

## *Retraction*

# **Retracted: A Complexity Analysis of User Interaction with Hotel Robots**

### **Complexity**

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

### **References**

- [1] L. Zhong, L. Yang, J. Rong, and X. Li, "A Complexity Analysis of User Interaction with Hotel Robots," *Complexity*, vol. 2020, Article ID 4537152, 13 pages, 2020.

## Research Article

# A Complexity Analysis of User Interaction with Hotel Robots

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Service robots have been introduced to hotel industry in the past decade and received various feedback on their performance. To provide better service, one needs to understand how the hotel customers look at the service robots. Understanding their interests, motivation, and behaviors in human-robot interaction is the key to develop high-quality services and improve robot's performance. This is the first work to study human-robot interaction in hotels in China. Frequent pattern mining and social network analysis techniques are used in this work to find out useful suggestions to both hotel management and robot manufactory. Turning on and off lights, TV, curtain, and window screens are popular services that most of the hotel customers preferred during their stays. Service robots are also found to entertain customers to carry out repeated commands for fun or to kill time. Customers also showed various motivations to stay in hotel rooms by calling different commands.

## 1. Introduction

Rapid development of IT and AI makes it possible to have intelligent robots in people's daily life. In terms of functionality, robots could be classified as industry robots and service robots [1]. By a close look at the service robots, a further categorization can be applied for professional use or for personal/private use [2]. Service robots for professional use are designed to accomplish a particular task or serve a target group of users. For example, professional service robots include cleaning robots, sewer robots, inspection robots, demolition robots, underwater robots, robots in medical institutions, robots with disabilities such as auxiliary robots and wheelchair robots, delivery robots, guidance robots, gas station robots, firefighting robots and air defense robots, construction robots, agricultural robots, etc. Service robots for personal and private use include domestic (home) robots, entertainment robots, educational robots, and so on. These service robots have been developed to assist human beings to finish daily tasks [3]. Both service robots are designed to assist and interact with human beings to complete tasks.

Current research focuses on the design, application, and evaluation of service robots. In terms of design, how do designers design robots, robot interactions, and experiences based on customer needs and preferences? They can weaken or strengthen customers' perception of value, leading to positive or negative word of mouth [4]. Ivanov and Webster [5] focus on the design of friendly hospitality robots. Korea Institute of Science and Technology (KIST) designed elderly robot [6]. Lakshmi et al. [7] designed a hospital nursing drug delivery robot. In terms of applications, unlike industrial robots, the accuracy or speed of service robots is not always the most important aspect. Their function or purpose is not only for entertainment but also to provide help, guidance, treatment, education, and communication [3]. In terms of evaluation, Ivanov et al. [8] used a questionnaire to explore how Iranians view the hotel robots, especially what Iranian consumers think robots can do for them and what they want robots to do. Ivanov et al. [8] investigated the attitude of young Russians towards introducing robots in hotels. Tussydiah and Park [9] focused on customer evaluation of hotel service robots. There is still a lack of understanding of the content and effects of robot services, which is why the paper is written. The existing studies have not explored

much in the service content of the hotel robots or effectiveness of the human-robot interaction.

Human-robot Interaction was distinguished by Thrun [10] into two categories: direct and indirect interactions. Direct interaction assumes a type of two-way communication, which shows equal status between humans and robots. Indirect interaction assumes a type of one-way communication, where the robot acts according to the users' command and reacts to its users. This work focuses on indirect interaction with remote-control robots. The remote-control robot is controlled by a human from a distance (near or far), and the human can control the robot through a joystick or instruction [11].

This work aims to study the actual services requested by human to be implemented by hotel robots by analyzing historical data collected from the real hotel rooms equipped with service robots from 2017 to 2018. This work tried to answer questions such as (1) what are the most popular services the users requested from the hotel robots, (2) what are the motivations for humans to interact with hotel robots, and (3) how often do users give commands to hotel robots. Furthermore, the responsiveness of the hotel robots to the commands received is another interesting topic in this work.

The rest of the paper is organized as follows: Section 2 reviews the current research work on service robots in hotel industry and customer feedback on their performance; Section 3 introduces the data resource and collection process followed by the details of selected data analysis methods; the interesting user command patterns as the experimental results are presented and discussed in Section 4; Section 5 concludes the entire work together with limitation and possible future work.

## 2. Literature Review

To conduct the study of human-robot interactions, the related literature has been carefully reviewed to have a comprehensive understanding of the current work of service robot applications in relevant industry, especially in hotel industry, and the technology level and the performance of the current hotel service robots in real world.

*2.1. Robot Applications in Service Industry.* Service robots are designed to support and service humans through physical and social interactions [12]. For frontline service robots, Martins [13] defined them as follows: a service robot is a system-based autonomous and adaptive interface to communicate and provide services to customers. Service robots play different roles, such as pets, companions, secretaries (or subordinates), and bystanders, just like the relationship with humans [14, 15]. Service robots can significantly reduce labor costs, and they are more like "tools" of technology and employees than their replacements [16]. Martins [13] considered the following three attributes related to service design: representation, personification, and task orientation. The service robot can have a physical representation (such as Pepper) or only a virtual representation (such as Alexa). Therefore, we believe that virtual AI software that can run

autonomously and learn over time can also be classified as a service robot. The service robot can be designed as a humanoid robot (such as anthropomorphic robot) that simulates the appearance of a human (such as Sophia) or it can be designed as a nonhumanoid robot (such as a cleaning robot). Finally, service robots can perform cognitive analysis tasks according to basic computer functions (such as image analysis software assistants for medical diagnosis) or emotional social tasks (such as receiving robots).

