Robots in my Contact List: Using Social Media Platforms for Human-Robot Interaction in Domestic Environment

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A THESIS SUBMITTED

FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF COMPUTER SCIENCE

SCHOOL OF COMPUTING

National University of Singapore

2011

Abstract

This thesis explores the application of existing social media platforms for human-robot interaction. With increasing popularity of social media platforms that connect humans, we propose to portray domestic robots also as buddies on the contact list of family members, thereby extending social connections among humans further to domestic robots. This proposed approach can contribute a more social, user-familiar, and natural interface for interacting with domestic robots. In detail, we developed a working system that includes four complementary social media platforms: short message services (*SMS*), instant messenger (*IM*), online shared calendar (*Calendar*), and social networking sites (*Facebook*). Hence, users can select and seamlessly switch among interfaces upon their needs and preference. The characteristics and strengths of these platforms are carefully studied and compared, and a user study is also devised in this work to investigate the user operations in the course of robot interaction.

Acknowledgements

First, I would like to express my most profound gratitude to my advisor, Dr. Zhao Shengdong, for his guidance and support. It has been an invaluable experience working with him in the past 2 years. Dr. Zhao Shengdong has helped me improve in a lot of aspects. It has been a great honor for me to be his student.

Second, I would thank my partners Ma Xiaoning and Dr. Philip Fu for their dedicated efforts on this project. I am also grateful for the encouragement and enlightenment they gave to me.

Third, I also want to express my sincere appreciation to my dear colleagues in NUS-HCI lab who have given me a lot of insightful comments on my project.

Fourth, I want to thank those participants who take their time to do my experiment by using the system and share their comments with me.

Finally, I would like to thank my family for their love and support. None of my achievements would be possible without their love and encouragement.

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Chapter 1

Introduction

1.1 Motivation

Social media platforms, or media platforms for social interaction, have been widely popular. Users today enjoy a wide range of social media platforms to interact with other people as well as to publicly express themselves; popular platforms include blogs, picture-sharing, video logs, wall-postings, email, instant messaging, music-sharing, crowdsourcing, voice over IP, etc.

Domestic robots have become increasingly popular among general public users in the recent decade, for example, the vacuum robot, *Roomba*, has been available on the market for seven years and has reached millions of users world-wide [90]. Other types of domestic-service robots are also emerging into the commercial markets, including *Scooba* for mopping, *Robomower* for lawn mowing, Dirt Dog for garage cleaning, *Dressman* for ironing [90]. It can be envisioned that domestic robots will offer significant help to housework tasks of their hosts in the near future.

However, controlling domestic robots are often not straightforward for general users. Unlike conventional electronic appliances such as washing machines and television sets, which are stationary, domestic robots can move around in our home and share the physical space with us. In addition, the ways to control them could be very different from conventional home electronics due to the increasing complexity we have with these robots. Furthermore, domestic robots manufactured from different companies typically come with different manuals and interface controls, thus users have to re-learn the interface when upgrading or switching to another robot. All these hinder further adoption and usability of domestic robots with the general public.

While those social media platforms have undoubtedly enriched our daily lives, we so far employed them mainly for social communication or interactions between humans. They certainly have great potential to be extended to interact with robots since robots are considered by most people as “human-like” beings.

In addition, there are a number of interesting prospects yet to explore and verify about the proposed social media platform based approach for human domestic robot interaction,

First, since social media platforms are so widely-adopted, the general public likes these platforms and already frequently uses them in daily life. The interface interactions could leverage natural language skills in human communication which most users already have. Interacting with robots through these *familiar interfaces* can ease the adoption of robots and help users overcome the psychological barriers of learning new interfaces.

Second, since different social media platforms come with their own unique characteristics and strengths, they could be integrated together to *complement each other* for different working scenarios. Users also have greater flexibility in choosing the platforms according to their preferences and needs. While learning to manage multiple interfaces could be a challenge, it is easier in our approach because most users are already familiar with the platforms.

Furthermore, since social media platforms are inherently designed for social interaction among humans, portraying robots as buddies on our contact lists could make interacting with robots more naturally perceived like human-to-human interaction. Hence, robots could appear to be *socially-interacting with us*, and come with social intelligence. Note that traditional approaches for improving social intelligence of robots often focus on the design of intelligence behavior using computational models on integrated robotic platforms [17, 95]. We believe that the use of social media platforms could be an effective alternative to promote the social aspect in HRI.

Lastly, since most social media platforms are designed for remote communication, using them to interact with domestic robots naturally supports *remote interaction*. Such interaction can be valuable for busy working professionals since they can extend their interaction with their robots from homes to their offices or on the road.

Besides this potential, we are also quite interested in human's perception towards this approach. Since social media platforms are inherently designed for social interaction among humans, will portraying robots as buddies on our contact lists make interacting with robots more naturally perceived like human-to-human interaction? If so, robots could appear to be socially-interacting with us , and people might feel this kind of interaction more human-like. However, there might be also negative effect. Will people feel strange or awkward talking to robot in social media? Will this approach make people feel more difficult than using other well-adopted traditional methods (such as using specialized control software)? These interesting questions have driven us to build our infrastructure system as a testbed and conduct an dedicated user study to investigate the user operations in the course of robot interaction.

1.2 Thesis Objective

The objective of this thesis is to explore the application of social media platforms for human-robot interaction (HRI) by harnessing the capability of several popular social media platforms for interacting with domestic service robots.

An integrated system infrastructure will be implemented for controlling domestic robots with assorted popular social media platforms, including short text message, instant messengers, Facebook, and Google calendar. The architecture design should provide a unified interface for users to control their home robots because we can centralize all the user communication through a central server at home, and the users can just use their familiar interfaces like SMS and MSN to assign tasks to the robots and to monitor the robot activities. Since the general public is already familiar with the user interfaces, general public users should be able to more easily control robots through this system infrastructure. Furthermore, the system should also naturally support remote robot manipulation and monitoring from office, as well as on the road.

An carefully designed user study will be conducted to gain insights into the usage of four popular platforms, including short text message services (*SMS*) through cell phones (3.4 billion unique users up till 2010), instant messenger services (*IM*) (1 billion users up till 2009), shared online calendar (176 million users for Gmail up till December 2009), and social networking sites such as Facebook (over 500 million active users), to interact with domestic robots. For convenience, these four platforms are referred to as *SMS, IM, Calendar,* and *Facebook* in the rest of the thesis. A detailed result analysis will be presented to show the insight we gained toward using social media platforms for interacting with domestic robots.

1.3 Thesis Contribution

The main contribution of my thesis are summarized as follows,

- First, the proposed system infrastructure tries to harness social media platforms for human-robot interactions was developed. By portraying robots as buddies on our contact lists, we can naturally interact with robots via various social media platforms. This is the first attempt we aware of in employing and studying assorted social media platforms for human-robot interaction.

- Second, we implemented an integrated working system for the four social media platforms (*SMS, IM, Calendar,* and *Facebook*), and developed a number of high-level tasks useful for domestic setting by customizing our robots.

- Lastly, we studied the characteristics and strengths of the four employed social media platforms, and experimented with several working scenarios with them. At the end, a user study is devised and results are analyzed for revealing insights on this proposed HRI approach.

1.4 Thesis Organization

To better explain my work, my thesis is divided into 7 chapter.

Chapter 1 **Introduction** explains the motivation, objective as well as the contributions for my thesis.

Chapter 2 **Usage Scenarios** presents a sequence of usage scenarios to illustrate how social media platforms can facilitate interaction with domestic service robots.

Chapter 3 **Related Work** discusses the related social media based application system and literature.

Chapter 4 **Characteristics of Interface** reviews the characteristics and strengths of the four employed social media platforms so that we can see how these influence the user interaction.

Chapter 5 **System Implementation** explains how the server end works as well as how the social media platforms are connected to the server.

Chapter 6 **User Study** describes the user experiment design as well as the results and findings about our system from different aspects.

Chapter 7 **Conclusion** summarizes the work done in the thesis and plans for future work.

Chapter 2

Usage Scenarios

To illustrate how social media platforms can facilitate interaction with domestic service robots, we first present a sequence of usage scenarios. In the scenarios we will see how family people can use different social media platforms to interact with their robots.

Profile. Jason is a busy professional, usually working from 9am to 6pm on working days, while his wife, Maggie, also works full-time. Their son, Mike is now studying abroad, and they have two domestic robots, Johnny (cleaning) and Robbie (surveillance), for household work and preparation for an upcoming Christmas Eve party. Note that the robots are named after the characters in the book "I, Robot."

Dec. 20, 10am, Party Scheduling (Google Calendar)

Maggie scheduled regular cleaning tasks with Johnny every week day using Google calendar to clean the bedroom at 3:30pm and living room at 5pm. Five days before Christmas Eve, Jason opens his Google calendar and tries to set up a party at 6pm on Dec. 24th. However, he finds that Johnny has been scheduled to clean the living room during that time. Hence, he reschedules Johnny's cleaning task to another time slot via the calendar interface. And due to the rescheduling, Johnny sent an automatic SMS/IM message to Maggie (the owner of the cleaning task) to inform her about the change. All robot messages regarding task scheduling are sent to the corresponding calendar entries automatically, so that Jason and Maggie could check the feedback from Robbie and Johnny to see if a task has been finished or any problem occurs when they log on to their calendars, see Figure 2.1.

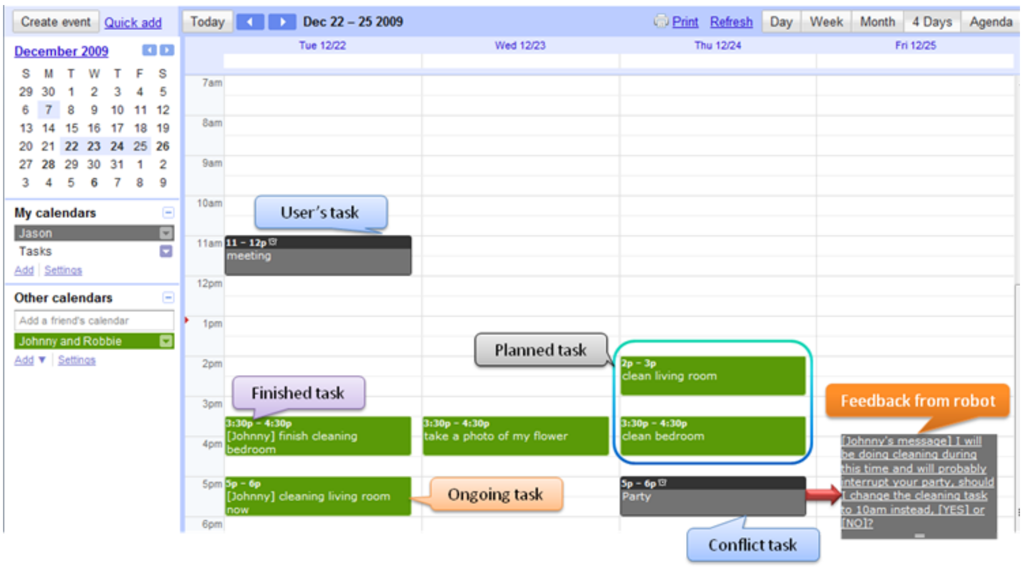

Figure 2.1: Using Google calendar to interact with domestic robots.

Dec. 22, 11pm, Progress Update with Facebook

Since Jason confirms the schedule of the Christmas Eve party, Robbie and Johnny keep posting the preparation progress made each day on Facebook, see Figure 2.2, in order to keep everyone excited about the event. Now, Robbie receives a message from one of Jason's friends concerning its previous message on the splendid Christmas tree it just put up in the middle of the living room. Jason's friend asks Robbie about how the tree looks like. Hence, Robbie goes to the living room, takes a picture with its camera, and shares the picture on its Facebook for Jason's friends to see.

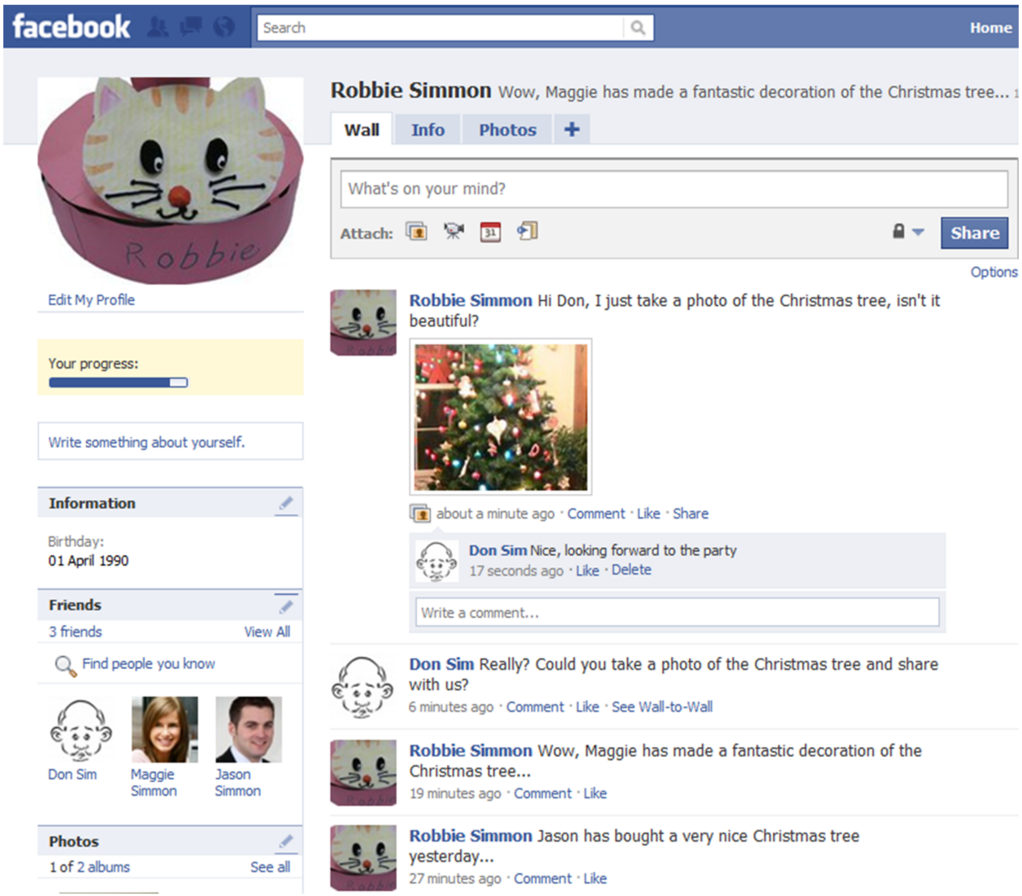

Figure 2.2: Using Facebook to interact with domestic robots.

