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Using Social Media Platforms for Human-Robot Interaction in Domestic Environment

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This article explores the application of existing social media platforms for human–robot interaction. With the increasing popularity of social media platforms that connect humans, we propose to portray domestic robots as buddies on the contact list of family members and present a robot management system that employs complementary social media platforms for humans to interact with the vacuuming robot Roomba and a surveillance robot developed on top of iRobot Create. The social media platforms adopted include short message services (SMS), instant messenger (MSN), an online shared calendar (Google Calendar), and a social networking site (Facebook). Hence, we can provide a rich set of user-familiar, intuitive, and highly accessible interfaces, allowing users to flexibly choose their preferred tools in different situations. An in-lab experiment and a multiday field study are conducted to study the characteristics and strengths of each interface and to investigate users' perception to the robots and behaviors in choosing the interfaces.

1. INTRODUCTION

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, e-mail, instant messaging (IM), music sharing, crowdsourcing, and voice-over IP.

Although these platforms have undoubtedly enriched our daily lives, we so far employ them mainly for social communication or interactions between humans. They certainly have great potential to be extended to interact with robots, as robots are considered by most people as "humanlike" beings.

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In this article, we 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. Domestic service robots are chosen as the topic due to their increasing popularity, as evidenced by the increasing proliferation of domestic helpers like the vacuuming robot Roomba (iRobot Corp.), lawn-mowing robot Robomower (Friendly Robotics Ltd.), and so on. In the future, homes are likely to be equipped with one or more robots to serve the need of users, especially those who may not stay at home all the time and thus have to rely on domestic robots to take care of the household and family. Therefore, it is crucial to provide a management system to enable people to efficiently, ubiquitously, and intuitively interact with domestic robots, and hence bridge the gap between domestic robots and the general public.

To serve this purpose, the system between robots and users must provide intuitive interfaces for the users to learn and use because domestic robots target ordinary home users who often have limited computing knowledge. Moreover, it must be able to handle the varying contexts and scenarios of interaction in order to ubiquitously connect human with their robots. It will be desirable if the system could provide complementary HRI interfaces that fit in different interaction contexts, such as working in stationary office environment, standing on a bus, walking, and so on.

We are unaware of any such systems that allow users to ubiquitously interact with multiple robots through a set of complementary and nonexclusive interfaces. Thus, in this article, we present a highly accessible and extensible robot management system that employed social media platforms to provide intuitive and easy-to-learn user interfaces. Specifically, four types of social media platforms—short text message services (SMS), IM (i.e., MSN), shared online calendar (i.e., Google Calendar), and social networking sites (i.e., Facebook)—are adopted in the system to interact with domestic robots. Our two robots include a vacuuming robot Roomba and a surveillance robot developed by us on top of an iRobot Create

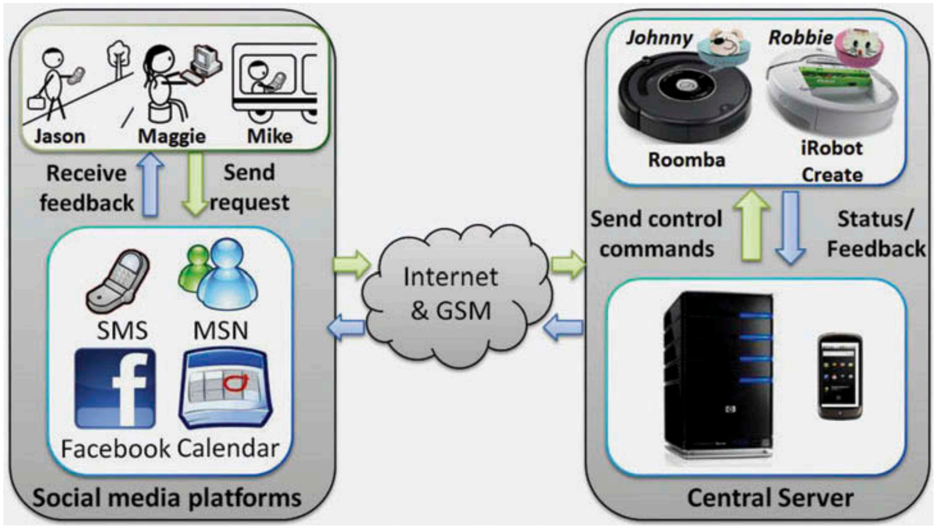


FIG. 1. Using social media to interact with domestic robots.

Note. SMS = short message services; GSM = Global System for Mobile Communications.

in the purpose of making our system more capable of doing household chores. The proposed approach, including the four social media platforms adopted, the picture of our robots, and the user scenarios, is shown in Figure 1.

We choose existing social media platforms to provide the user interfaces because social media platforms are highly popular with a large population of skilled users; therefore, reusing these platforms as the interaction media to domestic robots can minimize users' efforts for learning. Besides, because different social media platforms are designed to serve different kinds of needs in different scenarios, supporting multiple complementary platforms as in our system can thus cater to user's needs emerged from different scenarios, such as on the road or in the office.

The following items highlight the contributions of this article:

- First, this is the first article we are aware of that harnesses complementary social media platforms to achieve better user experiences in HRI.
- Second, we implemented a working system as described in this article, deployed it into a multiroom apartment, and recruited users to try out the system in a real home environment for 3 days. To the best of our knowledge, we are unaware of any other work that attempted to deploy such a system into a real home to study its effect on HRI for a period of multiple days.