Robots are widely used in the service industry. In terms of home education, South Korea has developed the world's first available e-learning home robot and demonstrated the future of robots as a new educational medium. The survey found that home robots are superior in promotion and application and are more able to focus students' attention and interests and improve their academic performance [17]. Ju et al. [18] designed an educational robot platform for the needs of robot education for elementary and middle school students. In terms of senior care, van Osch et al. [11] developed a home care robot called Rose, which is controlled from a long distance (8 km) to perform small tasks for the elderly. The Korea Institute of Science and Technology (KIST) has launched a new project to develop an elderly service robot named T-Rot at the Intelligent Robot Center [6]. Lee and Naguib [19] introduced the design and implementation of the next-generation elderly care robot "Home Mate" based on innovative commitment to sociality and reliability and extensive user research, which can be used for infotainment, video chat, games, and drug reminders. In terms of guidance, Bohus and Horvitz [20] introduced directional robots that can use natural language to interact with one or more participants and provide directions to offices, conference rooms, and other public areas within the building, such as kitchens, cafeterias, and bathrooms. Kanda et al. [21] developed a robot for a shopping mall designed to interact naturally with customers and provide shopping information emotionally. Linder et al. [22] experimentally tested the performance of tracking robots in dense places such as airport terminals for shopping malls. In terms of medicine, Mirheydar and Parsons [23] reviewed the application of robotic surgery in urology and pointed out that the safety of patients with robotic prostatectomy increases. Lakshmi et al. [7] introduced the design and manufacture of a drug delivery robot for hospitals to provide alternate care services. Hu et al. [24] designed a planner based on Gaussian process classification, which aims to promote the further integration of multifinger manipulators and medical image detection.

*2.2. Service Robots in Hotel Industry.* Service automation, artificial intelligence, and robotics offer huge opportunities for the hospitality industry [25]. Hotel robot functions include interacting with travelers and entertaining them, as well as physical assistance, such as transport, checking baggage, and guidance. [26]. Starwood has introduced a robot butler in their Aloft hotel mainly to provide conveniences to guest rooms [27]. Henn-na Hotel is the first hotel to hire hotel robots during the entire operation from check-

in to automatic baggage delivery, using robots to check in occupants and escort guests to their rooms. The robotic receptionist speaks Japanese or English, depending on guest preferences. It can set reservations for people, take them to their rooms, and adjust the temperature of their accommodation. In the room, guests can use voice commands to change the lights and ask questions about time or weather [28]. In collaboration with IBM, Hilton Worldwide is the first to launch the world's first robotic concierge service (using SoftBank's NAO robots) to gain knowledge from artificial intelligence systems and inform guests of local attractions, restaurants, hotel facilities, etc. [29]. The Las Vegas Wayne Hotel has announced that it will introduce Amazon Echo voice roll-up speakers in all rooms with Alexa digital assistants [30]. By the end of 2018, Alibaba's first future unmanned hotel "Flyzoo Hotel" has been put into operation [31].

From the demand side, economically, hotel robots can help hotels cope with seasonal employment and labor costs. Dirican [32] believes that artificial intelligence, especially the introduction of robotic services to hotels, greatly improves the efficiency of hotel services and reduces hotel operating costs, although some hotels with robots still consider investment costs to be high. With increasing labor costs, decreasing labor availability, decreasing robot costs, and increasing robot capabilities, many low-wage service jobs in the hotel industry are expected to be replaced [33]. The time spent on robot labor is less expensive than paying humans [34]. On the noneconomic side, using robots to complete some daily tasks may be considered by hotel managers as a good choice because it will save them most of the concerns of legal authorities, unions, and immigration offices such as seasonal layoffs. [12, 35]. Stringam and Gerdes [36] used a combination of quantitative and qualitative methods, pointing out that the self-service of hotels has not yet led to a significant reduction in labor. Due to hotel technology's labor savings, most hotels choose to redeploy employees to other tasks. It is improving customer service, not reducing staffing. Managing robots will be different than managing tangible goods. How robots, staff, and customers interact is an important focus for future travel and hotel managers [37].

From the supply side, Murphy et al. [38] discussed the design of robots for hotel and tourism industries and training in robot management. The implementation of hotel robots is usually integrated with other technologies such as facial recognition, automatic payment, drone delivery, and autonomous vehicles [9]. According to [39, 40], a robot control system requires three development levels, including hardware, functions, and services. Hardware refers to the shape of the mechanical design, which includes the main part of the service robot, the perception system (sensor), and the motion system (actuator). Function refers to the software architecture of the control system, which can implement navigation, dialogue, visual and speech recognition, positioning and mapping mechanisms, and the representation of knowledge mental models. Service refers to the added value that the hotel aims to create and provide customers with services to maintain a competitive advantage. Chung et al. [41] believe that a key requirement of the robot is that the

robot should perceive people around the robot. Through two field studies of custom programs and iterative design, a programming system for social interaction applications of mobile service robots has been developed. The timing for widespread deployment of service robots anywhere in the hotel will depend on when technical limitations can be addressed [42]. Zhang et al. [43] proposed a smart hotel robot based on ROS, which simplifies the check-in process. López et al. [44] proposed an automated hotel assistant system based on a series of mobile platforms that interact with guests to help them complete different tasks, including bring small items to customers, show them the different attractions of the hotel, accompany guests into their rooms, and provide them with general information.