Dec. 22, 5pm, Video Chatting through IM

Mike could not join the party since he is aboard, but he heard of the Christmas decoration at home, and so he would like to take a look. Hence, he checks with Robbie on his IM, see Figure 2.3, and starts a video conversation with Robbie:

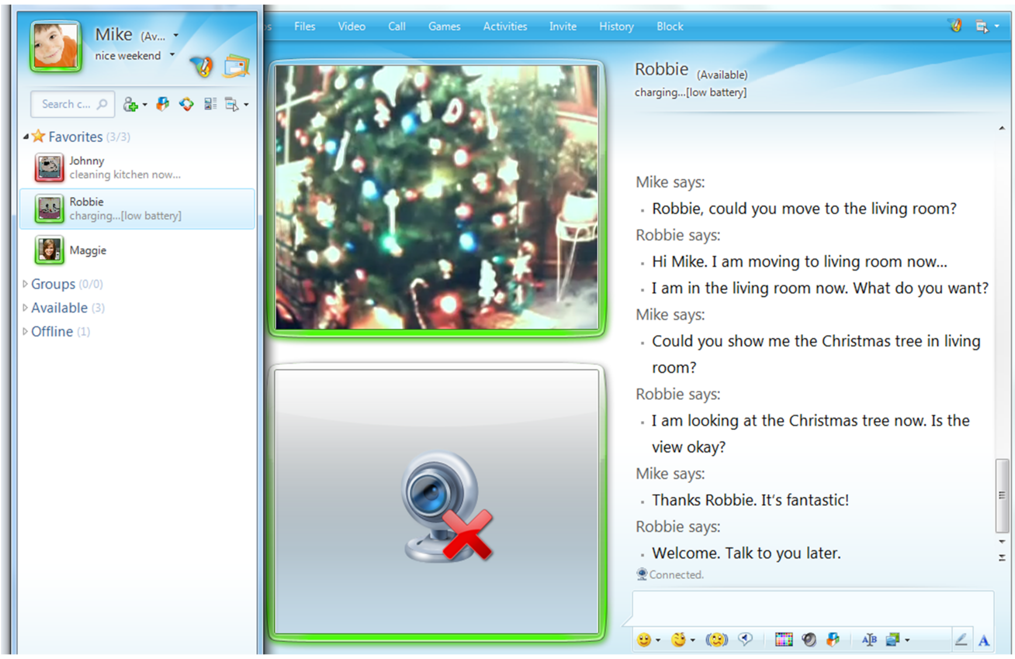

Figure 2.3: Using IM interface to interact with domestic robots.

`"Robbie, could you move to the living room?"`

`"Hi Mike. I am moving to living room now"`

`"Hi Mike. I am in the living room now. What do you want?"`

`"Could you show me the Christmas tree in living room?"`

`"I am looking at the Christmas tree now. Is the view okay?"`

`"Can you move to the left a bit?"`

`"Ok"`

`"Thanks Robbie. It's fantastic!"`

Dec. 23, 4pm, Sharing through IM

While Jason is working in his office, a colleague sends him an *IM* message, saying that he would like to visit Jason's home after finishing the work at 6pm. Jason realizes that the floor of his living room is dusty and he does not want to welcome his colleague like that. Hence, he looks for Johnny on his *IM* and finds that Johnny is now available. Then, Jason starts the following *IM* conversation with Johnny:

```
"Johnny, can you help to clean the living room now?"

"Sure, I will clean it and let you know when it is done."
```

