Smart Home Agents and Devices of Today and Tomorrow: Surveying Use and Desires

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ABSTRACT

How are people using current smart home technologies, and how do they conceptualize future ones that are more interconnected and more capable than those available today? We deployed an online survey study to 150 participants to investigate use of and opinions about smart speakers, home robots, virtual assistants, and other smart home devices. We also gauged how impressions of connected smart home devices are shaped by the way the devices interact with one another. Through a mixed-methods qualitative and quantitative approach, we found that people mostly use single devices for single functions, and have simple and brief interactions with virtual assistants. However, they imagine their future devices to have more control over the physical environment (i.e., interact with each other) and envision them interacting with people in more socially complex ways. These findings motivate design considerations and research directions for connected smart home technologies.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

survey, human-robot interaction, human-agent interaction, smart environments, smart homes, IoT

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1 INTRODUCTION

Nationwide surveys in 2019 and 2020 found an increase from 21 to 24% in U.S. adults who own smart speakers and increasing use of voice-operated personal assistants [23], echoing previous observations (e.g., [1, 4, 12]). We are moving in the direction of generalized home automation and Internet of Things (IoT) devices in personal spaces being the norm for many people for whom the requisite technologies are accessible and affordable. This myriad of artificially intelligent voice assistants, robots, thermostats, and cameras residing in people's living spaces is growing collectively more capable, more functional, and more networked. However, this growth and advancement is juxtaposed with persistent weaknesses in systems, such as failures to achieve user goals, a lack of connectivity across multiple devices in a household, and an inability to perform interactions that involve more than a simple command and response.

In 2019, a coalition of major technology companies announced plans to determine and implement connectivity standards for the Internet of Things. Such standards can render software and devices by different companies similarly secure, reliable, and cross-compatible [3, 17, 27], thereby removing a major barrier to interconnected systems. This effort complements the work of human-computer interaction (HCI) researchers who recently have begun to ground theoretical, contextualized work on smart homes in the realistic challenges of deploying products that exist today (e.g., [10, 13, 31]). It also has inspired work that explored boundaries and social mores for future "superhuman" social technologies [15, 22].

For a future in which the roles and designs of smart home technologies are functional, accessible, and socially and ethically responsible, it is necessary to determine what potential users value. We focus on the research questions: ***RQ1:*** *How do people currently use and interact with smart home and IoT devices in their homes?* and ***RQ2:*** *What do people want their use and interactions with smart home technologies to look like in the future?*

To answer these questions, we conducted an online study and found that while people currently use smart home technologies as single-function tools, they envision a future where these technologies both improve these functions and interact in more complex ways. We discuss these findings and design considerations for future smart home technologies.

2 RELATED WORK

Many papers have described exploratory and empirical findings regarding how people use smart speakers. Through interviews, one study on how smart home agents might manage multiple users

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found that it is extremely important for shared agents in the home to understand the relationships among their users [16]. Another study used Amazon Alexa audio logs and interviews to understand household use [26]. The authors suggested that future smart speakers refocus data mining on users' routines rather than topical recommendations, leverage knowledge of place, and connect multiple devices. In another study of users and non-users of Amazon Alexa devices, most users did not consider privacy when choosing a device location [14]. Several papers (e.g., [2, 18, 24, 25, 31]) have proposed design guidelines for smart home devices based on studies of what users and potential users value. Prior work has also explored user perceptions of smart home technologies that act as "routine assistants" [8], automating tasks based on observation of manual work and predictions about people's behavior, and proposed that smart home assistant creators consider how interactions might unfold in four design spaces: onboarding, routine prediction and automation, occasional tips and facts, and configuration panels. Ideally, devices should be able to interface with each other [24] and be cognizant of data privacy and security risks [11]. However, there is potential for privacy violations and problematic unawareness about privacy to deepen when multiple devices pass data back and forth. Thus, some work has focused on making the active agents in a multi-agent architecture selectively disclose user information to only specific parts of the entire system [28–30]. Industry and media surveys also provide useful insight into habits and patterns surrounding smart home device ownership and use, particularly for smart speakers (e.g., [1, 23]). Our survey differs from these works in that it studies both actual current use and possible future use of smart home technologies, and it is scoped to all kinds of smart home devices (including robots), rather than just smart speakers. Additionally, our study analyzes both closed-ended and open-ended questions asking participants to reflect on their thoughts, feelings, and use of present and future products.

3 METHOD

To balance the summative numeric insights of a large, quantitative survey and the detailed insights best afforded by qualitative interviews (see [7]), we used a survey with closed-ended questions about habits and impressions and open-ended questions about experiences, desires, and values for present and future devices.