2. RELATED WORK

This work uses social media platforms to interact with domestic robots in a remote (noncollocated) setting. In the followings, three aspects of HRI are reviewed.

2.1. Research in Domestic Robots

With the emergence of domestic robots in consumer market, a growing number of researchers began to explore this field. Although some researchers focused on the implementation and algorithmic aspects of domestic robots (Kawamura, Pack, & Iskarous, 1996; Roßler & Hanebeck, 2004), others studied the application of domestic robots (a majority of them focused on the vacuuming robot, Roomba), for example, on how design can influence HRI in home setting (Breazeal, 2001; Forlizzi, 2007; Kim et al., 2007). Many researchers are also interested in designing novel interaction methods to enable natural and intuitive HRI. Work in this direction includes the design of paper tag interfaces to facilitate implicit robot control (Zhao et al., 2009), the use of tangible objects such as toys (Guo, Young, & Sharlin, 2009), accelerometer-based Wii-mote (Guo & Sharlin, 2008), laser pointers (Ishii et al., 2009), sketching on a tablet computer (Sakamoto et al., 2009), using gaze and blink (Mistry et al., 2010), choreograph a series of actions (Shirokura et al., 2010), and using enhanced projector-camera (Linder & Maes, 2010) to control robots. Moreover, researchers also worked on extending robots to other housework tasks beyond simple vacuum cleaning (Okada et al., 2005; Sugiura et al., 2010). Although much research has focused on domestic robots, as far as we are aware, none of them explored the use of social media platforms to interact with domestic robots. The proposed work aims at filling such a gap with a study on this topic with complementary social media interfaces.

2.2. Tele-Robotics

The second category comes from the field of tele-robotics, which can be roughly divided into three separate but not necessarily mutually exclusive areas: tele-operation, tele-manipulation, and tele-presence. Tele-operation investigates the remote operation of robots. Most research in this area focused on tele-operation of robotic vehicles (Fong & Thorpe, 2001). 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 (Shimoga, 1993), whereas tele-presence offers immersive VR-like experience to the operators during the remote manipulation. Common practices in tele-presence are often associated with head-mounted displays and multimodal feedback (Ballou, 2001).

Although research in tele-robotics is abundant, such as joysticks (Sian et al., 2002) or using point & click interfaces (Kubota, Kamijima, & Taniguchi, 2005), most centers on industrial, medical, and military contexts to extend human activities to hard-to-reach or infeasible-to-stay places, for example, other planets or deep sea or hazardous environments (S. Kim, Jung, & Kim, 1999; Yoon et al., 2004). Few discuss the context of domestic setting, except the work presented by Roßler and Hanebeck (2004), which studied the error handling issues instead of primary interaction procedure.

2.3. Using Social Media to Control Electronics/Robots

Studies on social media platforms in HCI mostly concern human-to-human interaction (Gilbert & Karahalios, 2009; Turner et al., 2010) instead of with robots or devices, with the exceptions of the work presented by Faulring and Myers (2005); Goh et al. (2008); Khiyal, Khan, and Shehzadi (2009); and Mavridis and Rabie (2009). Intelligent virtual agents were usually used to communicate with humans via IMs (Goh et al., 2008) and to help humans to plan their calendars (Faulring & Myers, 2005). In addition to virtual agents, an SMS interface has also been proposed to control home appliances (Khiyal et al., 2009). Cellbots, an open source library (Cellbots.com, n.d.), also allows users to control different of robots (iRobot, LEGO Mindstorm, etc.) using SMS. Moreover, Mavridis and Rabie (2009) 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 performance. In a separate effort, a Facebook-connected desktop pet robot called Pingo (Arimaz Inc.) was brought to the market; it can read Facebook updates, news, sing songs, and give weather forecasts. Although these work leverages social media platforms, our work differs from them as follows.

First, our system involves real autonomous robots, instead of virtual agents (Goh et al., 2008) or stationary machines (Khiyal et al., 2009). 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 (Sung et al., 2007).

Second, unlike entertainment and social robots, domestic robots play a dual role of doing housework and acting like human companions or even family members (Young et al., 2009). These distinguish our work from the work presented by Mavridis and Rabie (2009) and Pingo, which employed Facebook only for socializing or entertainment.

Finally, instead of introducing a customized application dealing with a single robot, we study an open system with multiple complementary remote interaction tools and robots, hereby offering users a choice to interact with any robot on their preferred interfaces for different scenarios and tasks.

3. USAGE SCENARIOS

We designed the following scenarios to illustrate how our approach can employ complementary social media platforms to facilitate HRI. All the tasks and interfaces in these scenarios have been developed in our system and were used to conduct the lab experiment and multi-day field study.

3.1. Profile

Jason is a busy professional, usually working from 9 a.m. to 6 p.m. 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.

3.2. Party Scheduling Through Calendar

On December 20, Jason uses the Google Calendar to schedule a Christmas Eve party starting at 6 p.m. on December 24. The calendar shows that Johnny has been scheduled to vacuum the living room during that time. Hence, Jason reschedules Johnny's cleaning task to another time slot via the calendar interface. Due to the rescheduling, Johnny sends an automatic SMS to Maggie (the owner of the previous cleaning task) to inform her about the change. The calendar interface is shown in Figure 2.