Jason goes back to work. 30 minutes later, Jason receives a message from Johnny, saying that

```
"Hi Jason, I have finished cleaning the living room.

Later, Robbie will send you a photo of confirmation".
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He takes a look at Robbie's status on *IM*, which shows "busy taking a photo of the living room." One minute later, Robbie sends a photo to Jason, and Jason can then ensure a cleaned living room before welcoming his colleague.

Figure 2.4: Using SMS interface to interact with domestic robots.

Dec. 24, 8am, A Urgent Task by SMS

Early in the morning of the Christmas Eve Party, Jason is on a bus heading to work, and suddenly remembers of some leftover food he dropped after breakfast. His guests may reach his home soon after him, and he may not have time to clean the food. Jason immediately uses his cell phone to send an *SMS* to Johnny about this, see Figure 2.4. Soon after that, Johnny acknowledges Jason with an *SMS*; ten minutes later, Johnny sent another *SMS* to Jason to inform him of the task completion.

The scenarios above exemplify how users may interact with their robots with social media platforms. Our proposed approach can hide complicated operations and command sets, enabling users to effectively communicate with robots via natural language like communicating with human. Although the characters and stories are imaginary, all tasks and interfaces have been developed in our system and can work in the simulated home environment in our laboratory.

Chapter 3

Related Work

With the advance in robotics technologies, robots have started to enter our home [90]. A great deal of work has focused on the area of HRI. Our work uses social media platforms to interact with domestic service robots, mostly in a remote (non-collocated) setting. Figure 3.1 shows the classification of existing work related with our proposed technique.

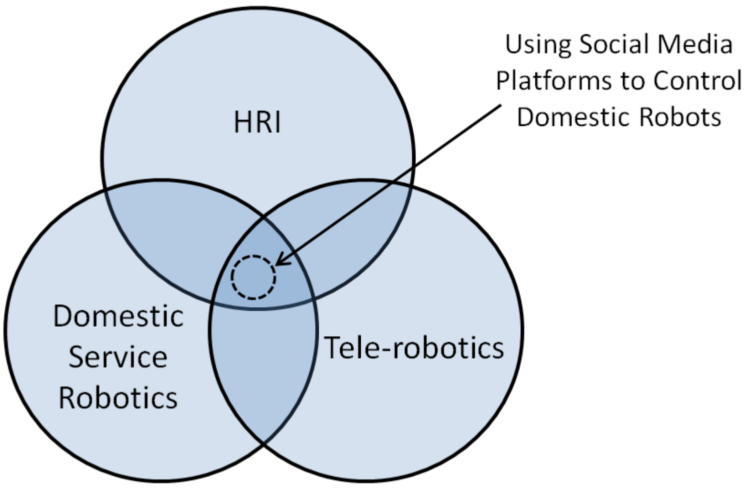

Figure 3.1: Classification of the related work.

In the followings, several different aspects of human-robot interaction are reviewed.

3.1 Different Approaches for Human Robot Interaction

The earliest method for Human Robot Interaction(HRI) was achieved through physical touch on touch screen or pressing on buttons on a robot. People have explored a lot different communication medium to support interaction between human and robot. Asoh *et al.* [8] introduced a spoken dialogue based interface with multiple speech recognition processes to support interaction with an office robot. In [44], Jiang *et al.* proposed methods of using speech and facial emotion as the medium to communicate with a robot. Waldherr *et al.* [98] and David *et al.* [54] presented the implementation of their gesture recognition based interaction with robots. Recently, motivated by the needs to support more natural human robot interaction, building multi-modal interfaces has become an active research area. In [71, 78, 74], HRI was supported by both gesture and speech based interaction.

A lot of researchers also put efforts on learning the ethnographic aspect involved in human robot interaction. In [40], Hayashi *et al.* did a field study at a train station with multiple humanoid robots to identify the most effective way of informing users and attracting users' attentions.

3.2 Research in Domestic Service Robots

A number of characteristics make research in domestic robots distinctive among other robotics fields.

- First, being domestic sets the special context, as opposed to being military, industrial, or medical. Home is a personal space where people's everyday life unfolds. People at home are not merely users, but rather individuals and families in co-habitation with technology. The material culture, everyday domestic practices, and intimate social nature make home vastly different from other worlds such as laboratory, factory, hospital, or battlefield [22].
- Second, being "robots" sets it apart from other types of electronic devices such as "desktop computers" or "home appliances". Unlike any stationary devices, robots actively and physically share spaces with people and display a level of autonomy and intelligence. Interacting with robots is more like interacting with a living entity instead of a static machine [90].

With the emergence of domestic service robots in consumer market, a growing number of researchers started to investigate into this field. Some researchers focused on the technical aspects of domestic robots [48, 26, 57, 73], while others study the actual use of domestic service robots (a majority of them focused on the vacuuming robot, Roomba), to provide understanding of how design can influence human-robot interaction in the home [14, 21, 22, 52, 91].

Extensive studies about human-robot interaction have also appeared in homes and schools [21, 93]. Sung *et al.* [91] conducted a study examining the emotional attachment of people with their Roombas. They found out that emotional attachments could help overcome technical unreliability and be the basis for a long-term (life) commitment to the product (also noted by [14]). Kim *et al.* [52] undertook a similar study, deploying five different vacuuming robots to homes in Korea in order to identify user trends that persisted across the robots. Some researchers focused on the implementation and algorithmic aspects of domestic robots, such as [48, 73].

Many researchers are also interested in designing novel interaction techniques to enable natural and intuitive HRI. Zhao *et al.* [108] proposed an alternative strategy for human robot interaction through implicit control. They designed a paper-tag-based interface where robots could discover the commands from these paper tags and complete the tasks in the background. Their system allows the asynchronous operation between human and robots while the existing methods only support synchronous interaction. Mistry *et al.* [64] designed a hands free interface for human interacting with robots. Users only need to gaze and blink in specified pattern to control a domestic robot. Shirokura *et al.* [81] developed a RoboJockey interface for coordinating robot actions. Their interface requires users to be familiar with their own predefined visual language. Work in this direction also includes the use of tangible objects such as toys [36], accelerometer-based Wii-mote [35], laser pointers [43], and sketching on a tablet computer [76] to control robots.

Moreover, researchers also worked on extending robot to other housework tasks beyond simple vacuum cleaning, such as [67] and [89].

Summary

Due to the special context of the home environment and cohabitant nature of human and domestic service robots, researchers have increasingly realized the importance of enhancing the social interaction between human and domestic service robots [90, 91]. While much research has attended to domestic service robots, none we are aware of so far explored the use of social media platforms to interact with domestic service robots. In addition, few worked on the design of such interfaces or interaction techniques, which motivated us to investigate into using social media platforms to facilitate both social and task interaction between humans and domestic service robots. Our proposed work aims at filling such a gap with a study on this topic with complementary social media interfaces.

3.3 Tele-robotics

The second category comes from the field of tele-robotics, which happens when the humans and robots are not co–located. With the explosion of the World Wide Web (WWW) and advance in Internet and wireless technologies, it provides a unique opportunity to connect robots to internet and enable people all over the world to control them and monitor their status. This category can be roughly divided into three separate but not necessarily mutually exclusive areas: 1)tele-operation, 2)tele-manipulation, and 3)tele-presence.

Tele-operation investigates the remote operation of robots. Most research in this area focused on tele-operation of robotic vehicles, see survey in [20]. One of the first Web-based tele-operation projects [31] involved a mock-up of an archaeological site situated in a radioactive area. Kaplan car [47] allowed a user to cotnrol the speed and direction of a remote control car using a video feed as guidance. WebDriver [33] and WITS [9] are examples of Vehicle tele-operation using JAVA over the Web. Kaymaz *et al.* [49] developed the interface on PDA to support teleoperation with a mobile robot through touch only based interaction. Lots of web based HRI systems such as [92, 84, 16, 30, 72] are developed. These systems collect information about the status of robots as well as information around them and then save them to server which will eventually be shown on the web where remote users could monitor. In addition to that, such systems also allow remote users to send commands to robots through the web and these commands will finally be sent to the robot by a server located near the robot.

Tele-manipulation, on the other hand, enables human to remotely manipulate objects via precise handling of robotic arms/hands/fingers by attaching sensors to human hands [80, 42, 66, 23, 106].

Finally, tele-presence offers immersive VR-like experience to the operators during the remote manipulation [68, 15, 41]. That is, tele-presence focuses on enabling realistic experience to remote environments as if the operators are physically there. Common practices in tele-presence are often associated with head-mounted displays and multimodal feedback [11, 65].

Interfaces used for remote robot control in tele-operation and tele-presence include direct operating the robots via hand-controllers (e.g., 3-axis joysticks to control direction and speed) while video feedback from vehicle-mounted cameras using either standalone software [37, 100] or via the web [85]. Head-mounted displays and multi-modal feedback can be used to increase the sense of remote presence [19, 56]. To support mobile interaction, Personal Digital Assistant (PDA) are also used as an interface devices [94, 101]. In tele-manipulation, interfaces often involves robust tactile sensing capabilities and tactile display devices[80, 79].

Summary

While research in tele-robotics is abundant(can trace back to 1970s), most center on industrial, medical, and military contexts to extend human activities to hard-to-reach or infeasible-to-stay places, e.g., other planets, deep sea or hazardous environments [53, 104, 38]. Few discuss the context of domestic setting, except [73], which studied the error handling issues, instead of primary interaction procedure. In addition, the interface and interaction methods supported by most traditional tele-robotics systems are either mechanical (e.g., joysticks) [83] or use point & click interfaces [55]. Such interaction methods, though being effective, regard robots as machines instead of "human-like" companions. As compared to industrial, military, or medical tasks, housework activities are often less complex but more relaxed. Users' responsibility, requirement, and feeling can be very different. For housework tasks, mobile and casual interaction is feasible and often more desirable [108]. Because in domestic setting, robots are often personalized and socially connect with their hosts, making it more desirable to explore more sociable and "human-like" interfaces and interaction methods. In addition, the social dynamics of interaction with domestic robots is also different. Studies have shown that domestic robots are often treated as another member of the house, much close to a companion instead of a working machine [24, 25]. Lastly, one common thing about all the existing methods is that there is always a new or customized interface created which users have to be familiar with before they can actually use them. Most of those interfaces require users to have some expertise or technical education. This will limit the usability and adoption of domestic robots among ordinary people because the owners usually do not have such technology background. When compared to previous work done in the field of tele-robotics, our work differs by aiming to support mobile, casual interaction as well as enhancing the social interaction between human and robots in the domestic setting.

3.4 Research in Social Media

Social media are media for social interaction, using highly accessible and scalable publishing techniques. Social media uses web-based technologies to turn communication into interactive dialogues [4]. Andreas Kaplan and Michael Haenlein also define social media as "a group of Internet-based applications that build on the ideological and technological foundations of Web 2.0, which allows the creation and exchange of user-generated content." [46] Social media has changed how people get information and communicate in many ways. We are not just consumers of media. With social media and new technology and tools, we also can easily make, change, and share media.

Social media can be categorized into six genres: 1) content creation and publishing, 2) content sharing, 3) social networking, 4) collaborative producing, 5) virtual worlds, and 6) add-ons [62]. Each of these genres has a main function, or in other words, a reason why that particular genre is used.

In [62], the following table summaries the social media genres and their main functions and shows examples of the various social media channels in each genre:

Social media genre	Main function	Examples of channels
Content creation and publishing	Production, publishing, dissemination	Blogs, wikis, podcasts
Content sharing	Sharing own content with peers	Flickr, YouTube, Delicious, Dopplr
Social networking	Keeping up old and building new network	Facebook, MySpace, LinkedIn
Collaborative producing	Creating content collaboratively	Wikipedia
Virtual worlds	Play, experience	Second Life, World of Warcraft, Aion, Eve Online, Habbo Hotel
Add-ons	Adding value to other sites	Google Maps, mashups

Table 3.1: Social media genres, functions, and channels.

Social media is a phenomenon of paradigm shift: passive spectators are becoming interactive participants [45]. First, people who were reading static websites started to require that the websites adapt to their needs and dynamically offer them content that they wanted to read. Second, people started to create content for the websites themselves in the form of comments, status messages, and photo and video uploads. On the other hand, not all people are equally interested in participating.

Social media are playing an increasingly important role as information sources for students, travelers, businessmen, and health care consumers etc. [10, 103, 87, 77, 39]. In recent years, there are a lot of work done in social media areas. Lenhart and Pempek investigated the social media use among teens or youth adults [58, 59, 70]. Black *et al.* [13] provided a pilot survey conducted to collect information on social media use in global software systems development. Their results show that social media can enable better communication through the software system development process. In [75], the authors investigated how social media affect museum communication. While Wright *et al.* [102] examined that the impact of social media on public relations practice.

The relationships of social media users are also been studied [28, 61]. Portions of analysis in [60] can be viewed as variants on the problem of link prediction [61] and tie-strength prediction [28], but in each case adapted to take the signs of links into account.

Summary

Social media creates an interactive two-way loop between the users and the technical communicators: the users can give feedback or author support content in a channel that is convenient for them, and the technical communicators can get the feedback or support content and use it for improving or adding to the company-created support content, after which the users can give more feedback or even more support content. Being different from the broadcast-based traditional and industrial media, social media has torn down the boundaries between authorship and readership, while the information consumption and dissemination process is becoming intrinsically intertwined with the process of generating and sharing information.

Given the continued interest and the ever-growing information and meta-information generated through social media, it is expected to continue enabling new exciting applications and revolutionizing many existing ones. In the following section, we will review some of these exciting work that rely on different social media platforms.

3.5 Using Social Media to Control Electronics/Robots

Studies on social media platforms in HCI mostly concern with human-to-human interaction [28, 97] instead of with robots or devices, except [18, 86, 50, 63]. Since our approach is to integrate interpersonal communication tools and social network into HRI, we provide the background information about each tool and examine some existing work on using such tools or network.

Short Message Service(SMS)

With the increased number of mobile subscribers over the whole world, SMS, which is an almost instantaneous communication medium, has gained large popularity. According to the report [69] written by Pastore M., SMS is now becoming an integral part of people's lives and aournd 15 billion SMS massages were sent over GSM wireless networks during December 2000. This shows that users manage their daily communication using SMS frequently. We therefore choose SMS as the communication tool to allow users to interact with their domestic robots. The approach has the following advantages:

- It relies on users' familiar interface, hence there is no extra burden for users to learn a new interface
- There is no context switch between software interface since all interaction could be finished just by their typical daily SMS activities

Authors in [51, 50] presented a design using SMS to control and monitor home appliances. However, there was no study about users' behavior on using such system. We, however, conducted a usability test and a controlled user study to learn about users' behavior on using SMS to interact with a domestic robot.

Instant Messenger