### *2.3. Related Work on Robot Service Quality and Feedback.*

Customers can feel valuable in the self-service process when interacting with service robots out of fun, enjoyment, and curiosity [45, 46]. Robot customization with user-friendly interface design is important to attract specific new customer markets [47, 48]. Although current robotics technology may not directly complement comprehensive human services, from a marketing perspective, service robots will indirectly attract existing and potential customers [49, 50]. Zhang and Qi [51] pointed out that people with high education and high income who are interested in AI technology are more looking forward to staying in AI robot hotels. Some authors have even suggested that marketers should start thinking about robots as attractions [52]. With the popularity of robots, curiosity will no longer be an important reason for guests to stay in hotels but instead will be service quality and customer satisfaction. Many scholars have researched and explored the service quality of robots [53–55]. Service robots can improve perceived service quality through new attractive interactive services, communication, and contact with customers [56]. Unlike industrial robots whose performance indicators depend entirely on efficiency, the success of service robots depends on user satisfaction [57]. Robots that fail to deliver services can severely impact customer satisfaction and hotel performance [58]. Nakanishi et al. [59] found that the warm heart interactive service of humanoid robots potentially improves customer satisfaction with the entire service.

Customer satisfaction with robot services is largely determined by the robot itself. Therefore, the optimal design of the robot is particularly important. One of the current research studies is to subjectively obtain feedback through customers' questionnaires, polls [60], secondary data analysis [61], hybrid approach [62], and so on. Jeonghye et al. [14] proposed an evolutionary model of service robots with LCD touch panels, such as home robots, by questionnaire survey of parents and children and proposed the importance of rebuilding the robot's facial expressions based on the evaluation model. Tussyadiah and Park [9] found that customers' perception of different types of hotel service robots is different through online surveys and the use of biosensors to measure automatic emotional responses, and the adoption of hotel service robots is significantly affected

by the following aspects: intelligent and perceived security. Another aim is to objectively optimize the algorithm, for example, Ju et al. [18] designed a Python plug-in management system based on the mechanical mechanism design of the robot platform to implement graphical programming to control the robot. Huang et al. [63] proposed a multi-attention-based group recommendation model (MAGRM), and experiments showed that its performance in solving group recommendation problems is significantly better than the latest technology.

The above methods are either subjective or disconnected from the customer, and it is important to find an objective and customer-relevant robotic optimization feedback channel, such as robot optimization through service commands issued directly by customers. Therefore, this paper analyzes the general situation of hotel robot service from the command, by studying what the consumer's commands to the robot mainly include, whether it has formed a certain pattern according to the time series, and whether there are different service differences from the response of the command. The aim is to analyze the service content and quality of hotel robots and to point out new directions and ideas for hotel robot design. It is expected to contribute to the further optimization of robot design, such as packaging preset behavior patterns, optimizing repetitive commands, and human development to improve the service quality of the robot.

### 3. Materials and Methods

To have a systematic analysis on human-robot interaction, a rich data source containing a large amount of interaction records is needed. Then, the collected big dataset is pre-processed to remove incorrect and irrelevant information to reduce possible bias in results. After a basic statistical analysis on the clean dataset, the paper uses a frequent pattern mining method to study the user command patterns and a social network-based clustering method, which aims to help understand users' motivations, interests, and particular behaviors.

*3.1. Data Collection and Preprocessing.* The data were collected from 88 hotels in 23 cities across the mainland China. The service robots are equipped in 789 hotel rooms in these hotels. A robot management system by robot manufactory recorded all the user commands received by the hotel robots in the rooms. In this work, the historical data of command records in 2017 are selected for analysis and evaluation purpose due to the stability of the robot operations and the completeness of data.

In the interaction between user and hotel robots, the commands were given by voice. The user spoke out their requests and then the robot received the entire voice sentences and converted them into simple text-based command labels by its voice recognition functions. The collected data were then preprocessed to remove the inconsistent command labels caused by the updation of the robot system. The unrecognized commands were also removed as they were mainly caused by accent issues. After preprocessing, 745,528

valid user commands from 49,955 hotel customers were kept and input into the next-step analysis processing.

*3.2. Association Analysis on User Commands.* To understand human-robot interaction, the commands given by the users are the only resource that can be carefully studied in this case. Frequent pattern mining is used to discover most popular user command patterns in order.

*3.2.1. Sequential Frequent Pattern Discovery from User Commands.* Frequent patterns are often used to present the most common or similar features among data examples in a dataset. Given a set of commands, frequent pattern mining aims to find the rules that enable us to predict the occurrence of a specific item based on the occurrence of other items in the commands. A frequent pattern can be determined by a set of standard constraints [64].

The simple form for frequency of a pattern can be easily gained by counting the total number of its occurrence in the entire dataset. This is commonly used for finding out the most popular patterns with only one individual command.