3.3. Progress Update Through Facebook

Because Jason has confirmed the schedule of the Christmas Eve party, Robbie and Johnny keep posting the preparation progress made each day on Facebook. On December 22, Robbie receives a message from one of Jason's Facebook friends asking about the Christmas tree in the living room. Hence, Robbie moves to the living room, takes a picture using its wireless camera, and shares it on its Facebook wall. This scenario is shown in Figure 3.

FIG. 2. Using Google Calendar to interact with the robots.

FIG. 3. Using Facebook to interact with domestic robots.

3.4. Video Chatting Through IM

Mike could not join the party because he is aboard, but he heard of the Christmas decoration at home, and so he would like to take a look. Hence, he starts an MSN video chat with Robbie, as shown in Figure 4:

Mike: Could you show me the Christmas tree in living room?
Robbie: I am moving to living room. . . .
Robbie: I am in the living room now.
Robbie: I am looking at the Christmas tree now.
Mike: Can you turn left a bit?
Robbie: I am turning left.
Mike: Thanks Robbie. It's fantastic!

3.5. Arranging an Urgent Task by SMS

Early on the morning of the Christmas Eve Party, Jason is on a bus heading to work and suddenly remembers some leftover food he dropped after breakfast. Realizing that he may not have time to clean it up before the guests arrive, Jason immediately sends an SMS to Johnny, as shown in Figure 5. Soon after that, Johnny acknowledges Jason with an SMS; ten minutes later, Johnny sends another SMS to inform him of the task completion.

4. SYSTEM IMPLEMENTATION

We envision a flexible and extensible domestic robot management system that could accommodate both single and multiple users, with each user free to choose the desirable client to interact with each robot at home. Based on the vision just presented, we designed and implemented a working system based on the client-server architecture. Figure 6 depicts both the hardware setup and the software components in the client and server side.

FIG. 4. Using MSN to interact with domestic robots.

FIG. 5. Using short message services interface to interact with the robots.

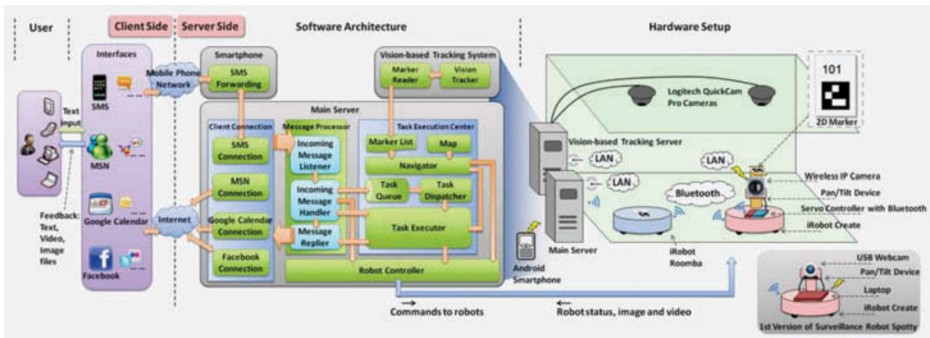


FIG. 6. Overview of system implementation: users, social media interfaces, software architecture, and home–robot system.

4.1. Client Side

The client side requires no development or maintenance efforts from users; the only step required is to install (if needed) the standard version of the social media platforms in their computer/tablet/smartphone, then add the robot's account to their contact list (just like adding a friend). For example, adding a robot to the user's MSN simply means installing the standard version of MSN and then adding the robot to one's contact list.

Although there are a variety of social media available, we choose the following four platforms (SMS, MSN, Google Calendar, and Facebook) due to their popularity and complementary abilities to serve a range of users' needs.

SMS

Text message interfaces like SMS allow us to interact with robots by sending quick text messages. It has a relatively short setup time and can be done almost anywhere with a basic cell phone network. We choose to support SMS because it is arguably the most widely used data application in the world, with 4.16 billion active users at the end of 2010 (Ahonen, 2011). Supporting SMS in our system helps increase the system ubiquity. However, most phone models support only short text-based messages in chunks without graphics and video feeds, which may limit the type of feedback that the robots might send to the users.

IM

Similar to SMS, IM clients are also widely adopted. Some popular clients have more than hundreds of millions of active users (i.e., Windows Live Messenger: 330 million active users by June 2009; Yahoo Messenger: 248 million active users by January 17, 2008). IM offers well-designed notification functionality so that it can easily get a user's attention while he is working with other computer applications. Users can also request video communication so that they can see the happenings on the robot's side. On the other hand, video chatting in IM typically needs a fast Internet connection, which may make it less ubiquitously available for HRI as compared to SMS. In our system, we currently support the Microsoft Windows Live Messenger client (MSN) as it is one of the mostly commonly used IM clients. To interact with a robot using MSN, users only need to add the robot's MSN account to their contact lists and then communicate with the robot just like chatting with anyone else.

Shared Online Calendar

Very different from SMS and IM, shared calendars are designed for both individuals and groups to manage, plan, and overview a working schedule. Interacting with robots via such an interface allows 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.

Our system adopted Google Calendar to interact with robots. Unlike our SMS and MSN clients, Google Calendar does not support real-time communication because excessively frequent data retrieval is prohibited by the Google server. According to our experience, the minimum time between successive accesses is around 40 s. Thus, Google Calendar functions more as a shared task-planning interface than a real-time communication interface in our system.

Social Networking Site

Facebook is a community-based social networking website designed for interaction among a large group of people. Last, Facebook can allow permanent public records like personalized journals for individual interactions, which is particularly useful for social and research purposes (see Figure 3).