With the popularity of informal communication on the Internet, chat application such as Microsoft MSN Messenger [6], America Online's Instant Messenger [1], Yahoo! Messenger [7], and GoogleTalk [3] have changed the way how people communicate with each other. Such technology has made communication much more convenient than emails or phone calls. A survey done by Pew Internet&American Life [82] reveals that 53 million adults trade instant messages and 24 percent of them use IMs more frequently than email. Such popularity has motivated IM applications. For example, Microsoft is trying to integrate conversation robots or bots in their MSN Messeger system so as to allows users to enquiry about the status of robots anytime they want by just talking to it. These robots which is called "virtual buddies" are actually programs capable of interpreting user's query and generating answers to it. Such IM applications are becoming extremely popular among companies [5, 2]. Goh *et al.* [29] proposed an overall design on how to create a robot as a "virtual buddy" in MSN and focused on examining the linguistic features of conversational logs between human and robots. Sing *et al.* [86] looked at the impact and language usage of IM users chatting with conversational bots.

Our work considers a much more comprehensive scenario, in which we are creating the real robot as "virtual buddy" in users contact list of their Messenger and provide them with the easy control of their robot. In addition to that, we conducted a user study evaluating this interface and take a step further to gain insights into users' typical behavior of using such interactive method on a domestic robot.

Social network - Facebook

Mavridis, *et al.* [63] proposed to embed robots in Facebook, where a social robot is used to wander in the lab, attempting to talk to people it encountered. This robot obtained people's information via Facebook to enhance conversation and face recognition power. In a separate effort, a Facebook-connected desktop pet robot called "Pingo" (by Arimaz Inc.) was brought to the market; it can read Facebook updates, news, sing songs, and give weather forecasts.

Calendar based system

Users have become much more enthusiastic in using digital calendar, such as iCal, Google Calendar, Yahoo, Calendar, outlook Calendar. Developing algorithms to make a calendar an intelligent agent and studying users' preference on calendar system has become an active area of research. Faulring *et al.* [18] proposed an interactive system that integrates natural language interpreter, scheduling algorithm in Artificial Intelligence and groupware calendar tools to help with the difficult task of scheduling multi-person meetings. Melinda *et al.* [27] described an adaptive system PLIANT which is based on machine learning techniques to adapt to user's preference on using calendar systems. When user is making a schedule request, PLIANT will suggest a set of alternative solutions which is learnt over time from previous preference. PTIME [99] is a system prototype that was built to provide interactive assistance to user while maintaining a gradually updated profile of user preference to guide its scheduling proposals. In [88, 34], a study was carried out to learn about users' preference for using calendar system and a survey was conducted to study how users manage their daily appointment with such calendar system. The above techniques have only focused on improving the functionalities of calendar and learning about how users use such calendar system. In contrast, our system adopts a different thinking. We try to use calendar as a shared medium between users and robots such that users could interact with robots indirectly by interaction on their digital calendar system. The feedback or status from a robot could also be viewed through the calendar. An algorithm for proposing schedule for robots are also developed.

Summary

While these work leverages social media platforms, our work differs from them as follows,

- First, our system involves real autonomous robots, instead of virtual agents [29] or stationary machines [50]. Being "robots" sets them apart from other types of electronic devices such as "desktop computers" or "home appliances." More than these stationary devices, robots can share physical spaces with people and can take the initiative to display a variety of autonomy and intelligence over the information world as well as the physical world [91].

- Second, unlike entertainment and social robots, domestic robots play a dual role of doing housework and acting like human companions or even family members [105]. These distinguish our project from [63] and "Pingo," which employed Facebook only for socializing or entertainment.

- Finally, instead of leveraging with only one social media platform, we employ multiple complementary platforms, hereby offering users a choice on their preferred interfaces for different scenarios and tasks.

Chapter 4

Characteristics of Interfaces

This section reviews the characteristics and strengths of the four employed social media platforms so that we can see how these influence the user interaction:

4.1 Text Message Interface (SMS)

Characteristics. Text Message interfaces like *SMS* allow us to interact with robots by sending quick text messages. It takes relatively short setup time and can be done almost anywhere with basic cell phone network. However, most phone models support only short text-based messages in chunks without graphics and video communications.

Interface design. In our system, users only require one simple action in this interface, i.e., sending a text message to the robot's phone number. The robot can respond back with text messages to the users' phones, see Figure 2.4.

4.2 Instant Messenger Interface (IM)

Characteristics. Besides offline messages, IM allows near real-time messages with robots and checking of robot status through their icons on the IM contact list. Users can also request video communication so that we can see the happenings on the robot's side. However, these interactions typically need fast internet connection and a computer, or at least a netbook or a powerful smartphone to operate as compared to basic cell phones in the case of *SMS*.

Interface design. Our system leverages existing interfaces of common instant messengers (without additional interface elements) to interact with robots, see Figure 2.3. Users only need to add the robots to their contact lists. After that, they can communicate with the robots with text messages and/or video chat. Instant messenger can run on both desktop PCs and smart phones, e.g., Android phones. However, due to technical limitations, our current implementation on smart phone supports only text conversation without video chat.

4.3 Shared Calendar Interface (Calendar)

Characteristics. Very different from *SMS* and *IM*, shared calendars are designed for both individual and group to manage, plan, and overview working schedule. Interacting with robots via such interface allow users to manage robot tasks together with their own tasks. It also allows robots to check the schedules of family members to automatically suggest new events or changes to existing events in order to minimize distractions to their hosts' activities.

Interface design. Our system uses the Google calendar interface to interact with robots. Each robot has its own dedicated calendar, and users can add both one-time and recurring events to robots' calendars. Robot activity status is updated on the event description, see Figure 2.1. Unlike *SMS* and *IM*, Google Calendar does not support real-time communication as real-time data retrieval is prohibited by Google website, which usually takes a time lag of around 40 seconds between two adjacent data retrieval. It is therefore unnatural to use this interface to have real-time interaction with robots; we can regard it as a specialized interface best suited for task and event planning.

4.4 Facebook Interface (Facebook)

Characteristics. Facebook is a community-based social networking website designed for interaction amongst large group of people. Taking into HRI, it allows a large pool of users to interact with robots for social purposes, mixing robots' activities with human's. In addition, the viral and snowballing effect of Facebook can also promote robot adoption to more users. Lastly, Facebook can allow permanent public records like personalized journals for individual interactions, which is particularly useful for both social and research purposes, see Figure 2.2.

Interface design. A dedicated Facebook account is created for each robot. Users can connect with robots just like connecting with anyone else on *Facebook*, and interact with them by leaving messages on robots' wall. Feedbacks from robots are sent back via posts on users' wall. Just like the calendar interface, the Facebook interface does not support real-time feedback, which makes it unsuitable for assigning immediate tasks or performing real-time interaction with robots. (To prevent spamming, the Facebook website currently prohibits frequent and automatic updates). However, the unique features of *Facebook* make it a highly-social environment for interaction between robots and a large group of users.

4.5 Web Control Interface

Interfaces

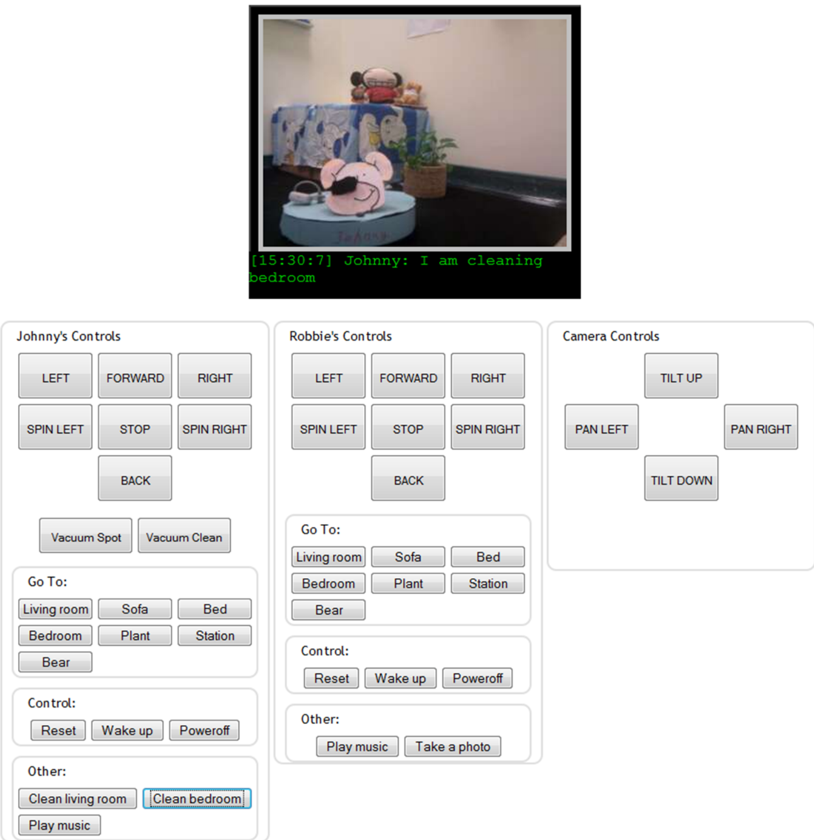

Figure 4.1: Web interface for interaction with domestic robots.

In addition to the four social media platform interfaces, we developed a point

& click web interface (*Web*) as a baseline for comparison. The *web* interface is created through augmenting the standard *roombacomm* control interface (see `http://hackingroomba.com/`). The design of the interface is similar to web remote robot control interface developed in previous research [32]. As shown in Figure 4.1, this interface supports live video feed with buttons and widgets for different robot tasks. Each robot has a separate control panel. Users only need to click on corresponding buttons to control the behavior of the remote robots. Note also that we have exhaustively put all different combinations of robot tasks in these buttons for the simulated home environment.

4.6 Comparison between Interfaces

	Short Message Services (SMS)	Instant Messenger (IM)	Web control	Shared Calendar	Facebook
Interactive Visual	No	Yes	Yes	No	No
Scheduling	No	No	No	Yes	No
Multi-user Social	No	No	No	No	Yes
Mobile	YES	No	YES	YES	YES
Devices	All mobile phones	PC	PC	PC or 3G mobile phones	PC or 3G mobile phones
Responsiveness	Immediate	Immediate	Immediate	Delayed	Delayed
Input/output	Text/Text	Text/(Text + video + image)	Clicking/(Text+ video)	Text/(Text + image)	Text/(Text + image + video)

Figure 4.2: Comparison on the characteristics of each social media platforms and the web interface

We have described four chosen social media platforms and the web control baseline interface in details from different aspects in the above sections. In this section, we will summarize the characteristics of each interface by putting them together. As shown in Figure 4.2, the comparison is made based on different dimensions of each platform.

Currently SMS does not support visual feedback and the message content is purely text. The unique feature about SMS is that usually it is attached to mobile phone, which makes it a suitable candidate to have communications with each other under different scenarios. For instance, users typically can send SMS while doing other things, such as walking. For SMS, the response is immediate which will be an advantage when the situation requires immediate response from the other side or an immediate action needs to be performed.

IM is similar to SMS, but it runs on local desktop PC or laptop, which usually have large screen. Visual feedback is supported on IM. It also has immediate response and great notification system. But due to the fact that it is often used on desktop or laptop, the mobility is greatly compromised.

Calendar interface is more narrow interface than other social media platforms, whose main purpose to serve users on their scheduling tasks. There is limited feedback from currently calendar interface and the response is often delayed. The feedback is also in purely text due to the nature of the interface.

Facebook interface has the unique feature which captures the scenarios of multiple users socializing with each other. It has several different kinds of feedback, such as text, photos or even videos. However, due to the inherent design logic, the response is not immediate either since it is more of a asynchronous communication most of the time. Since it can run on both local desktop or mobile platforms, such as smart phone, it also can support a wide range of scenarios.

Web interface, which is put here as a baseline interface, is more static in a way compared to the above four social media platforms. It has both visual and textual feedback. Fixed set of buttons are configured which puts an obvious limitation on the flexibility of users' inputs format.

Overall, each interface has its own unique features. In Chapter 6, we will investigate the connection between these features and users' choice of preferred interfaces for human robot interaction under different scenarios.

Chapter 5

System Implementation

In order to learn how our proposed social media platforms based human robot interaction works in reality and gain more insight into this new interaction paradigm, we developed a fully functional system. In this chapter, we will show the following aspects about our system: 1) Conceptual design of the system, 2) Design of system components, 3) Data flow diagram of the system, 4) Server side hardware setup, 5) Connect social media platforms to the centralized server, 6) Tasks supported by robots.

5.1 Conceptual Design of The System

We implemented our test-bed system based on a client-server model with a server PC connected with the four social media platforms (client side with the users) through the Internet, WAP and GSM network, see Figure 5.1.

The client side includes all the four social media platforms that we selected to support interaction with our domestic robots. From users' point of view, these

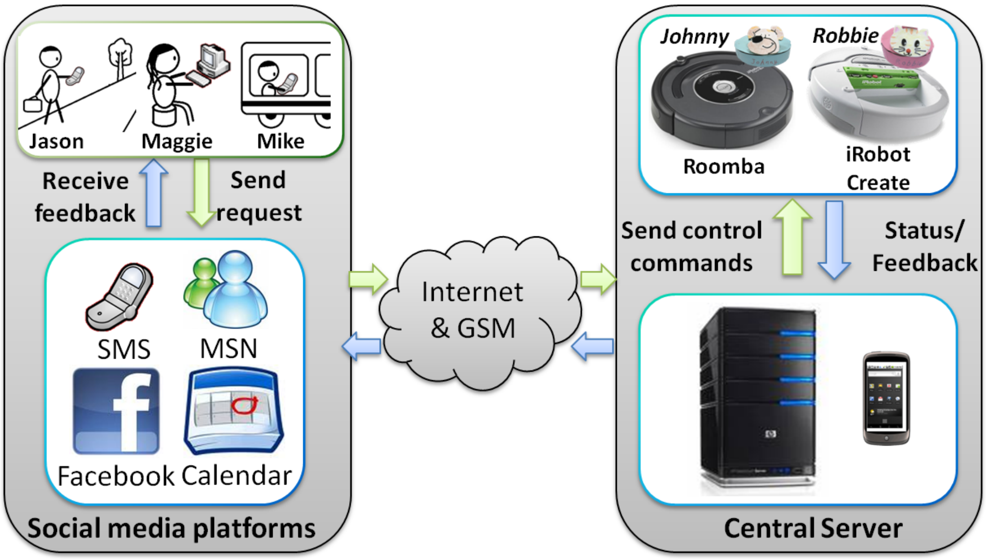

Figure 5.1: Using social media platforms to interact with Domestic robots.

social media platforms are exactly the same platforms they use everyday. It is just that they now have two more robots in their contact lists. They can talk to them by typing text into these platforms in the same way they talk with some people. The robots' messages will also be shown on these platforms just as some people have left them a message.

In the server side, we have a dedicated centralized server which serves as the agent to handle all the communication between different social media platforms and our two domestic robots. Users interact with robots by sending and receiving messages to/from the social media platforms. The centralized server is connected with the four chosen social media platforms through Internet and GSM. Our two robots are co-located with the centralized server and they are connected to the robots through Bluetooth connection and local wireless connection.

5.2 Design of System Components

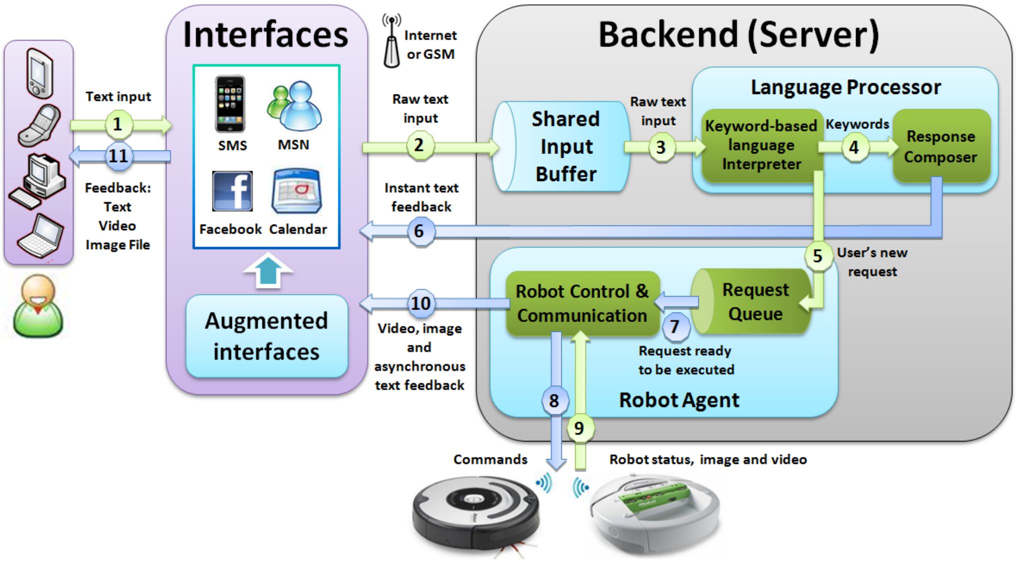

Figure 5.2: Data communication flow of the system

To make our system more robust and flexible, we have come up with a detailed system components level design. As shown in Figure 5.2, there are three key components in the system: a) Shared Input Buffer (for raw input) b) Language Processor, and c) Robot Agent. All three components run on the centralized server. The main functionality of each component is summarized as follows,

- Shared Input Buffer

  In the system, all the messages sent from different interfaces will be forwarded to the sever end. Since there might be multiple users using different interfaces to control the same robots or multiple messages from robots that will be sent back to users' social media platforms, we developed a shared input buffer to manage and store all these messages in a queue. Hence, our system will be able to handle multiple people talking with robots through different social media platforms simultaneously and synchronize robots' status message with each other as well.

- Language Processor

  To support textual communication with robots, we designed and implemented a simple natural language processing (NLP) algorithm that breaks an input sentence into words, and matches the words with keywords from the following four categories, in descending priorities: task action commands (e.g., vacuum), general contextual (such as task starting time, name of the robots and place, which direction to go), general inquiry (e.g., what's your schedule?), and socialization or greeting (e.g., hello). It also includes one extra default category to deal with undefined keywords.

  The detailed design of our NLP algorithm is illustrated in Figure 5.3 and the pseudo code of the actual implementation is shown in Figure 5.4. The algorithm takes the input sentence, our predefined keywords for each category as input. It will go through the four categories from the highest priority to the lowest priority. From the line 2-8, the input text is defined to contain a task set and we first extract the task set and further retrieve the associated contextual information with those tasks. For instance, if we find the keywords "clean" and later we locate there is contextual information "**Johnny, bedroom, and 5pm**", then we know the task is asking Johnny (our vacuuming robot) to clean the bedroom at 5pm. That is, the system is trying to interpret the commands as complete as possible from

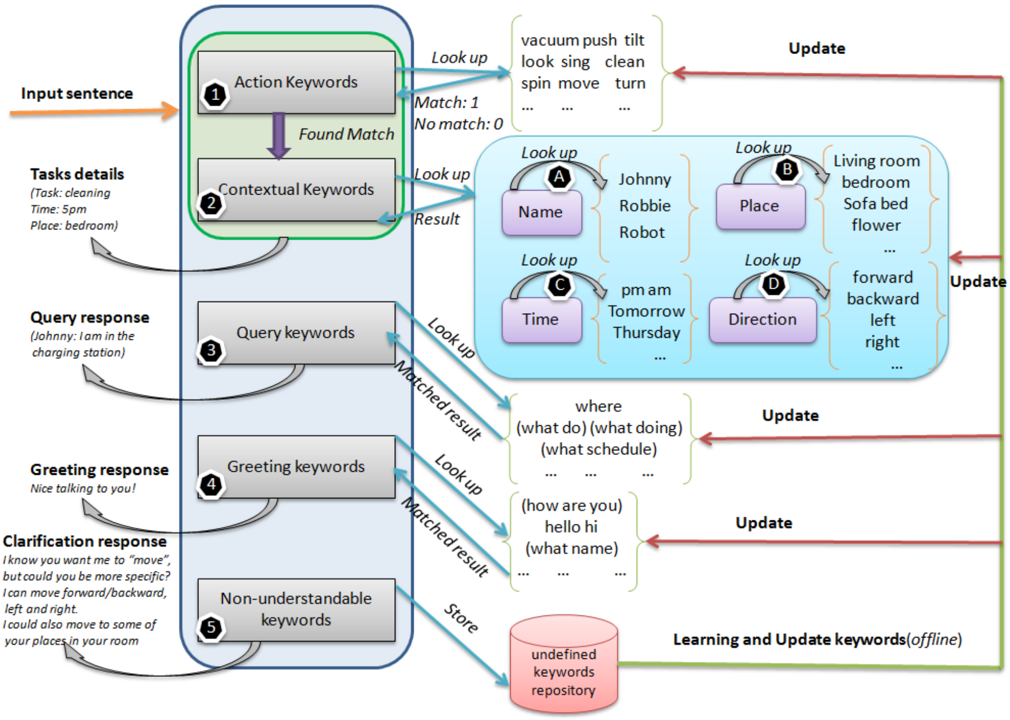

Figure 5.3: Conceptual design of NLP algorithm

users' raw text message. In addition to that, the system will compose the text response based on the extracted keywords information which will later be sent back to users. This is to make the feel the robots is talking with them like human being. If the users' message does not contain any action task related information, then line 9-13 will execute if the sentence contains keywords which lies in the general inquiry keywords set. It will also generate the response based on the keywords extracted. Similarly line 14-18 will be executed if the sentences are interpreted general greeting or socializing with robots. Line 20-22 will execute if the sentence does not any of the predefined keywords of the four categories. This sentence will be saved to our local data repository. This data repository will be further used to do analysis and update and extend our previous predefined keywords set.

Algorithm: NLP

Input: raw text sentence ***S***, predefined action keywords ***Ak***, predefined contextual information keywords ***Ck***, predefined query keywords ***Qk***, predefined greeting keywords ***Gk***

Output: text response ***T***, interpreted commands set ***C***, contextual information ***I***, query keywords ***Q*** *and* greeting keywords **G**

