interactions and opinions of people about the robot may have been influenced by Japanese culture. Japan has a collectivist society, which places high value on social norms and the conformity of others. Hence, Japanese people tend to follow others' guidance. In contrast, in individualist cultures like the United States where autonomy and personal freedom are prioritized [58] people may have a different, perhaps more negative, response to and non-compliance with the robot.

9. **Robot and children moral interactions**

   According to our observations during field trials, children show lesser compliance to the robot than adults and often need adults' guidance. It indicates the importance of investigating how the robot's moral interactions should be designed to effectively deal with children. Such functionality will be useful in situations when robots play a role that directly deals with children such as teaching assistants, coaches, and exam invigilators. To find a solution to improve children's compliance, it is necessary to learn the reasons for their non-compliance through interviews to identify the limitations of the robot's strategies. Furthermore, modelling the strategies of professionals who work with children could be a potential solution.

CHAPTER 7

Conclusion

In this thesis, we designed moral interactions for service robots in public environments and evaluated them with field studies. The contributions of this thesis are summarised in Table 7.1. We made the following contributions related to the development and deployment of such robots in public spaces:

- Contribution 1: Proposing designs for gaining people's compliance.
- Contribution 2: Proposing designs for acceptable moral interactions.
- Contribution 3: Expanding the knowledge of developing robot systems to operate in the real world.
- Contribution 4: Revealing the knowledge of people's perception and interaction with robots that execute moral interactions in daily life.

Our first study (Chapter 3) made contributions 2 and 4 by developing an acceptable admonishing service to a real-world shop worker robot and conducting a field study in an actual shop to understand how customers perceive the robot. Our study revealed *harmonized design of friendly and admonishing services* is one successful approach for an acceptable robot admonishing service. Findings of the field trial showed that unadmonished visitors and shop staff had a positive impression of our robot and high intention to use it.

Our second study (Chapter 4) made contributions 1, 2, and 4 by developing and deploying an acceptable and effective robot security guard for managing queues of people in public spaces. This study demonstrated that by *exhibiting an image of a professional security guard* a robot can regulate a crowd in a public event and receive visitors positive impressions. Observations and interviews with both admonished (6) and admonished (81) visitors and event staff provided insight into how people perceive a robot that is supposed to regulate their behaviour in real life.

Our third study (Chapter 5) particularly contributed to 2 and 3. This study introduced an autonomous shopkeeper that aimed to *exert social pressure from friendly behaviour* (i.e., recognise customers' actions and provide encouraging remarks). This study demonstrated how to develop such a complex robot system to function well in the real world through bootstrapping development and integrating real-world data into the robot development process. Furthermore, we proposed solutions to several real-world technical challenges in robot development.

Finally, we believe the findings of this thesis will help to achieve acceptable and effective moral interaction capabilities for service robots in public environments. Further, the knowledge we revealed through the field trials in public space may provide better insight into people's perspectives on service robots with moral interactions, which will help determine the best use of such robots in future society.

Table 7.1: Summary of Contributions

Moral interactions of robots	**Study**	**Proposed design concept**	**Main contribution**			
			Design for gaining compliance	Design for acceptable moral interaction	Revealed people's perception and reactions in daily life	Real-world robot system development knowledge
Direct	Shopworker robot with admonishing service (Chapter 3)	Harmonized design of friendly and admonishing service		✓	✓	
	Queue-managing robot (Chapter 4)	Creating a professional impression in robot	✓	✓	✓	
Indirect	Autonomous shopworker robot that aims to exert social pressure (Chapter 5)	Indirect social pressure from friendly behaviour		✓		✓

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Selected List of Publications

- **Journals**

  [1] Sachi Edirisinghe, Satoru Satake, and Takayuki Kanda. Field Trial of a Shopworker Robot with Friendly Guidance and Appropriate Admonishments. *ACM Transactions on Human-Robot Interaction. 12, 3, Article 34 (September 2023), 37 pages. https://doi.org/10.1145/3575805*, 2023. **Chapter 3**

  [2] Sachi Edirisinghe, Satoru Satake,Yuyi Liu and Takayuki Kanda. Enhancing Queue Management in Public Spaces: Field Trial of a Security Guard Robot *(Submitted to ACM Transactions on Human-Robot Interaction (received minor revision))* **Chapter 4**

- **International Conferences**

  [3] Sachi Edirisinghe, Satoru Satake, Dražen Brščić, Yuyi Liu and Takayuki Kanda. Field trial of an autonomous shopworker robot that aims to provide friendly encouragement and exert social pressure. *2024 19th ACM/IEEE International Conference on Human-Robot Interaction (HRI). IEEE*, 2024 **Chapter 5**