Facebook is included in our system as a representative social networking site due to a number of reasons. As of January 2011, it has more than 600 million active users. Besides, Facebook is a community-based website designed for interaction among a large group of people for social networking purposes. It has also been largely explored for many research purposes (Mavridis & Rabie, 2009; Sim et al., 2011). 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.

To talk to robots in Facebook, users can just add the robots' Facebook account as a friend, then talk to them by leaving messages on robots' walls. Feedbacks from robots are sent back via posts on users' wall. However, to prevent spamming, Facebook does not allow frequent data retrieval, which makes it unsuitable for performing real-time interaction with robots.

4.2. Server Side Design

The bulk of the implementation is done on the server side as illustrated in Figure 6. In the following sections, we first briefly introduce the hardware setup and then describe the software components in detail.

Hardware Setup

Main Server. There is a dedicated desktop computer (referred to as the main server in later sections) used to host the entire server side software components. The model number is Dell OptiPlex 780, which runs Microsoft Windows 7 Professional. A smartphone, a wireless IP camera, and a vision-based tracking server (all described in later sections) communicate with the main server via Wi-Fi network, and the robots communicate with it via Bluetooth.

Smartphone. There is also a Nexus One smartphone with Android 2.3.3 which runs an in-house-developed Java application that exchanges messages between the main server and the phone.

Vision-Based Tracking System. Aside from the dedicated main server mentioned previously, there is also a dedicated vision-based tracking server that connects two Logitech QuickCam® Pro cameras that installed in the ceiling 2.5 m above the floor and covered an area of 2 × 4 m. This server tracks the robots' coordinates in real-time by using a vision tracking method (Sakamoto et al., 2009) to recognize the markers on top of robots and send the coordinates to the main server via Wi-Fi.

Robots. We built our robots according to the hardware design shown in Figure 6. Both the Roomba and Create are connected with Bluetooth-to-serial converters called RooTooth so that they can communicate with main server over Bluetooth connection. Figure 7 shows a photo of the two robots.

The iRobot Create is augmented with additional hardware components to enable it to work as a surveillance robot, which include a BlueSMiRF Bluetooth module, a servo controller, a two degree of freedom (2-DOF) CrustCrawler S3 Pan/Tilt device, and an Axis 207MW wireless IP camera mounted on the Pan/Tilt device. The BlueSMiRF Bluetooth module enables the servo controller to receive commands from main server. The servo controller, upon receiving the commands, will control the Pan/Tilt device to make the corresponding movement, which

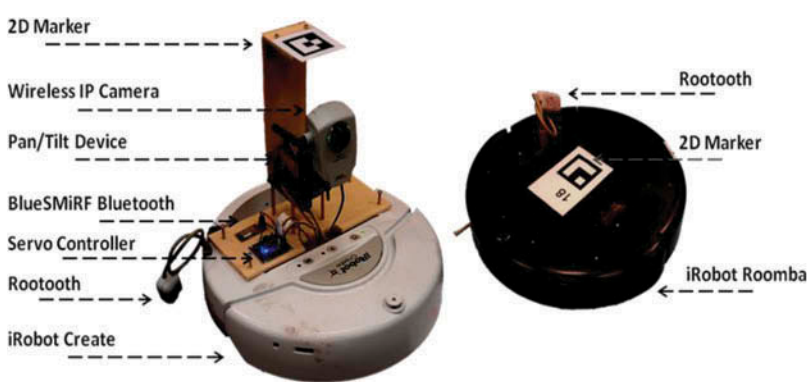


FIG. 7. Robbie the surveillance robot (left) and Johnny the vacuuming robot (right).

will alter the viewing angle of the wireless camera. Images from the wireless camera are then sent to the main server via Wi-Fi.

Software Components

A simplified work flow of the system is described as follows (illustrated in the middle part of Figure 6). Once a message is sent from the client side, it will be received by its corresponding receiver within the client connection component on the server side. The client connection component will then pass the message along with the information of the sender and client type to the message processor, which further analyzes and converts such input into executable tasks. After a message is processed, the message processor will send feedback to the user via the client connection component. Depending on the urgency of the task, it will be either buffered in the task queue or executed immediately by the task executor. The real-time location information of the robots and objects in the environment are supplied by the vision-based tracking component. To control the robot, the task execution center needs to communicate with the robot controller, which handles specific commands to each robot.

Client Connection. This component serves as the bridge connecting all clients, hence it is the only component needed to be changed when new social media platforms are introduced into the system. This component allows the server to receive and extract the necessary information from different types of clients, and it is also responsible for sending server-generated messages back to the clients. Currently, this component includes four client connection modules to communicate with the four social media platforms we mentioned. All the messages come from different clients or users are converted into the unified format (user-client-message), and then passed to the message processor.

SMS connection module. Sending and receiving SMS from the server is done by an in-house-developed Java application on an Nexus One smartphone, which is connected to standard mobile phone network and colocated with the main server via local wireless network so that the application can exchange text messages effectively with the main server.

MSN connection module. An open source application MSNPSharp (MSNP18 Release: 3.1.2 Beta by Xih Solutions) is used to develop an MSN client program running on the main server to communicate with the user's MSN. Currently, only the surveillance robot is equipped with a wireless camera, so the video conferencing capability is enabled only with this robot.