```
C = {}, T = {}, I = {}, Q = {}, G = {}
if (isContainActionKeywords (S, Ak)){//keyword match between S and Ak
   Add matched keyword to C;
   if (isContainContextualKeywords(S, Ck)) // keyword match between S and Ck
      Add the contextual keywords associated with the commands to I;
T = composeResponse(C, I); //generate human understandable feedback message for users
Return;
}
if(isContainQueryKeywords(S, Qk)){
Add matched query keywords to Q;
T = composeResponse(Q);
Return;
}
if(isContainGreetingKeywords(S, Gk)){
Add matched Keywords to G;
T = composeResponse(G);
Return;
}
//Default – no predefined keywords is found in the sentence
storeToDatabase(S);
T = composeResponse(NULL);
Return;
```

Figure 5.4: pseudo code implementation of NLP algorithm

Performance Analysis In our user study, we tested the performance of how well this algorithm works on 685 sentences generated from 12 users and it can correctly interpret 593 sentences with an accuracy of 86.57%. In addition, if a sentence was not understood, this component will send notification and instructions as responses to guild users on how to communicate their ideas to the robots. Our algorithm is not case-sensive since we have changed the entire text message and keywords set to be in lower case. Therefore, users have more flexibility on typing messages for robots.

However, according to our design of the algorithm, we can foresee once a sentence is determined to belong to one category, it will not be further considered for next keywords category with lower priority. This would limit users input flexibility to talk information which across different categories. In our future work, we want to address this problem by making the NLP algorithm more robust to handle the case when one sentence contains more than one category of keywords.

- Robot Agent

  The component is mainly responsible for communicating with and controlling the robots through wireless connection (including both *WIFI* and *bluetooth* connection). Considering there might be multiple commands for robots being received at one time, a queue is built for buffering those commands. This component translates every single command into machine code and sends it to robots through Bluetooth connection. The robots' sensor data or any feedback will be sent back to this component as well. It will forward these feedback message (such as video feed, photos from robots) to client side.

5.3 Data Flow Diagram of The System

A detailed data flow diagram of system is also shown in Figure 5.2 which illustrates how the data or message flows in the system for one typical interaction between human and domestic robots. The flow of data communication among different components we see earlier is also indicated by the numbering and arrows in Figure 5.2.

In step 1 and 2, users talks with different social media platforms by entering the text and the raw text will be buffered at the server side.

In step 3 and 4, messages in the buffer are then forwarded in the order of arrival to the keyword-based language processor for natural language processing into a set of commands. The language processor component is also responsible for generating text response to user according to the keywords in the text input or the status update message from Robot Agent component.

In step 5 and 7, the interpreted commands set generated from language processor module will be sent to robot agent module.

In step 6, the human understandable text response will be sent directly to social media platforms so that users can know robots are making response instead of keep them waiting for a long time.

In step 8 and 9, the robot agent component sends commands to the domestic robots as well as receiving feedback messages from them.

In step 10, the feedback messages from robots, whether it is purely text, image or video, will be sent back to corresponding social media platforms for users to view.

5.4 Server Side Hardware Setup

Our server side is an simulated home environment which is the essential part of the whole system. Figure 5.5 overviews our hardware setup on the server side. We have two robots (*iRobot Roomba* and *iRobot Create*), two Logitech

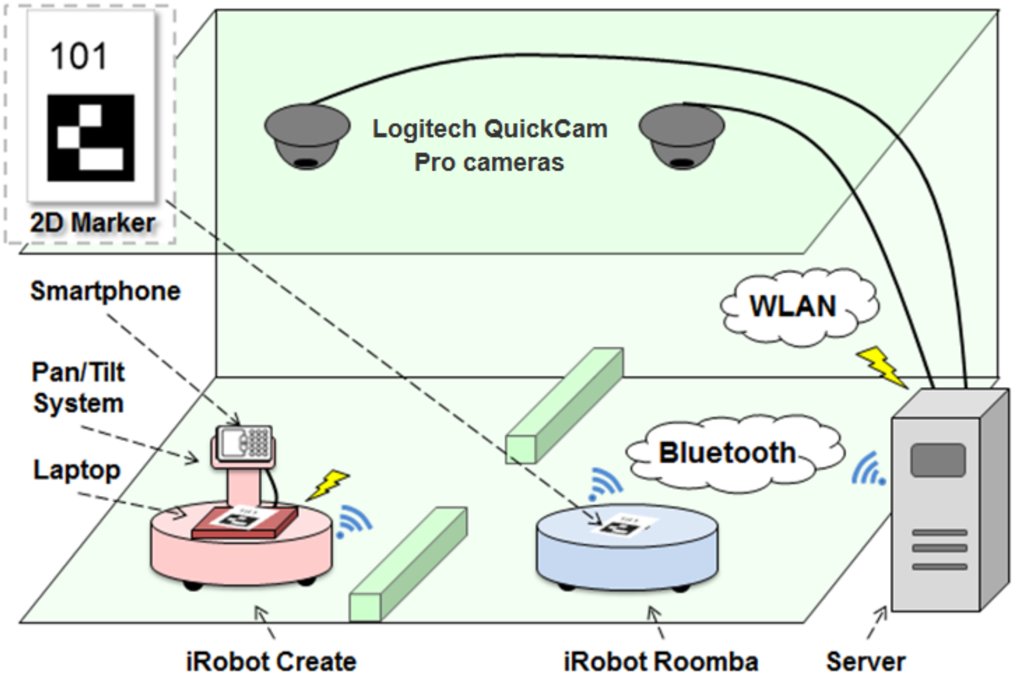

Figure 5.5: Hardware setup for the server side.

QuickCam®Pro cameras installed 2.5 meters above the floor, a dedicated server PC connecting to the two cameras through USB, a CrustCrawler S3 Pan/Tilt device with two degrees of freedom (2-DOF), a Fujitsu UH900 laptop, a Creative Live webcam on Notebook, and an Nexus one smart phone running Android 2.2.

The two cameras on the ceilings help to track and monitor the robots' location in this simulated home setting by using vision-based tracking method [108] to recognize the markers on top of the robots, see Figure 5.5.

The two robots are products of *iRobot* Corporation: One is a customized *iRobot Create* and the other one is a vacuuming *Roomba 560*. In our system and experiment, we call them Johnny(vacuuming robot) and Robbie(surveillance robot). Figure 5.6 shows how we customize Robbie and personalize both robots.

The Creative Live webcam is connected (co-located) to the Fujitsu laptop for supporting user requests on video chat with the robot via *IM*, see Figure 2.3.

The Nexus one smart phone is also attached to Robbie which has three main purposes: 1) Taking photos using its inherent camera, 2) Receive users' *SMS* message through GSM network and forward this message to the server for further analysis and processing, 3) Receive server's message through local wireless network and forward this message to corresponding users' cellphone through GSM network.

Both the Creative Live webcam and Nexus one smart phone are mounted on the CrustCrawler S3 Pan/Tilt device over Robbie so that Robbie can show different views to remote users.

The UH-900 Fujisu laptop is used here to run programs controlling the S3 Pan/Tilt device by sending information through standard COM port. In addition to that, it also buffers the video stream captured from the webcam and sends it back to users when needed.

5.5 Connect Social Media Platforms to The Centralized Server

Since our proposed infrastructure system for human interacting with domestic robots completely relies on existing social media platforms, we show here how our server connects with the four different social media platforms in our implementation.

***1) SMS* Interface.** To enable the *SMS* connection with the robots, we program the Nexus one smart phone (co-locate with the server) to send-and-receive *SMS*

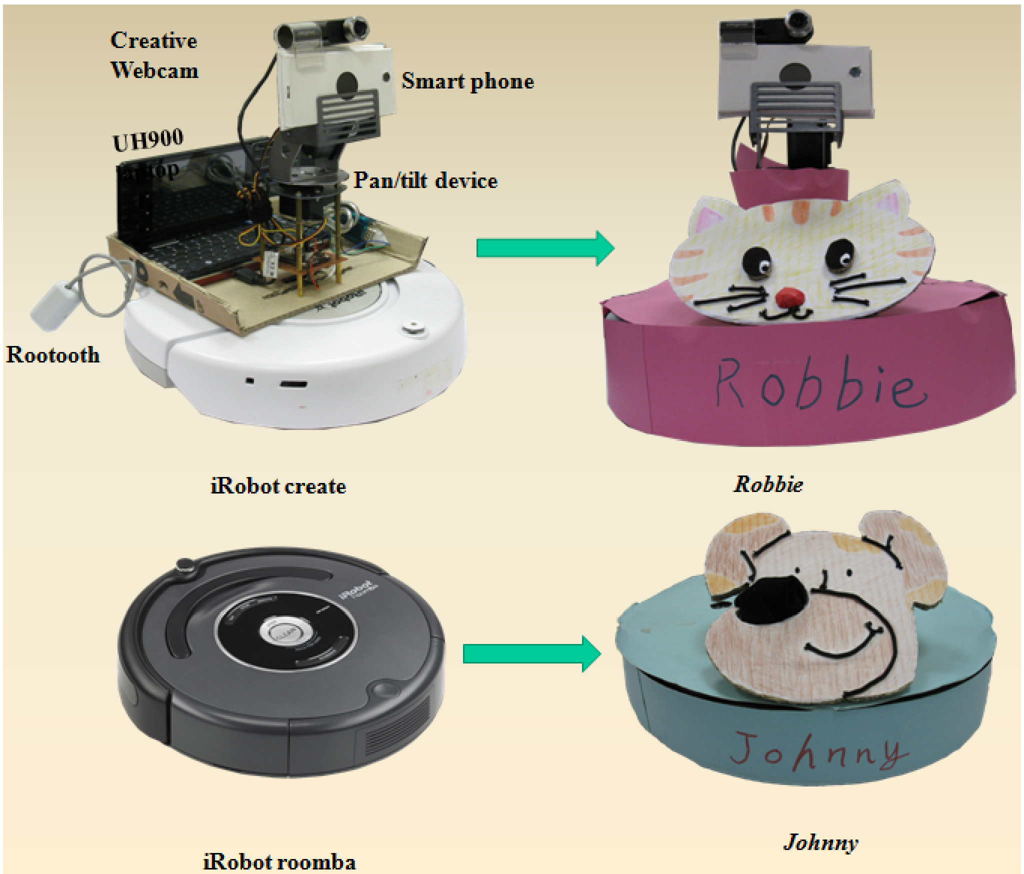

Figure 5.6: Customization done on the robots

messages with users' cell phone via standard GSM, see Figure 5.7. In addition, we use local wireless network to connect this phone to the server. Hence, the users' cellphone is indirectly connected with the server through the Nexus one smart phone. That is, users send message to robots' phone number which will be received by the smart phone. Upon receiving this message, it will forward this message to the server. If any response or feedback is sent out from server to the smart phone, it will send back this message to users' cellphone, see Figure 2.4

***2) IM* Interface.** As shown in Figure 5.8, an open source project called MSNPSharp (MSNP18 Release: 3.1.2 Beta by Xih Solutions) is used to de-

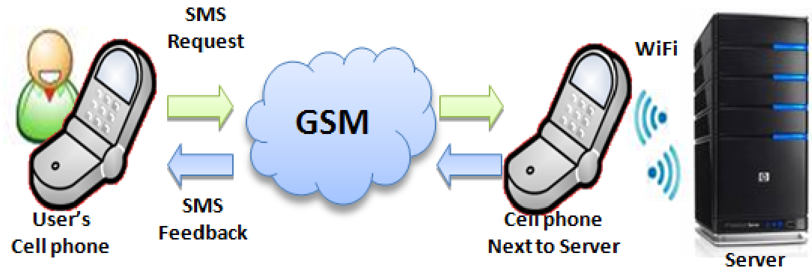

Figure 5.7: SMS interface implementation of the system

velop an *IM* client program running on the server PC to communicate with the user's *IM*. By using the open protocol, we can capture the message that was sent to our robots from users' *IM* account and also send back messages from server to users' *IM* account. The video from the Creative Live camera on Robbie is sent to the client's *IM* when required, see Figure 2.3.

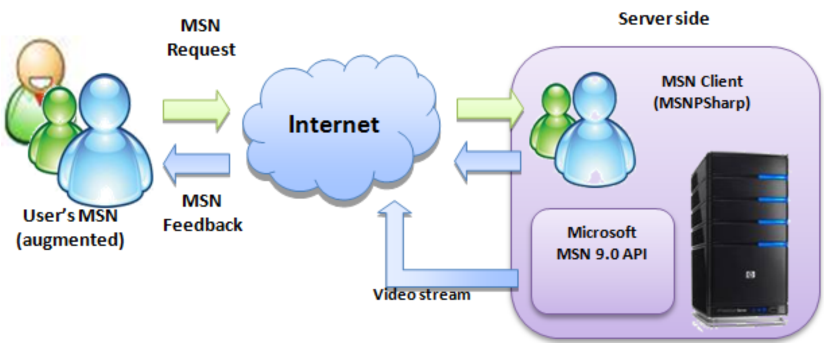

Figure 5.8: IM interface implementation of the system

***3) Calendar* Interface.** We implemented the shared calendar by using Google calendar data API 2.0 to build a client agent. Figure 5.9 shows how the calendar interface is implemented in our system. It runs also on the server PC to communicate with the Google calendar website. Since the Google calendar website will not inform our server PC upon user update, we implemented the standard pull technology on the client agent to periodically retrieve data from the calendar server hosted on the Google website. The server will update the corresponding calendar entry with feedback information from robots through the same API, see Figure 2.1.

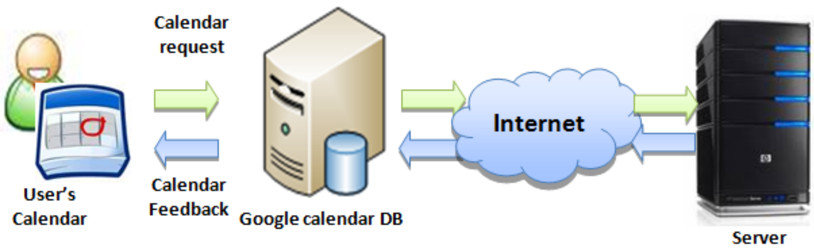

Figure 5.9: Calendar interface implementation of the system

*4) **Facebook*** **Interface.** Using the official Facebook Client Library (facebook-0.1.0), we built this interface as a Facebook application running on the server PC. Using this library API, our application can update robots' status, query updates on the two robots' Facebook wall posts periodically at every 90 seconds, and can also publish text and photos on users' wall if related permission has been granted, see Figure 5.10. Hence, robots can know the sender's identity and the message contents, and then respond to them in an appropriate way according to the received content, see Figure 2.2.

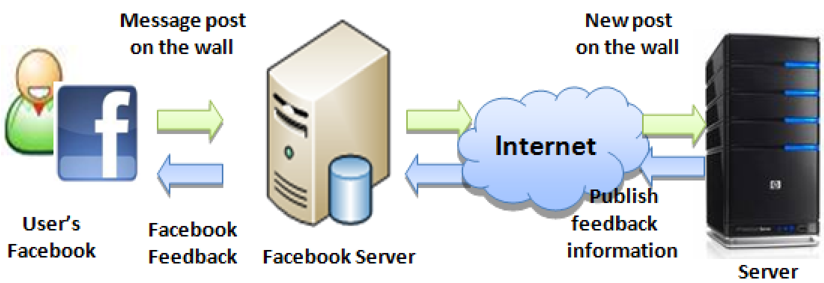

Figure 5.10: Facebook interface implementation of the system

5.6 Tasks Supported by Robots

Robbie	- move to any reachable place in home environment - Take a photo of one spot in the home and upload to Facebook album if required - Perform task at a scheduled time - Move to somewhere to sing a song and wake up someone - Deliver one object from one position to anther position
Johnny	- clean/spot any reachable place in home environment - Perform task at a scheduled time - Deliver one object from one position to anther position

Figure 5.11: Tasks supported by the two robots.

While we are proud of our prototype system, we are also aware of its limitations. The robots in our testbed system are simple iRobots that can only run on flat surfaces with limited support for housework tasks. Our current vision-based tracking system works reliably only in laboratory environment. However, our focus in this thesis is to explore the feasibility and potential of this novel interaction paradigm. The current prototyping system is sufficient to allow us to evaluate and investigate into the potentials of the proposed social media platform interfaces. Figure 5.11 shows the tasks that our robots can perform in our current implementation.

Chapter 6

User Study

As an exploratory concept, we are particularly interested in finding out answers for the following set of questions.

- First, how do users generally feel about our approach? Since users' experience of social media platforms is mostly between humans, will they feel comfortable or awkward to using these platforms to interact with robots?
- Second, are these social media platforms intuitive and easy to use for communicating with robots?
- Third, what are users' views on the strengths and weaknesses of these interfaces and how do they affect users' preferences in using these interfaces?
- Finally, can the use of social media platform interfaces increase the perception of robots being more human-like and sociable?

To answer the above questions, we conducted the following user study.

Participants

Freq. of use	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	Summary
SMS	3	3	1	3	3	1	2	2	3	2	3	3	Avg. 2.42
IM	3	3	3	2	3	3	3	3	3	2	3	1	Avg. 2.67
Calendar	1	3	2	2	0	0	1	1	0	0	1	0	Avg. 0.92
Facebook	2	2	2	3	3	3	2	2	2	2	3	2	Avg. 2.33

(Participant ID)

0:never, **1**: at least once a month, **2**: at least once a week, **3**:everyday

Figure 6.1: Participants' prior experience on the four platforms.

Twelve participants (6 females and 6 males, aged 19 to 30; mean 24.4, median 24.5) are involved in the user study. Among them, 9 are from the university and 3 are from the community (working professional). Figure 6.1 summarizes their prior experience with the four employed social media platforms. Each of them took around 2 hours in the user study and received 20 US dollars after the study.

Environment and Apparatus

Client: Two types of client machines are used: laptop PCs and mobile phones. The laptop PC is an Acer TravelMate 3002 WTMi, and the mobile phone is an HTC Nexus One running Android 2.2 operating system. The implementation of each software interface is described in previous section.

Server and robots: The setup is described in the Chapter 5, and we conduct the experiments in two different close rooms and an open hallway.

The five interfaces (the four social media platforms and the web interface) have different characteristics (see Figure 6.2). The four social media platforms use natural language as the main interaction method while *Web* uses *point &*

	mainly text input	mainly point & click	text feedback	image, video feedback	immediate feedback	short setup time	history of interaction	overview of tasks	share with group	good notification	anywhere access
SMS	x		x		x	x				x	x
IM	x		x	x	x		x			x	
Calendar	x		x				x	x			
Facebook	x		x	x			x		x		
Web		x	x	x	x						

Figure 6.2: Features and characteristics summary for each interface used in the use study.

click. *SMS, IM,* and *Web* interfaces support real-time (or near real-time) feedback, while Facebook and Calendar do not. *IM, Facebook*, and *Web* support images and video feedback but not *SMS* and *Calendar*. These interfaces are also designed for different purposes and scenarios, e.g., shared calendar is mainly for task scheduling while Facebook is good for social interaction with many people, etc. Given the different characteristics of each interface, we are interested to find out users' preferences in using them under different conditions which will be described in details later.

6.1 Study Design and Procedure

We designed two separated parts in the user study:

Part 1 is a general usability study for all five interfaces. *Part 2* is a 3x3 controlled study on the three real-time feedback interfaces (*SMS, IM,* and *web interface*) under three different conditions. Note that since *Calendar* and *Facebook* do not support real-time feedback, they are excluded from the second part of the study.

Part 1: overall impression and general usability of the five interfaces.

The purpose of part 1 of the study is to learn the overall impression and general usability of the five interfaces as well as to provide training for the second part of the study. Each participant had to perform a task for each of the five interfaces in a random order without any prior training, see the task list below.

1. *Send an SMS to Johnny's phone number to ask Johnny to vacuum your living room now*
2. *Talk to Robbie through IM and instruct Robbie to help find your wallet you dropped earlier in your bedroom*
3. *Control Robbie through the Web interface to help you find the notepad you left in your bedroom*
4. *Use Google calendar to schedule a task on Johnny: vacuum your bedroom at 3pm via a given URL*
5. *Use Facebook to ask Robbie to take and upload a photo of your plant and then share it with your family members*

For each task, the participant was given a 2-minute time limit. If he/she failed to complete the task within this limit, the experimenter will demonstrate the procedure to him/her and ask him/her to complete it again. By not providing any hints to users initially, we hope to test the walk-up usability of the interfaces. However, we do ensure users will finally know how to use each interface during this section since it also serves as a training section for the remaining parts of the study, see Figure 6.3-(a).

Part 2: 3x3 controlled study

The purpose of part 2 is to understand users' performance and preference when interacting with robots via three real-time feedback interfaces: *SMS*, *IM*, and *Web* under three different conditions: *single-tasking, multi-tasking*, and *walking*. Participants were asked to go through these three conditions in an order of increasing difficulty: *stationary single-tasking, stationary multi-tasking,* and then *walking*, while the order of interfaces within each condition is randomized to counterbalance the ordering effect. During the experiment, once a user finish one condition, they will fill out a questionnaire to help us collect some qualitative information about each interface's advantages and disadvantages. Each interface will also be ranked by participant based on his/her preference to use it under one type of conditions. At the end of the experiment, there will be a 15 minutes interview to ask users to share with us their general feeling toward each interface after trying out the system as well as their concerns and suggestions.

Conditions

1) Single-tasking condition. In this condition, participants can just sit in front of a computer to perform a single given task with his/her full attention. This condition simulates a basic environment in office like setting, see Figure 6.3-(c).

2) Multi-tasking condition. In this condition, participants again sit in front of the same computer as in condition 1 but they have to interact with robots as the secondary task while performing a primary task at the same time. This condition aims to simulate a usual situation in office where we have to attend to regular office work while interacting with others, say domestic robots. Here we adopt the low intensity multi-tasking condition from Birnholtz et al.'s study [12] by asking the participants to identify differences (as many as possible) between two images on the computer screen (primary task) while performing the robot interaction tasks at the same time, see Figure 6.3-(d).