Support, as one of the widely used constraints, was proposed by Agrawal et al. [65] in their Association Rule Mining (ARM) algorithm to identify a frequent pattern with two or more user commands. Let  $C$  be the complete set of all user commands in the collected dataset  $D$ .  $c_1$  and  $c_2$  be two commands from  $C$ , that is,  $c_1 \in C$ ,  $c_2 \in C$ .  $c_1$  and  $c_2$  are two different commands. The support of these two commands can be obtained by

$$\text{Supp}(c_1, c_2) = \frac{\text{number of interactions containing } c_1 \text{ and } c_2 \text{ in } D}{\text{total number of interactions in } D} \quad (1)$$

A pattern can be indicated as a frequent one if its support score is not less than a minimum support threshold  $\delta$ ,  $\text{Supp}(c_1 \text{ and } c_2) \geq \delta$ . The classic Apriori-heuristic-based ARM is not suitable for processing large-scale dataset as it is very time consuming and expensive in computation. The concept of interestingness is then considered into the process to avoid generating too many useless candidate command patterns [66]. Only the candidate patterns with a higher interestingness score than the minimum interestingness threshold can join the next round of candidate pattern generation. A candidate pattern with two commands is generated based on the single commands with acceptable support score in previous generation; the candidate patterns with three commands are generated from the candidate patterns with two commands, and so on. The interestingness is calculated by the leverage of two commands as an example below:

$$|\text{leverage}(c_1, c_2)| = |\text{supp}(c_1, c_2) - \text{supp}(c_1)\text{supp}(c_2)| \geq \theta. \quad (2)$$

In such a way, the computation time and waste can be controlled under an acceptable range. In this work, the

candidate command patterns are indicated as frequent patterns based on their frequency of occurrence. One of the reasons is due to the high repeats of the same command patterns in one interaction. The user could place the same set of commands one after another, for example, “turn on lamp, turn off lamp, turn on lamp, play music, turn off lamp, turn on lamp ...” Therefore, the strength measurement constraints in ARM do not fit and are ignored in this study.

Another special feature in this work is that the actual time when users placed the commands was recorded as well, which makes the collected data time-series data. Time-series data are often presented in data sequences. In this work, each sequence records an interaction between the user and the robot. Accordingly, the command patterns are not random combination of the commands, and the order of the commands is also important.

**3.2.2. Social Network Analysis for User Clustering.** In recent years, the world has become more and more complex, and the research community has done a lot of work on the measurement of complexity. Social network is an analysis and simulation method that attempts to use the relationship between points and lines to analyze complex systems through the algorithmic characteristics of graphs. Social network analysis is widely used to understand the nature and discover useful patterns representing the relationships among members in a group [67]. In this work, the relationships among the hotel customers (users) were studied based on the commands they placed. The dataset was reorganized into a collection of the sequences of commands recorded for each individual user. A  $n \times n$  matrix  $M$  was obtained where  $n$  is the total number of the user commands. The intersection  $m_{ij}$  records the number of occasions that command  $c_i$  and command  $c_j$  are in the same clique. A clique is a subset of commands that always occur together over all the command sequences [68]. The total number of links in the network is calculated by  $l = \sum \sum m_{ij}$ .

Hierarchical clustering (Johnson, 1967) was then used to group commands into clusters based on the nearest pair of commands. By clustering the commands together, the users’ interests are discovered, that is, what commands are always called together with high densities. The social network analysis was implemented using a software called UCINET [69].

## 4. Results and Discussion

This section presents the experiment results obtained by applying the selected method on the collected data. The results are explained with the method used, respectively, followed by discussion of overall findings.

**4.1. Dataset and Descriptive Statistical Analysis.** After data cleaning and preprocessing, a total number of 103 individual commands were extracted from the collected historical data. Table 1 lists the top 50 commands placed

TABLE 1: Top 50 frequent individual user commands received by hotel service robots.

Top #	Command	Frequency	
1	OpenLamp	125,855	16.97%
2	CloseLamp	118,271	15.95%
3	TVOFF	103,759	13.99%
4	OpenCurtain	91,146	12.29%
5	CloseCurtain	78,049	10.53%
6	CloseScreen	41,324	5.57%
7	MusicPlay	33,254	4.48%
8	AirON	30,307	4.09%
9	OpenDoor	17,435	2.35%
10	TVON	15,416	2.08%
11	AirOFF	9,099	1.23%
12	OpenPowerLight	8,879	1.20%
13	MeetingModeON	2,842	0.38%
14	TVChannelChange	2,629	0.35%
15	TVVolUp	2,325	0.31%
16	ServiceON	2,267	0.31%
17	OpenBedroomLight	2,236	0.30%
18	CloseWCLight	2,207	0.30%
19	MusicStop	2,045	0.28%
20	OpenWCLight	2,002	0.27%
21	SleepModeON	1,974	0.27%
22	CloseReadLight	1,972	0.27%
23	CloseDengDaiLight	1,860	0.25%
24	OpenNightLight	1,719	0.23%
25	OpenLangLight	1,503	0.20%
26	OpenDengDaiLight	1,390	0.19%
27	OpenTopLight	1,378	0.19%
28	MusicNext	1,376	0.19%
29	OpenReadLight	1,291	0.17%
30	OpenBedLight	1,265	0.17%
31	BlueTooth	1,242	0.17%
32	ClosePowerLight	1,206	0.16%
33	OpenLivingroomLight	1,031	0.14%
34	AirCondSet25	956	0.13%
35	OpenJingQianLight	953	0.13%
36	AirCool	934	0.13%
37	AirCondSet24	933	0.13%
38	CloseLangLight	921	0.12%
39	OpenStudyLight	888	0.12%
40	CloseLivingroomLight	856	0.12%
41	AirCondSet26	852	0.11%
42	CloseTopLight	852	0.11%
43	TVVolDown	851	0.11%
44	AirCondSet20	769	0.10%
45	CloseBedLight	759	0.10%
46	AirHeat	750	0.10%
47	MusicPrev	713	0.10%
48	OpenBackgroundLight	713	0.10%
49	OpenScreen	696	0.09%
50	AirCondSet30	688	0.09%

by the users in the interaction with hotel robots. The top 12 commands have much higher frequency to be called by the users than the rest, which have over 90% of the listed commands. Close to 70% of user commands fall into one of the OpenLamp, CloseLamp, TVOFF, OpenCurtain, and CloseCurtain commands. That is, about 90 commands have less than 0.4% of chances to be called once in a year.