Google Calendar connection module. This module is implemented using the Google calendar data API 2.0. It runs on the main server to communicate with the Google calendar client website. Because the Google calendar website will not inform our server upon users' update, data are pulled from the client website every 40 s.

Facebook connection module. Using the official Facebook Client Library (facebook-0.1.0), we built the Facebook connection module as a Facebook application running on our main server. This module queries message updates on robots' Facebook wall every 90 s and responds to users' requests by posting text and photos on users' wall.

Message Processor. The message processor is responsible for translating the incoming messages from the client connection component into executable tasks. It analyzes the incoming messages using a simple natural language processing method: Each input sentence is first broken into words and matches against the keywords from the following three categories in descending priorities: tasks (e.g., vacuum the bedroom now), general contextual inquiry (e.g., what's your schedule?), and socialization (e.g., hello). If a sentence contains keywords in more than one category, keywords of the highest priority category are used.

Task sentences are identified by a few action keywords (e.g., "vacuum"). Once a sentence is identified as tasks, we further look for other details of the tasks such as time (e.g., "now," "5 pm"), location (e.g., "bedroom"), item (e.g., "trash can"),

TABLE 1
Tasks Supported by the Two Robots

Robots	Johnny (Vacuuming Robot)	Robbie (Surveillance Robot)
Specific tasks	vacuum/clean	take photo/picture look forward look up/down/left/right
Common tasks		move/go forward/backward turn/spin left/right/around stop; go home, dock, charge/charging
Target locations		bedroom, bed, window, door flower/flowers, dog/pet
Time		now/10 a.m./5 p.m./etc.

and convert the message into a task object. The currently supported tasks and their corresponding keywords are listed in Table 1.

Task Executor Center. The task executor center consists of several parts: a task queue, a task dispatcher, a task executor, and a navigator. Each task in the task queue will be assigned to a task executor by the task dispatcher in a first-in-first-out order.

The navigator is responsible for navigating the robots to some specific locations. Robot and object locations are updated in real-time by a vision-based tracking system (which is introduced in more detail in the upcoming Vision-Based Tracking System subsection). Certain fixed locations are prestored in the system map. Based on the robots' and locations' coordinates, the navigator computes the routes and directs the robot controller to move the robots to the required location.

Robot Controller. The robot controller is responsible for communicating with the robots through wireless connection. Because multiple household tasks can be received simultaneously, a queue is built for buffering the tasks. The robot controller retrieves each task from the queue, translates it (such as "take a photo of the window") into a series of basic movement commands for each robot (such as "move forward," "stop," "turn right"), and sends the commands to the robots via Bluetooth connection. The robot controller currently supports iRobot Roomba and iRobot Create by using the roombacomm Java library provided by hackingroomba.com.

Vision-Based Tracking System

As described in former subsections, we set up a vision-based tracking system to support robot navigation. The vision tracking component uses proprietary 2-D planar ID-markers as shown in Figure 6 (upper right), which were similar to those in earlier work such as CyberCode (Okada et al., 2005) and ARTag (Forlizzi, 2007). A marker consists of a 3 × 3 black-and-white matrix pattern within a black border surrounded by white margin. Each marker is about 5 × 5 cm^2, in which we managed to recognize stably using two 960 × 720 resolution ceiling cameras (2.5 m high) covering a 2 × 4 m region on the floor.

5. USER STUDY

We conducted our user studies in order to seek answers for the following questions: (a) Will the users feel comfortable, natural, and intuitive to "chat" with robots using the interfaces that are originally designed for interpersonal communication? (b) What are the factors that affected users' feeling and decisions in choosing different interfaces? (c) Do these interfaces complement each other when interacting with domestic robots in varying contexts/scenarios? We first conducted usability experiments in our lab to seek answers for the first and second questions. Then we conducted a multiday field study, attempting to seek answers for all three questions in real setting.

5.1. Usability Experiment

Participants

Twelve participants (six female, six male, 19–30 years of age; $M = 24.4$, $Mdn = 24.5$) are involved in this experiment. Among them, nine are from the university and three are from the community (working professional). Each received about $US10 for the experiment. Table 2 summarizes their prior experience with the four employed social media platforms.

Environment and Apparatus

We decorated a 4 × 2 m space in our lab to turn it into a simulated living room and a simulated bedroom, as shown in Figure 8. In Figure 8, the two robots were decorated with colorful paper to make the participants feel familiar with the whole environment.

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 a previous section.

Server and Robots. The setup is described in the System Implementation section, and we conducted the experiments in two different closed rooms and an open hallway.

TABLE 2
Participants' Prior Experience on the Four Platforms

	Participant ID												
	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	Average
Frequency													
SMS	3	3	1	3	3	1	2	2	3	2	3	3	2.42
MSN	3	3	3	2	3	3	3	3	3	2	3	1	2.67
Calendar	1	3	2	2	0	0	1	1	0	0	1	0	0.92
Facebook	2	2	2	3	3	3	2	2	2	2	3	2	2.33

Note. SMS = short message services; 0 = never; 1 = at least once a month; 2 = at least once a week; 3 = everyday.

FIG. 8. Experiment setup for the usability experiment in the lab.

Interfaces

In addition to the four social media platform interfaces, we developed a *point & click* web interface (*Web*) for comparison. This interface is created by augmenting the standard *roomba-comm* control interface (obtained from http://hackingroomba.com/). The design of the interface is similar to the web remote robot control interface developed in previous research (Sakamoto et al., 2009). As shown in Figure 9, this interface supports live video feed with buttons and widgets for different robot tasks. Each robot (Johnny and Robbie) 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.