3) Mobile Walking Condition. Walking is a representative on-the-move scenario [107]. Since using mobile devices while walking is very common today, this condition has important practical value. The participants in this condition were asked to walk in an open hallway (25 meters long and 2.5 meters wide) with regular walking traffic. They had to walk back and forth in the hallway with normal walking speed while interacting with a robot via their cell phones, see Figure 6.3-(b).

Domestic Tasks.

In each condition, participants were presented with all three interfaces in random order. For each interface, users were asked to interact with robots to complete a domestic task which consists of 3 steps. Instruction for each step is shown only after the previous step is completed by the robot. A sample domestic task is illustrated below.

- Step 1: Please instruct Johnny (the vacuuming robot) to vacuum your living room
- Step 2: Please instruct Robbie (the surveillance robot) to go take a photo of your plant in the bedroom and share it with your friends.
- Step 3: Please instruct Johnny (the vacuuming robot) to vacuum your bedroom.

Figure 6.3: User study procedure (a) shows user is doing the usability test in room A; (b) shows user is performing interaction with domestic robots while walking in the hall way; (c) shows user is interacting with robots in Room B under both single-tasking and multi-tasking conditions; (d) shows the primary task used for the multi-tasking condition, which is a game that requires user to spot all differences between images

Overall Procedure.

Upon arrival, each participant was first taken to the room where our server system resides. Part 1 of the user study and pre-study questionnaires were carried out in this room where participants can interact with the interfaces while seeing the tasks being carried out by the robots. After part 1, they were taken to a separated room away from the robots to simulate a remote interaction scenario. After the first two stationary conditions, they were further taken to an open hallway to work on the tasks in the mobile walking condition. After part 2, they were then brought back to the first room to complete the post-study questionnaire and interview. The entire study including questionnaires and interviews is performed at one sitting, including breaks, in around 2 hours.

6.2 Results and Discussion

Part 1: Overall impression and Interfaces' usability.

Most participants are very positive and excited about the idea of using social media platforms to interact with robots. They described their general feeling as *"exciting," "eyes-opening."* They found it *"very cool to be able to communicate with robots anytime, anywhere with their cell phones"* and *"especially entertaining to see robots having their own IM account and Facebook profile page."*

Participants find interacting with domestic service robots using these common social media platforms a natural and intuitive idea. All participants can complete assigned tasks using all interfaces in a short time (within 2 minutes) without prior training or help from the experimenter (except one participant failed the assigned task with Facebook).

Participants commented that *SMS* and *IM* are the easiest to learn and use, since all of them have significant prior experience in using them (see Figure 6.1). Interacting with robots using *Facebook* and *Web* interfaces are also easy and intuitive, but participants commented that both interfaces look slightly more complex than *SMS* or *IM*, which require additional learning time at the beginning. A number of participants (5 out of 12) have never used Google *Calendar* before, so they require additional time to figure out how to use the interface. However, once they learnt it, all of them found the five interfaces to be intuitive and easy to use.

There are two subjects who expressed their privacy concerns about people viewing video and image data from the surveillance robot on Facebook, but no such feelings have been expressed for other interfaces. Before domestic robots become smart enough to understand the rule of behavior in human-dominated world, one potential solution is to give more consideration in privacy control when designing the interfaces.

Part 2: 3x3 controlled study

Task completion time and completion rate

Since all participants can successfully complete the tasks, there are no differences in task-completion rate across all the 33 cases. We will focus on the task completion time for each interface and condition in Part 2 of the user study (Figure 6.4). Task completion was measured from the moment a task instruction was given to the participant up to the time the participant received the final notification message from the robot that all three steps of the task have been completed.

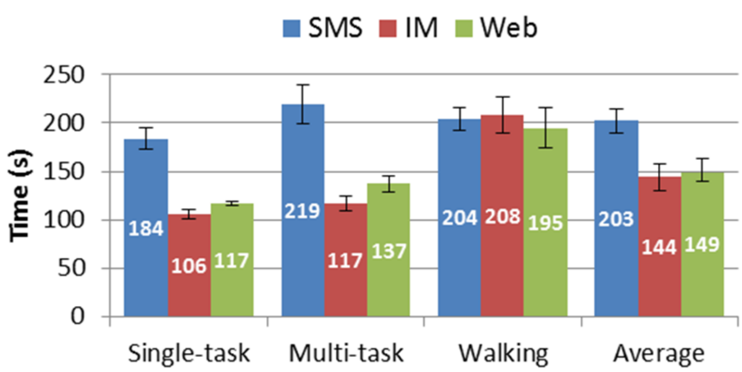

Figure 6.4: Task completion time (sec.) for the three interfaces under various conditions. Error bar shows the standard error.

Among all combinations of conditions and interfaces, repeated-measure ANOVA analysis showed that there was a significant main effect on *interface* ($F_{2,22} = 21.48, p < .001$). Pairwise t Tests (LSD) showed that *SMS* (202.56 s) is significantly slower than either IM (143.83 s) and Web (149.47 s) (both $p < .001$). However, *IM* and *Web* were not significantly different from each other ($p = .51$). There was also a significant effect on condition ($F_{2,22} = 23.74, p < .001$). Pairwise t Tests (LSD) showed that all three conditions are significantly different from each other (all $p < .01$), with single-task condition being the fastest (135.8 s), followed by multi-tasking condition (157.7 s), and then walking condition (202.35 s). There was a significant interface x condition interaction effect ($F_{4,44} = 11, 93, p < .001$). Examining the data in more detail reveals that the performance of *SMS* does not change much across conditions, while the performance of *IM* and Web decrease significantly from stationary conditions to walking condition (see Figure 6.4) ($p < .01$).

Within the single-task condition, pairwise t Tests (LSD) showed that *SMS* (184 s) was significantly slower than both *IM* (106 s) and Web (117 s) (all $p < .001$). Similar results were found within the multi-tasking condition, where *SMS* (219 s) was significantly slower than *IM* (117 s) and Web (137 s). This is because typing in *SMS* is significantly slower than typing with a computer. But in the walking condition, *SMS* is no longer slower than *IM* and Web ($p > .05$). Most participants commented that they are used to use *SMS* while walking but found typing in *IM* very awkward and difficult. For Web, although it also becomes slower, participants still found it easier to use while walking since tasks can be done with single (or a few) button clicks.

In addition to that, we also measure the average interaction time for each interface under different conditions. Here the interaction time is defined to be the time between users' first interaction with a interface to the time when the task is confirmed to be finished by the experimenter. The interaction time for different interface under each condition is shown in Figure 6.5.

The interaction time of three interfaces didn't change much between the two stationary conditions, except that in multi-tasking condition the interaction time is a bit shorter in all interfaces as subjects were trying to do the tasks faster. In the experiment, participants are asked to rank the three interfaces once they finish doing tasks for one condition. The total number of times each interface is ranked first with regarding to different condition is shown in Figure 6.6. The result for subjects' ranking of preference is quite consistent across the two stationary conditions with the trend of total interaction time shown in Figure 6.5. 8 out of 12 subjects preferred MSN the most in single-tasking condition, and it increased to 9 in multi-tasking condition. Some users share their reasons as follows,

- *"MSN offers obvious notifications of new message, so I don't need to constantly switch back and forth to check the task status."*
- *"I always have my MSN on when I am with a computer."*

However, in walking condition the interaction time in MSN and web interface increased dramatically, which is mainly because typing in MSN and clicking in web while moving is much more difficult than it is in stationary conditions according to our observation and participants' comments they shared during the interview. In contrast, SMS interaction time only slightly decreased as all subjects are quite familiar with sending SMS while walking. That is why we see nobody rank MSN interface as their favorite interface in walking scenario, while SMS and web interface are preferred by 5 and 7 subjects respectively. In the interview, participants gave us the following reasons,

- *"I prefer web because clicking is much easier for me than typing when I am walking."*

- *"I prefer SMS better because I feel this is the most natural way to do it. I send SMS while walking every day."*

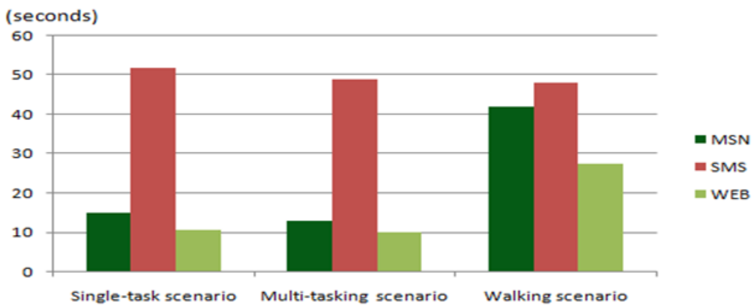

Figure 6.5: Average interaction time for each interface under different condition

Participants' preference

Participants were also asked to rate the preferred interface for each condition in part 2 of the study, see Figure 6.7.

For the *single-task* condition, 8 participants preferred *IM*, 2 preferred *SMS*, and 2 preferred *Web*. In the *multi-tasking* condition, 10 participants preferred *IM*, 2 preferred *Web*, and no one preferred *SMS*. In the walking condition, 7 participants preferred *Web*, and 5 preferred *SMS*.

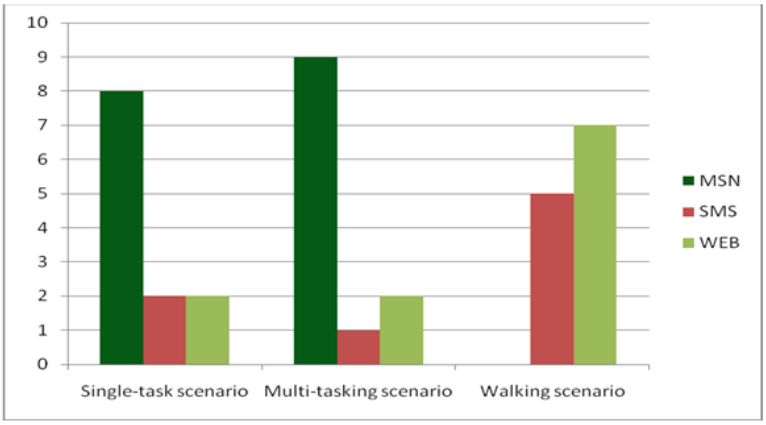

Figure 6.6: The total number of times for each interface to be ranked as the most preferred in each condition

Preference	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	Summary
Single-task	I	S	I	W	I	I	I	I	W	I	I	S	8(I), 2(S), 2(W)
Multi-task	W	I	I	W	I	I	I	I	I	I	I	I	10(I), 2(W)
Walking	W	W	W	S	S	W	W	W	W	S	S	S	7(W), 5(S)
Overall	D	W	I	D	I	D	D	D	D	I/S	I/S	I/S	6(D), 2(I), 1(W), 3(I/S)

S:SMS, I:IM, W:Web, D:Depends on situation

Figure 6.7: Participants' preferred interface in each condition.

SMS is obviously not preferred in the stationary conditions due to the inconvenience of typing on a mobile phone and the need to switch back and forth between devices, although one participant ($p12$) mentioned that he still prefers *SMS* in *single-task* condition since *IM* is banned in his company.

When comparing *IM* and *Web*, we are somewhat surprised to find out that most participants prefer *IM* over Web in both stationary conditions. The *Web* employs the *point & click* interaction method, and it is well known in the HCI literature that *point & click* interfaces are preferred over command line interfaces [96]. In the post-study interview, we found out the reasons why most participants still choose *IM* as their preferred choices.

First, *IM* has a much better notification system than the Web. In Web, robot feedback only appears within the web page. Participants need to explicitly switch to that page to see these messages. *IM*, on the other hand, "offers obvious notifications of new message via task bar and popup messages, so I don't need to constantly switch back and forth to check the task status."

Second, to existing *IM* users, it is more efficient, convenient, and familiar to use *IM* since they are "always on," so participants need not start another application.

Lastly, participants also felt that *IM* is more human-like and entertaining to use compared to Web, see elaboration later.

In the mobile scenario, the situation differs. None of the participants prefer *IM*. They either choose Web or *SMS* as their preferred interfaces. To the participants, the *IM* client on mobile phones is unfamiliar and tedious to use. In contrast, "clicking is much easier for me than typing when I am walking." *SMS* is preferred by some participants largely due to familiarity, as many (6 out of 12) of them stated that they use *SMS* often while walking. Furthermore, all users agree that *SMS* is the only choice in many outside areas where reliable internet connection is often not available.

However, when asked about an overall favorite interface across all conditions, many (6 out of 12) said that it depends on the situations. Three participants said that they prefer either *SMS* or *IM*, while two mentioned *IM* alone and one mentioned Web. These results show that for different tasks and conditions, users prefer different interfaces. No interfaces can simultaneously satisfy needs of all users. Hence, multiple complementary interfaces can better adapt to diverse needs from users in different situations.

From the experiment result, we also found that the correlation effect is evident that prior experience has a strong influence on subjects' preference of their most preferred interfaces. All 10 users that ranked Instant Messenger as their favorite HRI interface are already frequent (everyday) users of Instant Messengers. The same observation applies to the subject who chose SMS as the overall favorite interface. A majority of subjects also explicitly pointed out the correlation in quotes.

- *"I will use MSN rather than other four because I always have my MSN on."*
- *"I prefer SMS the most because I feel that SMS is the most normal way to do it as I already often type on a handphone."*

On the other hand, lack of prior experience made subjects feel unfamiliar and biased against the corresponding HRI interfaces, as well as being slow in learning the interfaces. In usability study, all the 7 subjects that failed or took longer time to use Google calendar interface are infrequent users or non-users of Google calendar.

Overall results

At the end of the user study, we also asked users about the advantages and drawbacks of each of the 5 interfaces. While the previous sections have already summarized *SMS, IM*, and *Web*, below is what participants said about *Calendar* and *Facebook*: 9 out of 12 participants commented that they like to use the Calendar interface for scheduling tasks (e.g., "Calendar interface is good since it allows me to schedule things later, and it is always visible whenever I check it, and no other interfaces allow me to do that."), and 8 out of 12 prefer the *Facebook* interface to easily share robot activities with their family members and friends. However, since these two interfaces are unable to provide real-time feedback, all users commented that they were unsuitable for assigning immediate tasks to robots.

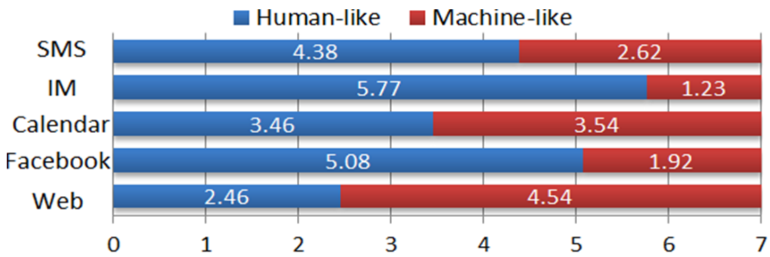

Figure 6.8: Average score of human-likeness for each interface.

Besides preferences, we also asked users to rank the social perception of robots from a Likert scale of 1 (machine-like) to 7 (human-like). Results are summarized in Figure 6.8. We compared the scores using one-way repeated-measure ANOVA analysis, and found a significant main effect on interface ($F_{4,44} = 13.48, p < .01$). Pairwise t Tests (LSD) showed that all social media platform interfaces (except Calendar) are significantly more human-like than Web ($p < .05$). Among the 4 social media platform interfaces, *IM* (5.77) is significantly more human-like compared to both *SMS* (4.38) and Calendar (3.46) ($p < .05$), but is not significant different from *Facebook* (5.08). *Facebook* (5.08) is significantly more human-like than *Calendar* (3.46) ($p < .05$), but is comparable to *SMS* interface (4.38).

Although we expect that the social media platforms could help to increase the perception of human-likeness of robots, we did not realize that there are wide ranges of differences among various social media platforms. Via post-study interviews, we identified the following factors that contribute to the difference in users' perception of robots.

Interaction method. 9 out of 12 participants consider "typing (using natural language) to be more human" than *point & click*. This revealed one reason that social media interfaces generally scores higher in human-likeness than Web.

Interface design. Participants commented that both *IM* and *Facebook* are more human-like because they contain more "human" elements, such as icons and images representing people on their contact lists with profile pages. They also found both interfaces richer and more entertaining.

Current usage. For most participants, interacting with robots using *IM* and *SMS* interfaces feels more sociable and human-like because these interfaces are primarily used by them to interact with other humans.

Responsive-ness. The feedback speed also appears to contribute. Most users rank *IM* higher than *Facebook* because they feel that *IM* is more responsive.

Overall, *IM* has the most of the above factors that contribute to human-likeness, while Calendar has the least among the four social media platforms. Designers are suggested to consider the above factors for their interfaces if they want to augment the perception of robots, making them appear more sociable and human-like.

Summary.