*4.2. Time-Based User-Robot Interaction Analysis.* Analyzing the active degrees of user commands helps to understand the peak and off-peak periods of human-robot interaction. An hour-based activity frequency chart is presented in Figure 1. Some common senses can be detected including the interactions which always start alone with users waking up in the morning from 6 am and increase to reach the first high point around 10 am. A small drop is found around 12 pm when users leave the rooms for lunch, and the number of commands climbs back quickly from 1 pm and remains stable until dinner time. The peak time is around 10 pm when users stay in the room to enjoy entertainment. It is a surprise to see that users still communicate with service robots after midnight. Finally, the quiet time starts from 2 am to 5 am. Many people stay late in the hotel rooms and talk to service robots.

A month-based activity frequency chart is presented in Figure 2. During the whole year, the service robots are busy in July and August and most of them are in idle or standby status in January and February. This matches the factor that during summer time, more hotel reservations and travels are made in general. The monthly-based interaction data also indicate that most of the users who lived in the hotel rooms equipped with service robots tried to interact with them almost every time. The service robots are accepted by users who stayed in the hotels anytime.

*4.3. User-Robot Interaction Pattern Discovery.* Frequent command patterns are expected to provide some knowledge about users' interests, behaviors, and the responsiveness performance of service robots.

#### *4.3.1. Command Patterns for Popular Command Combinations.*

In human-robot interaction analysis, a main object is to find out the user interests when they request robots for services. The frequent command patterns can indicate what groups of commands users preferred to work with service robots. The frequent individual user commands are listed in Table 1. Tables 2–4 list top 10 frequent patterns as the permutations of two, three, and four commands, respectively. The pattern generation stopped at four-command level since the frequency and support score of the candidate five-command patterns were too low to have significant influence. The frequency was measured by the total number of occurrences including the repeats in the same interaction. The number of interactions when a pattern appeared at least once was also recorded. The difference between these two numbers indicate that many patterns have high repeats in a single interaction. The reasons to have this situation are complex and will be explained in the following context. Note that the order of commands is a key concept to be considered in all cases.

In the frequent two-command and three-command patterns, most of the patterns contain operations of turn on and off lamp (all lights), curtain, and TV. In the frequent four-command patterns, close screen (for windows) as a new command can be seen in most of the patterns. However, the number of commands increased in the

patterns, and the total number of occurrences dropped significantly. A common behavior from all the pattern sets that can be seen is that users like to turn off light, curtain, window screen, and TV together. The difference is just the order of turning which one first. For those patterns regarding TV, users turned off the TV more frequent than to turn it on because the TV was automatically turned on after the user entered or returned to the rooms in many hotels in China region. In addition, from all the frequent patterns in these three tables, the lamps (lights) and the curtains were turned on or off together. If the curtain was closed, then the lamp would be off too, and vice versa. It is not a common case to close the curtain and turn on the lights, from which one can claim that such operation was normally done before the user went to bed. It also confirmed that the human-robot interactions were active in the late hours of the day (as shown in Figure 1). The patterns of opening curtain and turning on the lamps may suggest the natural lighting in the rooms is insufficient.

A particular behavior is found from the analysis, in which the users tried to “play” with service robots by placing paired commands. That is, when the first command was given, immediately another command followed. The paired commands are always to turn on or off one device, such as lamps, TV, curtain, and air conditioner. This indicates that the users were bored and called those commands without a clear purpose. They might just want to talk to service robots for fun or kill time. Table 5 lists the top 20 paired commands in this category. Rather than turning on and off a particular light, users preferred more to turn all the lights on and off. For TV and air conditioner, the same situations are detected. Users did not give details in order but went for simple and short commands.

#### *4.3.2. Robot Responsiveness Analysis.*

Although the human-robot interaction is identified as the indirect one that only one-way communication is applied, the responsiveness of the service robots to the user's commands is an interesting topic to be explore more in this section.

The responsiveness analysis carried out in this work is to look at how many times a user needs to repeat continuously the same command until the robot takes action or the user gives up. From the frequent pattern analysis above, there are some differences between the total number of the occurrences of the patterns and the number of the interactions having the patterns. They are not the same numbers, and in many cases, there are big gaps between them. The reason for this is that some commands are repeated many times in one interaction. The commands with repeats were closely observed, and the findings are summarized in Figure 3. The number of repeats for one single command daily is around 2.9, which indicates that the service robot's responsiveness still has a big room for improvement. Top 20 repeated commands were extracted from the analysis. By comparing with the initial count on top 50 frequent individual commands in Table 1, 17 out of 20 most frequent commands are found to have high repeats. Most of the commands were repeated within 2 seconds.