The five interfaces (the four social media platforms and the web interface) have different characteristics (see Table 3). The

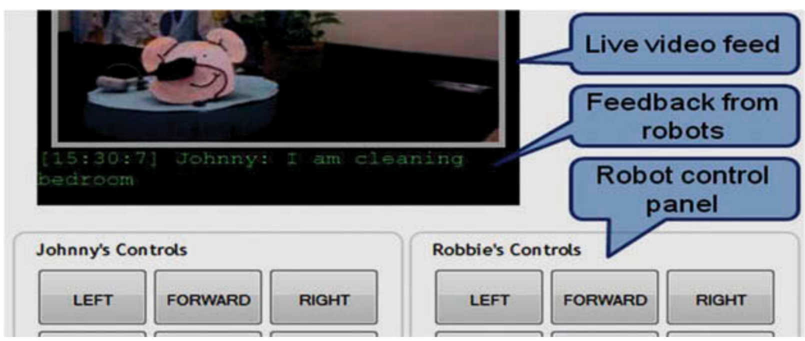


FIG. 9. Web interface for interaction with domestic robots.

TABLE 3
Features and Characteristics Summary for Each Interface Used in the Use Study

	mainly text input	mainly point & click	text feedback	image, video feeback	immediate feedback	short setup time	history of interaction	over-view of tasks	share with group	good notification	anywhere access
SMS	X		X		X	X				X	X
IM	X		X	X	X		X			X	
Calender	X		X				X	X			
Facebook	X		X	X			X		X		
Web		X	X	X	X						

Note. SMS = short message services; IM = instant messaging.

four social media platforms use natural language as the main interaction method, whereas Web uses point & click. SMS, IM, and Web interfaces support real-time (or near real-time) feedback, whereas 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, for example, shared calendar is mainly for task scheduling, whereas Facebook is good for social interaction with many people, and so on. Given the different characteristics of each interface, we are interested to find out users' preferences in using them.

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 3×3 controlled study on the three real-time feedback interfaces (SMS, IM, and web interface) under three different conditions. Note that because 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 Table 4. For each task, the participant was given a 2-min time limit. If he or she failed to complete the task within this limit, the experimenter will demonstrate the procedure to him or her and ask him or her to complete it again.

Part 2: 3×3 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, whereas the order of interfaces within each condition is randomized to counterbalance the ordering effect.

Conditions

1. *Single-tasking condition*. In this condition, participants can just sit in front of a computer to perform a single given task with their full attention. This condition simulates a basic environment in office-like setting.
2. *Multitasking condition*. In this condition, participants again sit in front of the same computer as in Condition 1, but they have to interact with robots while performing a primary task. This condition aims to simulate a usual situation in office where one has to attend to regular office work while interacting with others, say, domestic robots. Here we adopt the low-intensity multitasking condition from the study presented by Ahonen (2011) 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. Due to space constraints, please refer to Ahonen (2011) for details.
3. *Mobile walking condition*. Walking is a representative on-the-move scenario (Young et al., 2009). Because 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 m long and 2.5 m 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.

Domestic Tasks. For each interface, participants were asked to do a domestic task with robots in three steps. Instruction for the next step is revealed only after receiving robot's notification on completion of the previous step. A sample task sequence is listed next:

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.

Overall Procedure. Upon arrival, each participant was first taken to the room where our server system resides. Part 1 of the user study and prestudy 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 first two stationary conditions, they were then taken to an open hallway to work

TABLE 4
Tasks Used in Part 1 of the User Study

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 3 p.m. 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.

on the tasks in the mobile walking condition. After Part 2, they were brought back to the first room to complete the poststudy questionnaire and interview. The entire study including questionnaires and interviews is performed at one sitting, including breaks, in around 2 hr.

Results

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" and "eye-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 min) without prior training or help from the experimenter (except one participant who failed the assigned task with Facebook).

Participants commented that SMS and IM are the easiest to learn and use, as all of participants have prior experience in using SMS and IM (see Table 2). 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 (five of 12) had never used Google Calendar before, so they required additional time to figure out how to use the interface. However, once they learned it, all of them found the five interfaces to be intuitive and easy to use.

Part 2: 3 × 3 Controlled Study.

Task completion time and completion rate. Because all participants successfully completed the tasks, there are no differences in task-completion rate across all the 3 × 3 cases. We focus on the task completion time for each interface and condition in Part 2 of the user study (Figure 10).

Task completion was measured from the moment a task instruction was given to the participant up to the time that the participant received the final notification message from the robot that all three steps of the task have been completed.

Among all combinations of conditions and interfaces, repeated-measure analysis of variance showed that there was a significant main effect on interface, $F(2, 22) = 21.48$, $p < .001$. Pairwise t tests (least significant difference [LSD]) showed that SMS (202.56 s) is significantly slower than either IM (143.83 s) or 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 multitasking condition (157.7 s), and then walking condition (202.35 s). There was a significant Interface × 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, whereas the performance of IM and Web decrease significantly from stationary conditions to walking condition (Figure 10; $p < .01$).

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 multitasking 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, because tasks can be done with single (or a few) button clicks.