Our evaluation shows that using social media platforms to interact with domestic service robots is a promising idea. For users with prior experience on social media platforms, they can naturally and almost effortlessly extend their usage of these interfaces to interact with robots, indicating re-using existing popular interfaces to achieve new purposes and functionalities has great potentials. We also found that each interface has its pros and cons, and is suitable for different tasks and conditions. It is unrealistic for a single interface to satisfy users in diverse scenarios and goals. Providing a set of complementary interfaces gives users greater flexibilities and better user experience.

Using social media platforms also enhances the perception of social intelligence of robots, making robots appear more human-like and sociable. We found users' perception of robots' social intelligence is a function of many factors, including interaction method, interface design, purpose of the interfaces, and responsive-ness of the interfaces. Future robot interface designers can study these factors when presenting robots to users. However, we also observe a trade-off between efficiency/convenience in interfaces vs. perception of human-likeness and sociability. Though *point & click* interaction method is more convenient than *typing*, it makes robots appear less human-like and sociable.

While most people embrace the idea of using social media platforms to interact with robots, there are also concerns that point to future research direction, e.g., 2 participants raised the issues of privacy and security in sharing information at home, especially images and videos, via robots on *Facebook*. How to design and manage the privacy settings with robots, their hosts, and their hosts' extended social networks could be an interesting future topic for research.

Design implications.

	Short Message Services (SMS)	Instant Messenger (IM)	Web control	Shared Calendar	Facebook
Interactive Visual	No	Yes	Yes	No	No
Scheduling	No	No	No	Yes	No
Multi-user Social	No	No	No	No	Yes
Mobile	YES	No	YES	YES	YES
Devices	All mobile phones	PC	PC	PC or 3G mobile phones	PC or 3G mobile phones
Responsiveness	Immediate	Immediate	Immediate	Delayed	Delayed
Input/output	Text/Text	Text/(Text + video + image)	Clicking/(Text+ video)	Text/(Text + image)	Text/(Text + image + video)
Suitable Scenarios	Mobile scenarios, such as when users are walking or having urgent tasks	Stationary places for both single and multi tasking with rich feedback and immediate response	Mobile scenarios and stationary scenario when typing become troublesome	Scheduling tasks when no immediate feedback is required	Entertainment and socialization between human and robots with no immediate feedback

Figure 6.9: Characteristics and suitable working scenarios for each social media platforms and the web interface

In chapter 4, we have reviewed the characteristics of the four social media platforms and the web interface. According to the result in this devised user study, we have summarized the relationships between the general interface characteristics and application scenarios in Figure 6.9.

Due to the lightweight design of SMS and having immediate response, it is considered by most participants to be most suitable for users when they are under multi tasking scenario, such as walking. IM is an useful candidate interface to use when users are in stationary environment (eg. office) for both single tasking and multiple tasking. The feature of having immediate response and great notification system alleviate users from always keeping their attentions on the interaction. Calendar has its unique advantage in the scenario when scheduling tasks become necessary. Since users can view the interfaces from different operating platforms, it also has the flexibility to support interaction everywhere. Facebook interface can be a good platform for entertainment and socializing with robots as it is able to promote users' social activity with robots and increase users' perception of human-likeness level of robots. As a baseline interface, web interface has less flexibility and the input and output format is fixed as buttons and textual/visual content. It is using point and click technique and is more suitable for scenarios when input text becoming inconvenient or troublesome.

In addition, the co-relation effect is obvious when we find out all those participants have significant prior experience with their preferred interface under different situations. Therefore, when trying to leverage on some existing social media platforms, target user group's usage behavior of them in addition to their inherent features should be taken into consideration as well.

Particularly, we also want to highlight the following guidelines on designing interfaces for human robot interaction in domestic environment,

- Users have different expectation on HRI interfaces in different conditions. Generally, they might hope to use an easy-to-operate interface while walking, an easy-to-operate interface with most noticeable notification while busy working, and a responsive interface while they need to have urgent talk with robots. A single and integrated interface might not be able to fulfill users' various demand in various conditions. Therefore, building a family of HRI interfaces based on different types of social media platforms is a viable solution to fit users' needs.

- Designing and implementing various interfaces based on different interpersonal communication tools to fit to uncertain and unpredictable conditions and user preference will be a good way to win over the large number of existing users of the widely popular social media platforms, as a lot of users (although not all) prefer to use familiar interfaces.

- Making full advantage of the personification elements in social media interfaces could effectively make human users generate a feeling of human-likeness and sociability towards robots.

- Among various social media platforms, those one-to-many interfaces (such as Facebook) make users care more about their domestic robots' behavior, consequently require more efforts on designing the robots' behavioral system to ensure that they are able to act properly in human's social network.

Chapter 7

Conclusions

In this chapter we are concluding the thesis and summarizing the results we have reached. This is a new area of research and hence there are many opportunities for improvement. This chapter will also contain some of the ideas of our future work.

7.1 Conclusion

Interaction with domestic robots is a hot research area. Social media platforms have been widely popular nowadays. This thesis work explores the application of popular social media platforms to support interaction with domestic robots.

We presented a sequence of usage scenarios to firstly illustrate how social media platforms can facilitate interaction with domestic service robots under different circumstances. We also did a thorough literature review on existing work of different topics, including 1)different approaches for human robot interaction, 2)current research in domestic service robots 3)tele-robotics 4)social media platforms and the current research trend 5)social media platforms and their existing applications.

The characteristics of four complementary social media platforms, including short message services (*SMS*), instant messenger (*IM*), shared calendar (*Calendar*), and social networking sites (*Facebook*), are carefully compared and studied. Strengths and weaknesses for each platform are also explained in details. Our proposed system design was significantly influenced by these characteristics of the four social media platforms.

We have developed an integrated system to naturally extend the social connections among humans further to domestic robots. The system infrastructure and implementation was explained in details from different aspect, such as the design, communication, hardware setup and etc.

A usability test and controlled user study was also devised in this work to investigate the user operations in the course of robot interaction. Our evaluation shows 1)that using social media platforms to interact with domestic service robots is a promising idea and 2)users' perception of robots' social intelligence is a function of many factors, including interaction method, interface design, purpose of the interfaces, and responsive-ness of the interfaces. In addition, we demonstrate with our results in user study that our approach can contribute to deliver a more social, user-familiar, flexible, and natural interface, as a novel and promising interaction paradigm with robots.

Our approach of leveraging multiple, complementary social media platforms for HRI could open many prospective research directions. Researchers are encouraged to study the long term effects, e.g., the security and privacy issues, of using the proposed (and other forms of) social media platforms when interacting with robots. With advancement in robot technologies, we envision the potentials of our approach as a practical and natural interaction style with robots, more easily to be adopted by the public.

7.2 Future Work

We also suggest the following ideas for our future work:

- We hope to conduct a longitudinal study through deploying our system into a real home. By doing that, we want to explore the long term effect of HRI using social media platforms on human's perception and emotional attachment to domestic robots. This would provide more real data for us to gain insights into our proposed new interaction paradigm.
- Currently, we only choose 4 popular social media platforms in our system. In the future, we want to extend our system by including more popular social media platforms. In this way, we aim to achieve truly flexibility for all different kind of people with different preferences of using social media platforms under different circumstances.
- As seen in Section 5.6, our current system can only support limited number of domestic tasks for users. Before we conduct our longitudinal study, we want to further customize our current robots to make it support more tasks,

such as watering flowers, picking up things from floor or folding clothes.

- As discussed earlier in the user study, some users shared their concerns on privacy and security issues involved in using our system. For example, robots may put some private information online which they do not want to see. Future research will touch on how to refine our system design and what kind of polices to adopt in our current system infrastructure to make it more easily adaptive to a variety of people with different level of privacy and security concerns.

- Currently, our natural language processing algorithm, which is an essential part for understanding users messages and generate appropriate responses to users, still has limitations. For the future work, we mainly want to revise the algorithms to achieve three goals 1) The algorithm should be able to generate more appropriate and meaning responses when facing some text messages that could not be understood. Currently, we send limited and repeated sentences to users most of the time. By doing this, we foresee users would be inclined to feel the robots are more human like and therefore the social attachments between them will probably increase as well. 2) The algorithm should be able to do self-learning efficiently. That is, robots should be able to increase its knowledge from every talk between users and them. 3) The algorithm should be more robust to interpret the complete messages from users sentence when it contains keywords across different categories. Our current category priority based keywords analysis can understand partial meanings of the whole sentence if it contains keywords from more than two categories.

- As part of our future work, we want to improve the accuracy of our tracking system. The tracking system is the eyes of the robots, which make them possible to navigate in the whole environment. However, there are two limitations with the current tracking system 1) the maker based tracking system is very unstable when the intensity of light changes and is not very robust when the tracking object is moving, such as the two robots we used here. 2) To deploy our system, we need to set up the two ceiling cameras in the room, most users shared their concerns about this and they consider as a intrusion of their privacy. Therefore, we want to develop an alternative tracking algorithm which performs well under varying lighting conditions and does not need to set up cameras in any home environment.

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Appendix A

System Source Code Organization and Set Up Tutorial

A.1 Introduction

A.1.1 Purpose

This document is mainly used to describe and explain how the whole social media based human robot interaction system works. This will also let you gain better understanding of the code and how to set up the whole system.

A.2 Code Level Explanation

The whole structure of the system's source code packages is illustrated in Figures A.1. As can be seen, there are mainly four parts 1) social medial platforms code 2) web server code 3) pan/titlt device servo control code 4) MSN standalone server code

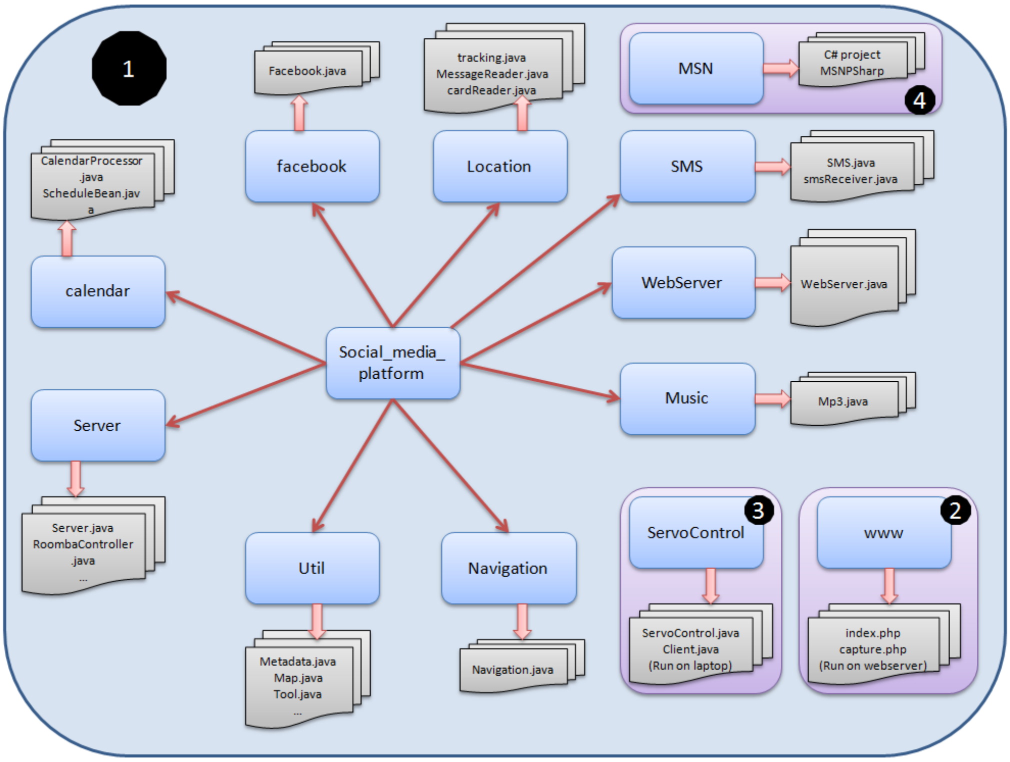

Figure A.1: Source code structure of the whole system

A.2.1 Social Media Platforms Code

This is the most essential part of our system, which is responsible for 1) connecting our robots with four different social media platforms 2) interpreting users' messages 3) managing robots' activity. In the following parts, the purpose of each package of code will be carefully explained.

Calendar package As the server needs to connect to Google calendar server to maintain the update and poll of information, the code in this package is using the standard API to achieve the above goals. *CalendarHandler.java* & *CalendarProcessor.java*: These two files contain the functions to periodically update and poll information to/from Google calendar server. *Calendar.java*: This file is test entry to test the basic functionality developed. (Please refer to `http://code.google.com/apis/calendar/` for the public Google calendar API information) *scheduleBean.java*: This class defines the entity which is used to encapsulate the information returned from Google calendar server.

Facebook package This package contains only one Java file named *Facebook.java*. This files defined the main functions which we used to pull information from Facebook server and maintain the message exchange between Facebook Server and our local server. Location package This is the most important part of our system which contains three java files. *CardReader.java*: Defines the information entity used for each piece of card *MessageReader.java*: This Java file contains the main function to receive the tracking information from the two ceiling camera and other necessary functions to perform mathematic calculations towards these captured data. *Tracking.java*: This file contains the main functions/strategies we used for robots' navigation system. That is, how the two robots are able to know where to go and how to go there. In addition to that, the robot's actions, such as doing cleaning task are defined in this class as well.
Music package This is a supplementary package which contains the file to enable the sound feedback from robots.
Navigation package The most essential high level task we implemented is defined in this package which contains only one Java file named *Navigation.java*. Navigation.Java: The Java files defined the functionalities of 1) simple basic movement task 2) high level tasks 3) pan/tilt devices controlling 4) post message/photos to Facebook wall. Simple natural language processing based on keywords classification.
Roombacomm package This package is downloaded from `http://hackingroomba.com/code/roombacomm/`. It is public API written for controlling Create/Roomba through Bluetooth connection. It has all the necessary interfaces which frees you from checking the manual to define the functions you want your robots to perform.
Server package This package is the main entry that you want to start the centralized server. It has the following 4 java class files. *Calibrate.java*: This file is used to run and test how long it takes for an Create or a Roomba to spin one round. *RoombaController.java*: This class file defined the basic functions for connecting and controlling our two robots. *Server.java*: This is the server main entry and running it will start the whole server. *userInput.java*: This file

defines how the user's text input from different platforms is saved as an entity.

Util package This package contains a series of supplementary class for the server to use. *Metadata.java*: This file defined the configuration metadata. Every time you change something, such as the IP address of the server, then you need to update this file to reflect about your change. ImageNameGenerator.java: this file is used to generate an image name every time a photo is taken by the robot. *Log.java*: this file is used to log user's interaction history with robots. Basically it records everything for our research analysis. *Map.java*: this file is used to paint the environment, such as what you wish to be in your room. Only the existing locations can be understood by the system. *Tool.java*: This file is used to analyze and process users' text input message to see whether it is a scheduled task or not. If it is a scheduled task, it will inform user about this, can invoke the quick Add API provided by Google Calendar API to insert a new task entry in the calendar.