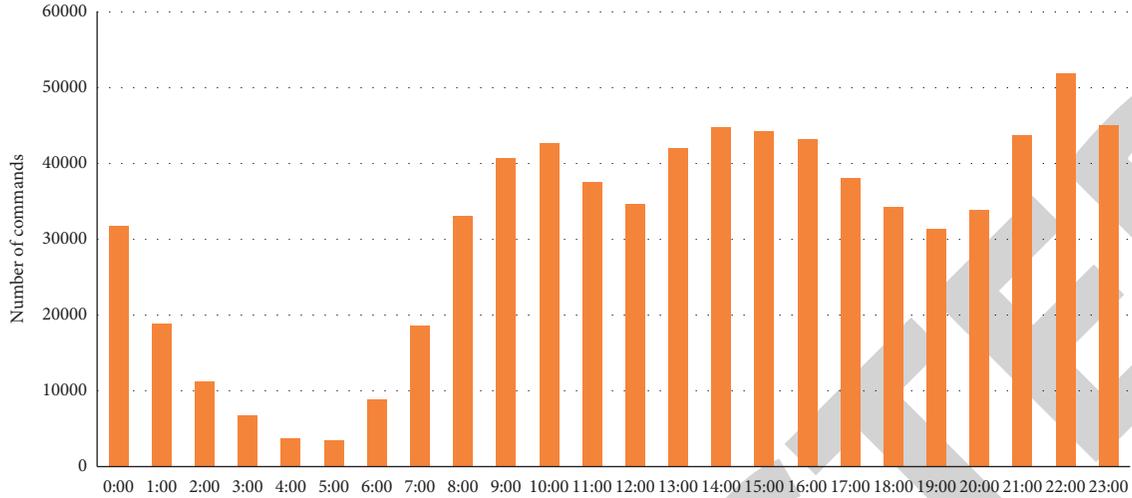


FIGURE 1: Hour-based human-robot interaction.

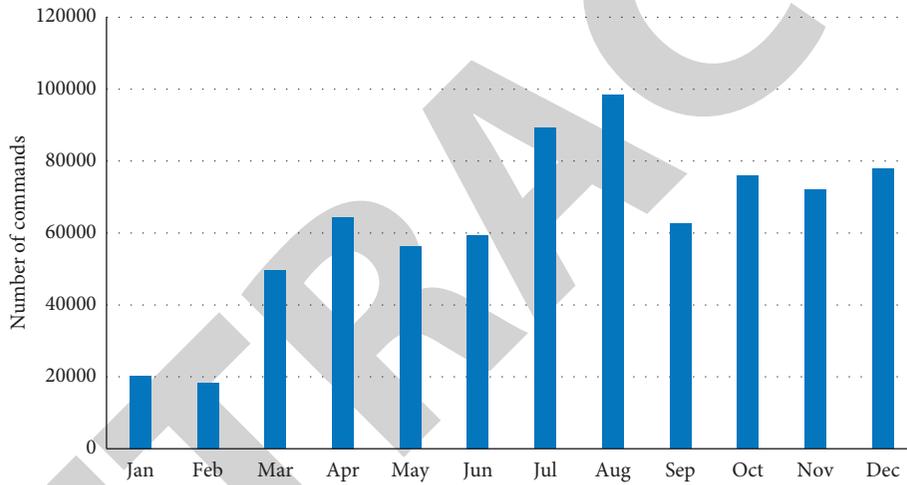


FIGURE 2: Monthly human-robot interaction.

TABLE 2: Top 10 frequent two-command patterns.

Two-command frequent patterns	Frequency	
	Total occurrences	No. of interactions
CloseCurtain, CloseLamp	33,255	15,250 (30.53%)
CloseScreen, TVOFF	31,976	14,284 (28.59%)
CloseLamp, CloseScreen	28,713	13,092 (26.21%)
OpenLamp, CloseLamp	21,253	12,973 (25.97%)
TVOFF, CloseCurtain	16,870	9,245 (18.51%)
OpenCurtain, CloseCurtain	11,531	7,859 (15.73%)
OpenLamp, TVOFF	11,410	7,417 (14.85%)
OpenLamp, OpenCurtain	10,641	8,467 (16.95%)
TVOFF, OpenCurtain	9,554	6,692 (13.40%)
CloseCurtain, OpenCurtain	8,253	5,946 (11.90%)

Table 6 lists the top 20 commands that have the most repeats. Not all of them have repeats due to the poor responsiveness of the robots. The repeats may be caused due to the nature of the commands themselves. For example, MusicVolDown, TVChannelADD, TVVolUp, MusicVolUp,

TVVolDown, and TVMenuUp are six commands that the users will repeat several times to reach their satisfied status. It is understandable that a user will keep on calling the command MusicVolDown to turn the music volume down to an acceptable amount. However, other commands to be repeated are treated as the cases of poor responsiveness of service robots. ReadLightMax has the highest repeat rate over 85% followed by OpenPowerLight (81.32%). These commands with high repeats need special attention to the service robot manufactory for performance.

**4.4. User Command Clustering.** The user clustering based on the commands they called in the human-robot interaction is shown in Figure 4. In total, six user clusters were obtained from social network analysis by UCINET. They are colored in Figure 4 for visualizing the user groups and the commands used by each group. Overall, a set of common commands is detected, which confirms the most popular commands like switching lights, pulling curtains, watching TV, and playing music are the favorites for all six groups of

TABLE 3: Top 10 frequent three-command patterns.