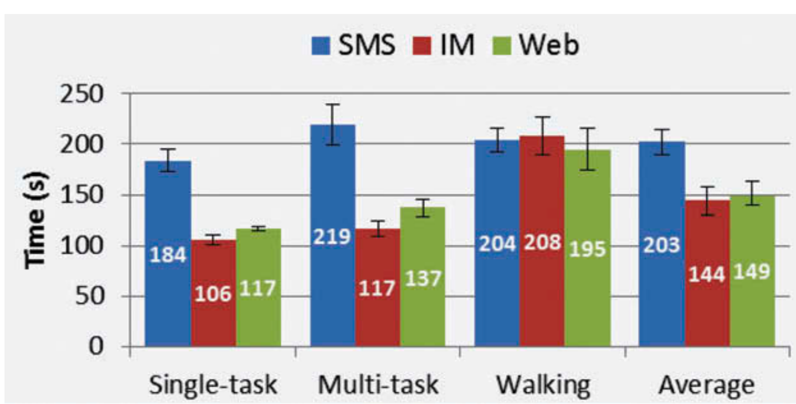


FIG. 10. Task completion time (seconds) for the three interfaces under various conditions.

Note. Error bar shows the standard error. SMS = short message services; IM = instant messaging.

Participants' preference. Participants were also asked to rate the preferred interface for each condition in Part 2 of the study (see Table 5). For the single-task condition, eight participants preferred IM, two preferred SMS, and two preferred Web. In the multitasking condition, 10 participants preferred IM, two preferred Web, and no one preferred SMS. In the walking condition, seven participants preferred Web, and five preferred SMS.

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, as 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 (Sugiura et al., 2010). In the poststudy 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, as they are "always on," so participants need not start another application. Last, participants also felt that IM is more humanlike and entertaining to use compared to Web; see an elaboration later.

In the mobile scenario, the situation differs. None of the participants preferred IM. They chose either 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 (six 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 (six of 12) said that it depends on the situations. Three participants said that they prefer either SMS or IM, whereas 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.

5.2. Overall Results

At the end of the user study, we also asked users about the advantages and drawbacks of each of the five interfaces. Although the previous sections have already summarized SMS, IM, and Web, what follows is what participants said about Calendar and Facebook: Nine 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 eight of 12 prefer the Facebook interface to easily share robot activities with their family members and friends. However, because these two interfaces are unable to provide real-time feedback, all users commented that they were unsuitable for assigning immediate tasks to robots.

Besides preferences, we also asked users to rank the social perception of robots from a Likert scale of 1 (*machine-like*) to 7 (*humanlike*). Results are summarized in Figure 11. We compared the scores using one-way repeated measure analysis of variance 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 humanlike than Web ($p < .05$). Among the four social media platform interfaces, IM (5.77) is significantly more humanlike compared to both SMS (4.38) and Calendar (3.46; $p < .05$) but is not significant different from Facebook (5.08).

TABLE 5
Participants' Preferred Interface in Each Condition

	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	Summary
Preference													
Single-task	I	S	I	W	l	l	l	l	W	l	l	S	8 (l), 2 (S), (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.
Note. S = short message services; I = instant messaging; W = Web; D = Depends on situation.

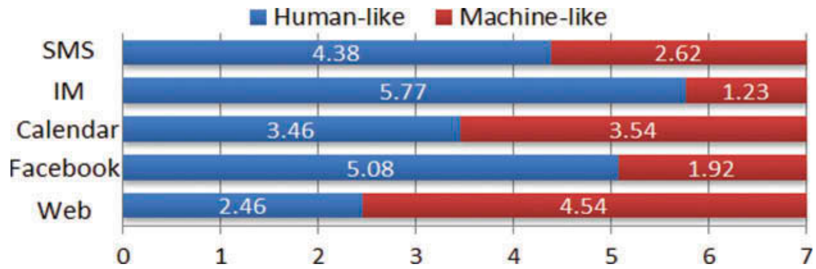


FIG. 11. Average score of human-likeness for each interface. *Note.* SMS = short message services; IM = instant messaging.

Facebook (5.08) is significantly more humanlike 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 poststudy interviews, we identified the following factors that contribute to the difference in users' perception of robots.

Interaction Method

Nine 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 humanlike 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 humanlike because these interfaces are primarily used by them to interact with other humans.

Responsiveness

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 aforementioned factors that contribute to human-likeness, whereas Calendar has the least among the four social media platforms. Designers are suggested to consider the aforementioned factors for their interfaces if they want to augment the perception of robots, making them appear more sociable and humanlike.

5.3. Overall Results

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 that reusing 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 humanlike and sociable. We found that users' perception of robots' social intelligence is a function of many factors, including interaction method, interface design, purpose of the interfaces, and responsiveness 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 versus perception of human-likeness and sociability. Although *point & click* interaction method is more convenient than *typing*, it makes robots appear less humanlike and sociable.

Although most people embrace the idea of using social media platforms to interact with robots, there are also concerns that point to future research direction, for example, two 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.

5.4. Field Study

Participants

Two participants were recruited. Their background information is listed in Table 6. Each participant spent 3 days for this study and received an amount of $US64.

TABLE 6
Participants' Background in the Field Study

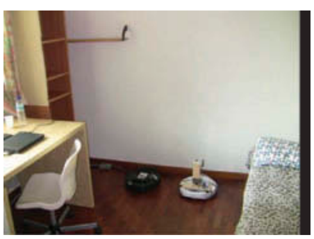
		Participant 1	Participant 2
Gender		Female	Female
Age		30	27
Occupation		Computer engineer	Assessment officer
	SMS	Everyday	Everyday
Prior	MSN	At least once a week	Everyday
experience	Google calendar	Once over a month	Once over a month
	Facebook	At least once a week	Once over a month

Note. SMS = short message services.