Webserver package *WebServer.java*: To run the baseline interface, this is the centralized server that handles the information received from web interface. It also has the function to send feedback to the web interface.

SMS package The SMS agent code which runs on Android phone is in this package. *SMS.java* and *SmsReceiver.java* basically defines what will the Android phone do if it receives information from client's side or server's side.

A.2.2 Web Server Code

This package contains the php code which defines a series of functions such as updating robots' Facebook wall, extracting update from its wall or capturing a photo from Android phone's camera. It can run on WAMP server (`http://www.wampserver.com/en/`). But other server which can support PHP page running will also be fine.

A.2.3 Pan/Tilt Device Servo Control Code

There are currently three java files on the small laptop side which is on top of one of our robots. ServoControl.java: This class defines the driver for the pan/tilt devices we use and is served as a public API. Client.java: This class is to handle the connection between the pan/tilt devices and the centralized server through Bluetooth connection.

A.2.4 MSN Standalone Server Code

The standalone application written in C# is used to handle the incoming message from client MSN interface. The received information is forwarded to server and the reply from server will then be forwarded to client's MSN interface thought our MSN message handler. The platform is built upon an open source project called MSNPSharp (http://code.google.com/p/msnp-sharp/).

A.3 Deploy The System

This part will guide you through on how to set up the whole system from this source code.

A.3.1 Deploy The Centralized Server Code

- Import the entire external library. The entire library is located under the calendar_interface/java/lib, please import all the library files here.
- Change the local IP address, cards used for each robot, and the com port of each robot's connection in the metadata.java file located under util package. Note: IP address is your IPV4 address and ports number can be seen from the Toshiba Bluetooth stack you are using, and the cards are just what you select to use.

A.3.2 Deploy The MSN Agent Code Written in C#

- Change the IP address used in the *conversationForm.cs* to the local IPV4 address of your computer.
- Login in with the robot's account

A.3.3 Deploy The SMS Agent to Android Phone.

- Simply change the IP address in smsReceiver.java to your current server address

A.3.4 Deploy The Servo Control Code to The Small Laptop

- The code running on Fujitsu laptop will be responsible for the handling the request from server to control the pan/tilt devices. Change the server address to your current address in Client.java file.

- You **MUST** login in with the same robot's MSN account here as well so that users can enable the video conversation with robot at any time.

A.3.5 Deploy The PHP Code for Facebook Agent

- The php code for Facebook is run on WAMP server and you should put it under the www directory. (In my project setting, I have put it under www/src/index.php. Hence you can visit it with the URL as `http://localhost/src/index.php`)

- Make sure you have started the WAMP server before you can use the Facebook platform

Please ensure that the server, the Fujitsu laptop and the android phone we use uses the same local network. So that they can communicate with each other without any security constraints. If there are still any problems pertaining to the setup or source code, please contact YANG XIN or drop me an Email at yangxinnus@gmail.com.

Appendix B

Experiment Design

In this section, we show how we conduct our usability test and controlled user study experiment.

B.1 Experiment Script

B.1.1 Pre-experiment Procedures

Before we start the actual experiment, we start video recording, audio recording and screen recording which data will be used for our analysis. The steps that participants and experimenters will perform in this stage will include

- Participant reads and signs the consent form and video recording consent form.

- Participant fills out a questionnaire on his/her brief demographic and technical background.

- Experimenters give a brief introduction

  - Experimenters introduce the project and the system.

  - Remind participant that currently the two robots are sharing one account in each social media platform, so he/she needs to specify the robot's name when talking to it.

- Remind participant to save the robots' cell phone number as a contact in his/her cell phone.

B.1.2 Experiment Part 1: Tutorial and Usability Test

Participants will try out each of the five interfaces, one task for each interface. During this part, they will stay in the same room with the robots. We will ask the participants to try to use the interface without giving them any hints first. This is to test the walkup learnability of the interfaces we designed.

We will print the following ten tasks in ten pieces of A4 paper, and give them to participants in random order, so that each participant will go through the ten tasks in different sequence.

- **Facebook** Ask Robbie to take a picture of the flower and share it with friends.
- **Google Calendar** Schedule Johnny to vacuum living room on 3pm.
- **SMS** Ask Johnny to vacuum the living room now.
- **MSN** Ask Robbie to go to your bedroom to look for your wallet.
- **Web Control Interface** Ask Johnny to vacuum your living room now.

B.1.3 Experiment Part 2: Controlled User Study

Participant and experimenters will go through the following scenarios in another room or in the corridor, away from the robots. Each task will be printed in a piece of A4 paper separately from other tasks. For each task in each scenario, we will give tasks to participant in random order, so that each participant will go through the 2 or 3 tasks in different sequence.

Stationary Single-task Scenario

This is the section when participants are sitting in an room doing nothing but interacting with domestic robots through different social media platforms.

- Participant and experimenters go to an experiment room other than the robot room. Participant will sit down in front of a computer.
- Experimenters explain the relaxed scenario to participant.
- Participant executes the multiple instructional task using SMS.
- Participant executes the multiple instructional task using MSN.
- Participant executes the multiple instructional task using web control interface.
- Participant gives comments on which interfaces he prefers to use for this task in this scenario.
- Participant executes the visual interactive task using MSN.
- Participant executes the visual interactive task using web control interface.
- Participant gives comments on which interfaces he prefers to use for this task in this scenario by filling out a questionnaire.

Stationary Multi-tasking Scenario

This scenario is to examine how well users perform the interaction when they are busy doing a primary task.

- Experimenters explain the multi-tasking scenario to participant.
- Participant executes the multiple instructional task using SMS, and in the same time tries to finish the game in 4 minutes.
- Participant executes the multiple instructional task using MSN, and in the same time tries to finish the game in 4 minutes.
- Participant executes the multiple instructional task using web control interface, and in the same time tries to finish the game in 4 minutes.
- Participant gives comments on which interfaces he prefers to use for this task in this scenario.

- Participant executes the visual interactive task using MSN, and in the same time tries to finish the game in 4 minutes.

- Participant executes the visual interactive task using web control interface, and in the same time tries to finish the game in 4 minutes.

- Participant gives comments on which interfaces he prefers to use for this task in this scenario by filling out a quesionnaire.

Mobile Scenario

This is the scenario when users are moving while interacting with domestic robots.

- Experimenters take the participant to the corridor outside the robot room.

- Participant walks from door A to door B outside the lab, experimenters measure the time he takes to complete the walk.

- Participant executes the multiple instructional task using SMS, and in the same time tries to finish the walking in the same amount of time 2.

- Participant executes the multiple instructional task using MSN, and in the same time tries to finish the walking in the same amount of time 2.

- Participant executes the multiple instructional task using web control interface, and in the same time tries to finish the walking in the same amount of time 2.

- Participant gives comments on which interfaces he prefers to use for this task in this scenario by filling out a questionnaire.

Interview

During this stage, we will conduct a interview with the participants based on what they did on the questionnaire and our observations. In addition to that, we also ask about their some general feelings to gain some qualitative data.

B.2 Pre-experiment Questionnaire

The Pre-experiment questionnaire is shown in Figure B.1.

1. What is your age range?
   <20 ☐ 21-25 ☐ 26-30 ☐ 31-35 ☐ 36-40 ☐ 41-45 ☐ 46-50 ☐ >50 ☐

2. What is your gender? Male ☐ Female ☐

3. What is your marital status? Single ☐ Married ☐ Others ☐

4. What is your employment status?
   Current student ☐ Employed ☐ Unemployed ☐ Self-employed ☐
   If you chose "Current student", please indicate your major here________________________
   If you chose "Employed", please indicate your occupation here________________________
   If you chose "Self-employed", please indicate industry here. __________________________

5. What is your education level?
   High school ☐ Bachelor ☐ Master ☐ Doctorate ☐ Others ☐

6. How often do you use SMS in mobile phone?
   Everyday ☐ At least once in a week ☐ At least once in a month ☐ Once over a month ☐
   Never ☐

7. How often do you use instant messaging tools such as MSN, Google Talk, QQ, AIM, etc.?
   Everyday ☐ At least once in a week ☐ At least once in a month ☐ Once over a month ☐
   Never ☐

8. How often do you use Google Calendar?
   Everyday ☐ At least once in a week ☐ At least once in a month ☐ Once over a month ☐
   Never ☐

9. How often do you use Facebook?
   Everyday ☐ At least once in a week ☐ At least once in a month ☐ Once over a month ☐
   Never ☐

10. How often do you use instant messaging tools such as MSN, Google Talk, QQ, AIM, etc.?
    I am working in robotics related area ☐ I am not working in robotics related area, but I've been interested in robot toys, news, videos, movies, etc. ☐ I am not interested in robot things ☐

11. Have you heard about Roomba before? Yes ☐ No ☐
    If you chose "Yes", describe your knowledge about Roomba__________________________

12. Have you heard of the term "domestic robot" before? Yes ☐ No ☐
    If you chose "Yes", describe your knowledge about Domestic robot___________________

Figure B.1: Pre-experiment questionnaire

B.3 Post-scenario Questionnaire

The Post-scenario questionnaire is shown in Figure B.2.

1. Stationary **single-task** scenario, **multiple instructional** task
   a) After using different interfaces to complete the same task (which is to go through a series of robot tasks when you are staying in office in relaxed mood), please rank these interfaces (SMS, Instant Messenger, Web interface) in order of preference.
      Rank 1:______ Rank 2: ______ Rank 3: ______
   b) Please tell us why you rank them in this way
      ____
      ____
   c) Imagine that you are staying in office in relaxed mood, and want to ask your robots to do something for you, which interface you will probably use? Please rank all these five interfaces in order of your preference.
      Rank 1:______ Rank 2: ______ Rank 3: ______ Rank 4: ______ Rank 5: ______
2. Stationary **multi-task** scenario, **multiple instructional** task
   a) After using different interfaces to complete the same task (which is to go through a series of robot tasks when you are very busy working in office), please rank these interfaces (SMS, Instant Messenger, Web interface) in order of preference.
      Rank 1:______ Rank 2: ______ Rank 3: ______
   b) Please tell us why you rank them in this way
      ____
      ____
   c) Imagine that you are busy working in office as you have to finish something within the time limit. Meanwhile you have to ask your robots to do something for you, which interface you will probably use? Please rank all these five interfaces in order of your preference.
      Rank 1:______ Rank 2: ______ Rank 3: ______ Rank 4: ______ Rank 5: ______
   d) Please tell us why you rank them in this way
      ____
      ____
3. Stationary **mobile** scenario, **visual interactive** task
   a) After using different interfaces to complete the same task (which is to go through a series of robot tasks when you are very busy working in office), please rank these interfaces (Instant Messenger, Web interface) in order of preference.
      Rank 1:______ Rank 2: ______
   b) Please tell us why you rank them in this way
      ____
      ____
4. Stationary **mobile** scenario, **multiple instructional** task
   a) After using different interfaces to complete the same task (which is to go through a series of robot tasks when you are walking to some place), please rank these interfaces (SMS, Instant Messenger, Web interface) in order of preference.
      Rank 1:______ Rank 2: ______ Rank 3: ______
   b) Please tell us why you rank them in this way
      ____
      ____

Figure B.2: Post-scenario questionnaire used for each task scenario

B.4 Post-experiment Questionnaire

The following is our questionnaire used after participants finished all the tasks.

1. Describe your feelings when interacting with the robots using the following interfaces. Please try to comment on different aspects of the feeling, such as performance, entertainment value, emotional attachment, etc. Briefly explain what makes you feel that way.

Comments on SMS interface:

____

Comments on Instant Messenger interface:

____

Comments on Calendar interface:

____

Comments on Facebook interface:

____

Comments on Web Control interface:

____

2. When using the SMS interface, I feel the robots are:

Machine-like	1	2	3	4	5	6	7	Human-like

3. When using the Calendar interface, I feel the robots are:

Machine-like	1	2	3	4	5	6	7	Human-like

4. When using the Instant Messenger interface, I feel the robots are:

Machine-like	1	2	3	4	5	6	7	Human-like

5. When using the Facebook interface, I feel the robots are; Machine-like; Human-like:

Machine-like	1	2	3	4	5	6	7	Human-like

6. When using the Web Control interface, I feel the robots are:

Machine-like	1	2	3	4	5	6	7	Human-like

Difficult to learn	1	2	3	4	5	6	7	Easy to learn

7. When I just started using the Facebook interface, I feel the interface is:

8. When I just started using the Instant Messenger interface, I feel the interface is:

Difficult to learn	1	2	3	4	5	6	7	Easy to learn

9. When I just started using the Web Control interface, I feel the interface is:

Difficult to learn	1	2	3	4	5	6	7	Easy to learn

10. When I just started using the Calendar interface, I feel the interface is:

Difficult to learn	1	2	3	4	5	6	7	Easy to learn

11. When I just started using the SMS interface, I feel the interface is

Difficult to learn	1	2	3	4	5	6	7	Easy to learn

12. When using the SMS interface, I feel the robots are:

Machine or tools	1	2	3	4	5	6	7	My friends or family

13. When using the Facebook interface, I feel the robots are:

Machine or tools	1	2	3	4	5	6	7	My friends or family

14. When using the Web Control interface, I feel the robots are:

Machine or tools	1	2	3	4	5	6	7	My friends or family

15. When using the Instant Messenger interface, I feel the robots are:

Machine or tools	1	2	3	4	5	6	7	My friends or family

16. When using the Calendar interface, I feel the robots are:

Machine or tools	1	2	3	4	5	6	7	My friends or family

17. When using the Instant Messenger interface, I feel that I am ( ) from/to the robots.

Isolated	1	2	3	4	5	6	7	Connected

18. When using the Calendar interface, I feel that I am ( ) from/to the robots.

Isolated	1	2	3	4	5	6	7	Connected

19. When using the Web Control interface, I feel that I am ( ) from/to the robots.

Isolated	1	2	3	4	5	6	7	Connected

20. When using the Facebook interface, I feel that I am ( ) from/to the robots.

Isolated	1	2	3	4	5	6	7	Connected

21. When using the SMS interface, I feel that I am ( ) from/to the robots.

Isolated	1	2	3	4	5	6	7	Connected

22. Do you feel the robots have personality when you are using SMS interface? If yes, how do you describe the personality? ____________________

23. Do you feel the robots have personality when you are using Instant Messenger interface? If yes, how do you describe the personality? ____________________

24. Do you feel the robots have personality when you are using Calendar interface? If yes, how do you describe the personality? ____________________

25. Do you feel the robots have personality when you are using Facebook interface? If yes, how do you describe the personality? ____________________

26. Do you feel the robots have personality when you are using Web Control interface? If yes, how do you describe the personality? ____________________

27. Were there any particular problems you experienced? Or any comments, suggestions, or other things you would like to share with us? Please write them here. ____________________