Three-command frequent patterns	Frequency	
	Total occurrences	No. of interactions
CloseCurtain, CloseLamp, CloseScreen	26,062	12,141 (24.30%)
CloseLamp, CloseScreen, TVOFF	26,421	12,227 (24.48%)
CloseScreen, TVOFF, CloseCurtain	7,846	4,528 (9.03%)
OpenLamp, CloseLamp, OpenLamp	6,547	4,512 (9.06%)
CloseScreen, TVOFF, OpenLamp	6,128	4,356 (8.72%)
CloseLamp, OpenLamp, CloseLamp	5,359	3,766 (7.54%)
CloseCurtain, CloseScreen, TVOFF	4,896	3,596 (7.20%)
OpenCurtain, OpenLamp, TVOFF	4,360	2,841 (5.69%)
OpenCurtain, OpenLamp, CloseLamp	3,800	3,649 (7.30%)
CloseScreen, TVOFF, OpenCurtain	3,608	2,724 (5.45%)

TABLE 4: Top 10 frequent four-command patterns.

Four-command frequent patterns	Frequency	
	Total occurrences	No. of interactions
CloseCurtain, CloseLamp, CloseScreen, TVOFF	19,487	8,979 (17.97%)
CloseLamp, CloseScreen, TVOFF, OpenLamp	4,974	3,558 (7.12%)
CloseLamp, CloseScreen, TVOFF, OpenCurtain	2,708	2,009 (2.59%)
OpenLamp, CloseCurtain, CloseLamp, CloseScreen	2,538	1,973 (3.59%)
CloseLamp, OpenLamp, CloseLamp, OpenLamp	1,874	1,307 (2.62%)
OpenLamp, CloseLamp, OpenLamp, CloseLamp	1,830	1,294 (2.59%)
CloseLamp, CloseCurtain, CloseLamp, CloseScreen	1,578	1,438 (2.88%)
MusicPlay, CloseCurtain, CloseLamp, CloseScreen	1,332	1,184 (2.37%)
OpenCurtain, CloseCurtain, CloseLamp, CloseScreen	1,206	1,018 (2.04%)
OpenCurtain, OpenLamp, CloseLamp, OpenLamp	681	672 (1.35%)

TABLE 5: Top 20 paired commands.

Command 1	Command 2	Frequency (total occurrences)
OpenLamp	CloseLamp	21,253
CloseLamp	OpenLamp	19,884
OpenCurtain	CloseCurtain	11,531
CloseCurtain	OpenCurtain	8,253
TVOFF	TVON	7,832
TVON	TVOFF	4,162
AirON	AirOFF	2,241
AirOFF	AirON	1,524
MusicPlay	MusicStop	420
MusicStop	MusicPlay	253
OpenWCLight	CloseWCLight	250
OpenLangLight	CloseLangLight	222
CloseWCLight	OpenWCLight	149
OpenTopLight	CloseTopLight	124
CloseBackgroundLight	OpenBackgroundLight	118
OpenLivingroomLight	CloseLivingroomLight	117
OpenBedroomLight	CloseBedroomLight	113
CloseLangLight	OpenLangLight	105
OpenDengDaiLight	CloseDengDaiLight	102

users. Individual groups also have their preferred commands. Even with the same devices, they have different operations. Each group is discussed in more detail in the rest of the section.

Group 1 (in pink) has the biggest set of the commands. Except the commands related to switching TV, light, and curtain operations, this group works more active in playing

music and changing TV channels. The users in this group may prefer more to turn on TV to play music, but few of them used commands to adjust room temperature.

Group 2 (in dark blue) has the active users who used service robots to mainly adjust the room temperature by air conditioner. A set of temperature setting commands like “Aircondset25,” “Aircondset24,” “Aircondset26,”