Environment and Apparatus

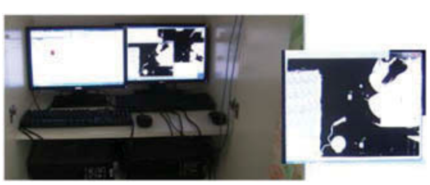
We rented a multiroom apartment for this field study and deployed the entire system in one of the bedrooms. The bedroom is about 3 × 5 m, whereas the available space for robots to roam is only about 1.5 × 3 m; therefore, two ceiling cameras are enough to cover the entire space for robot navigation.

To hide the supporting equipment from participants' normal lives, we installed the vision tracking server and main server in an empty wardrobe. The only equipments exposed to the participants are the two robots and their charging docks, and two ceiling cameras, as shown in Figure 12. Please refer to our supplementary video for a visual description of the settings.



(a) The two robots in the bedroom.

(b) Ceiling cameras for the vision-based tracking system.



(c) Main server and vision-based tracking server in the wardrobe.

FIG. 12. System setup in the experimental apartment.

Procedure

The 3-day field study consisted of two sessions. The first session was conducted in the 1st day of the 3 days. During the 1st day, participants needed to remotely carry out the tasks in Table 4 while working in the office. This session served as a tutorial of the four HRI interfaces. In the evening of the 1st day, the experimenter interviewed the participants for feedback.

The second session was conducted in the next 2 days, where the participants were free to use the robots as they like. In addition, the experimenter also sent some requests to the participants through SMS to trigger certain interactions. We carefully picked the time to send these messages so that we could cover more diverse set of scenarios that the participants may encounter (such as on the way to work, walking, sitting next to a computer, having meal with others, talking, etc.). The participants were so busy working that they ignored some of our notifications; therefore the numbers of tasks both participants actually completed are not equal.

After the second session, the experimenter interviewed the participant again to collect their overall feedback.

Results and Discussion

In summary, both participants enjoyed using existing social media platforms to interact with domestic robots. Although the robots' capability is limited, both participants are convinced about the potential of domestic robot systems.

During the second session, Participant 1 chose to use SMS for 50% of the tasks (four of eight tasks) and Facebook for the other 50%, whereas Participant 2 chose to use MSN for 100% of the tasks (seven of seven). This is coherent with their prior experiences summarized in Table 6, which indicated that Participant 1 uses Facebook much more often than Participant 2 (at least once in a week vs. once over a month), whereas she uses MSN much less often than Participant 2 (at least once in a week vs. everyday). In the interview, Participant 1 summarized her reason for preferring SMS as "SMS is definitely the most easy and convenient way (to talk to robots)," and the reason that she also prefers Facebook is that she is using a Facebook app integrated on her iPhone.

Similarly, Participant 2's reasons for preferring MSN over any other interfaces is also that she is using an integrated MSN app on her iPhone every day. This demonstrated that prior experience in using the social media for interpersonal communication have strong influence on the participants' choice to interact with the robots.

It is also obvious that both participants were trying to keep using the same social media platforms for various types of tasks, no matter whether they were using a phone or a computer, working in the office, or walking down the street. Both of them never used Google Calendar at all throughout the second session, even when they received request to schedule a repetitive routine task. In the poststudy interview, both participants expressed that they do not have the habit of using Google Calendar, and it makes them feel that the robots are less interactive.

The aforementioned observations seem to be contrary to our design purpose that different interfaces would be used in different contexts/scenarios. However, we argue that this is because the prior experience has greater effect on interface selection than the complementary ability of different platforms, and the Google Calendar interface could be more useful for overviewing scheduled tasks, in particular when the same robot is being deployed to more than one family members (which is not covered in our field study as it is hard to find a whole family to try out the system). More specifically, the users would only switch between those interfaces that they prefer to use. This is supported by Participant 1's behavior in the second session because she chose Facebook whenever there is available Internet connection and SMS whenever there is no Internet. Participant 2 also explained in the interview that she would probably switch from MSN to SMS if she is driving or when the Internet is not available.

When asked about suggestions, both participants suggested to include more popular clients such as Skype, Google Talk, and so on, in our system. More interesting, participants hope to see more humanlike features attached to robots by the interfaces. For instance, Participant 2 said she expects to see the notification "Johnny is typing . . ." in MSN chat window while talking with the robot, although she is aware that the robots are wirelessly communicating with the MSN client rather than physically tapping on keyboard. These suggestions made us believe that using social media platforms to interact with robots is a promising approach to bridge the gap between robots and ordinary users.

6. CONCLUSION

This article explores the application of multiple popular social media platforms to support interaction between human and domestic robots. A working system integrating four complementary social media platforms (SMS, MSN, Google Calendar, and Facebook) and two domestic robots (a vacuuming robot and a surveillance robot) was developed to extend our interpersonal communications further to domestic robots. We have conducted lab experiments and multiday field studies, which showed that the approach can contribute to delivering a more user-familiar, flexible, and intuitive interface for common users to interact with robots.

Our approach of leveraging complementary social media platforms for HRI could open up new prospective research directions. Researchers are encouraged to study the longer term effects, for example, 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.

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