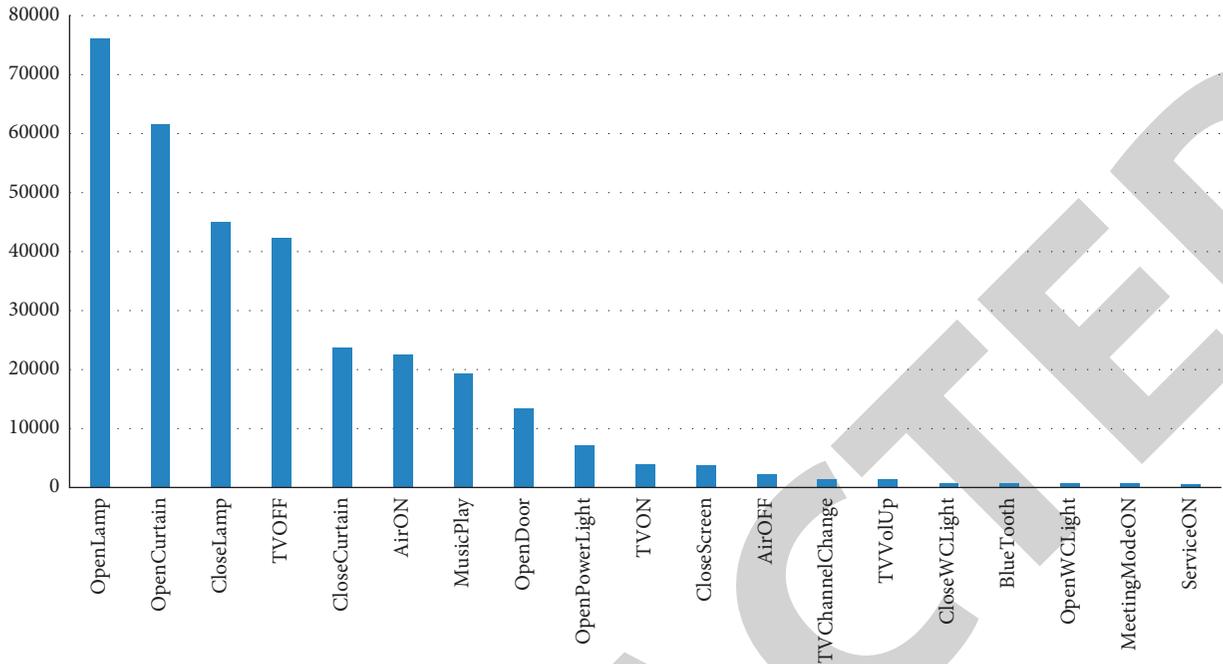


FIGURE 3: Top 20 repeated user commands.

TABLE 6: Top 20 commands with most repeats.

Top #	Command	Repeat rate (%)
1	Read LightMAX	85.28
2	OpenPowerLight	81.32
3	OpenDoor	77.32
4	AirON	74.49
5	TVChannelSub	74.42
6	MusicVolDown	67.94
7	OpenCurtain	67.62
8	TVChannelADD	64.42
9	TVVolUp	60.82
10	OpenLamp	60.50
11	MusicPlay	57.89
12	BlueTooth	57.57
13	TVChannelChange	54.62
14	MusicVolUp	54.03
15	CloseBedLight	53.75
16	OpenLivingroomLight	53.35
17	TVVolDown	50.65
18	CloseLivingroomLight	49.30
19	TVMenuUp	48.61
20	CloseDoor	48.12

“Aircondset20,” and so on is detected in this group particularly. The temperature range is from 17°C to 29°C across the year, which falls into the normal external temperature adjustment of the human body. This user group focused more on the operations with accurate requirements rather than some general commands preferred by Group 1.

Group 3 (in light blue) is a small one at the margin areas. The commands used more by this group are entertainment-related operations on TV and playing music. They used “Bluetooth” to connect with their own smart devices and played music on TV. They also used “Checkoutn”

command to inform the service robot before they left the room. They can be indicated as avant-garde customers for hotels.

Group 4 (in green) often used robots to call for room service. The users in this group put “Nodisturbon” and “Cleanon” to call for cleaning service. They also watched the charge channels on TV rather than browsing the noncharge channels. These customers preferred more to keep the hotel room as their private space and had strong control on the activities in their space.

Group 5 (in yellow) and Group 6 (in brown) are two groups with the users who spent more time on switching lamps in the room to adjust the lighting. These two groups do not share a lot of overlaps with the other groups; especially Group 6 has commands with only one connection. These two groups have high interests to particular lights at different positions in the room. They did not use general commands to turn all the light on or off, but carefully and clearly gave the name of the lights. This behavior shows that the users moved a lot inside the room. They are energy savers to use individual lights in small areas.

**4.5. Discussion.** From the analysis on the results above, a number of issues and valuable points obtained need special attention from hotel management and technical experts in service robot manufactory.

In terms of theoretical contributions, this article makes an in-depth analysis of the services provided by robots from the perspective of the service industry. Different from the traditional robot research, it closely integrates human feelings and robot design and provides more knowledge to this area. Furthermore, this paper proposed a command mode for hotel robots through a complex network analysis



customers and robots in the hotel rooms by applying frequent pattern mining and social network analysis techniques to find out hotel customers' interests, motivations, and behaviors when they interact with service robots.

Among a total of 103 user commands called by over 49,955 hotel customers during their stays in 88 hotels from 23 cities in China, the frequent command patterns indicate that most of the customers called service robots to do simple operations such as switching on or off the lights, TV, curtain, and window screen. Hotel customers have special preferences on services when they interacted with service robots. Some like to try a big range of service; some prefer to give accurate commands to adjust the room environment; some spend their time in hotel rooms for entertainment; some take time to enjoy themselves in hotel rooms as their private spaces; and others treat service robots as a company to kill time by repeating same set of commands continuously. Robots are also found to be slow to respond to some of the user commands, and potential improvement is expected to be made in near future.

Since this is the first work of this area, there were some limitations when the research was conducted. The raw data collected from the robot management system by manufacturer contain inconsistent command labels due to system updation. Only the data in 2017 are complete to be used in this work. The users' information is lacking in this work due to privacy concerns and since their personal information cannot be shared by hotels. In addition, whether social network analysis is applicable to robot commands needs to be carefully studied afterwards. However, these issues did not stop this work from discovering useful knowledge to understand hotel customers' interaction with service robots, and this is a remarkable step in human-robot interaction study in the future. The findings help hotel management to adjust the services that the customers are interested in and what the robots could provide.

### Data Availability

The data are owned by the robot company and could not be released.

### Conflicts of Interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

### Authors' Contributions

Lina Zhong was responsible for conceptualization, methodology, writing, and funding acquisition. Liyu Yang contributed to literature review. Jia Rong reviewed and edited the manuscript and supervised the study. Xiaonan Li was responsible for software and formal analysis.

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