Participants first reported their mood via two Affective Sliders measuring pleasure and arousal [5].[1] We did not find any extreme response data. To address RQ1, we asked participants to report the smart speakers, robots, smart home devices, and virtual assistants they used. Participants were asked if they had any technologies in each category[2]. If so, they were asked to report each product they owned and the quantity of that product they had. They answered questions pertaining to what led them to begin using each product, what they liked and found frustrating about their interactions with the product, and who the primary and secondary users of the product were. We also asked multiple choice and short-answer questions that were specific to each technology type. For smart speakers, participants indicated whether the speaker had a screen and its location. For robots, they described its typical use and whether it was connected to other devices in the home. For smart home devices, they described its typical use and how it was usually controlled. For virtual assistants, they indicated whether the default voice was used, whether it was connected to other home devices, its usual uses, the hardware devices used to interact with it, and whether the interactions differed by hardware device. To further examine RQ1, we asked several fill-in-the-blank questions about what participants "would usually do" in various scenarios evocative of situations people encounter in everyday life. Participants reported on three questions pertaining to future smart home devices. We used this data to answer RQ2 and to inform needs and design recommendations for future devices.

We recruited 150 adult participants in the U.S. and Canada through Prolific.co. (Four additional participants did not successfully complete the survey.) Participants ranged in age from 18 to 63 years ($M = 30.33, SD = 9.5$). Eighty-four participants self-identified as female, 62 as male, 1 as non-binary, and 3 as other genders. 121 participants lived with others; 29 did not. All participants reported having a smartphone (76 Android, 72 iPhone, 2 other). Most participants spent 20-40 minutes on the study; each received $6.00 USD. Our study was approved by our Institutional Review Board.

Participants from Prolific.co were directed to a Qualtrics page where the survey was hosted. After consenting to the study, participants answered the mood questions, the use of smart home technologies questions, the habitual interactions and desires for future devices questions, and demographic questions[3].

We used a mixed-methods approach, drawing on statistical analysis, qualitative coding, and thematic analysis. We used a detailed coding process for eight qualitatively measured variables and a broad thematic analysis for several other variables. For the eight coded variables, we applied an inductive coding approach (see [6, 9]) to group the short-answer responses according their topics. This process included two coders looking at a portion of the data to generate an initial set of labels, coming to a consensus, independently coding additional data, and calculating agreement. Then, the coding scheme was revised and the rest of the data were coded with a 40% overlap in sets. Agreement (Cohen's κ) scores are reported in Results. Other questions were analyzed at a less-granular level through affinity diagramming and discussion.

4 RESULTS

4.1 Use of smart home technologies

Of our 150 participants, 95 owned at least one type of smart home technology (smart speaker, robot, or other smart home device). Most participants (76) owned between 1 and 4 devices. No participant owned more than 2 different robots, more than 3 different smart speakers, or more than 3 different smart home devices. The maximum number of each smart home technology product reported by any participant was 2 for robots, 5 for smart home devices, and more than 6 for smart speakers. Use of smart home devices and smart

[1] We especially wanted to check for effects of mood because our survey took place a few months into the COVID-19 pandemic. (Research suggested that use of smart speakers rose during this period [23].)

[2] We provided participants with a few example technologies in each category, e.g., "Amazon Echo" for smart speaker, "Roomba" and "Jibo" for robot, "thermostat" and "outlet" for smart device, and "Siri (Apple)" and "Alexa (Amazon)" for virtual assistant.

[3] Participants also answered questions about hypothetical future smart home systems and customization, but these data were not analyzed for this paper.

speakers was correlated, $r = .374$, $p < 0.001$; no other correlations among smart speakers, robots, smart home devices, and virtual assistants were found. Across all 202 devices owned by participants, 159 had the participant as a primary user, 77 had another primary user, and 82 had secondary users. 114 devices were purchased by a participant, 36 by another household member, 36 as gifts to a participant, 6 as gifts to another household member, and 10 were free with another product or the home itself.

Smart speakers. Across all participants, 102 smart speakers were owned. The most common brand for smart speakers was Google (47), followed by Amazon (44), Apple (3), and Lenovo (2). Other brands included Facebook, Jambox, COWIN, Mint, and Sonos (1 each) and unknown (2). When asked what they most liked about their interactions, most participants mentioned the convenience of using voice interaction for simple tasks like finding out the weather and playing music. Some participants mentioned the quality of voice interaction (e.g., "spot on"–P135). A few people liked their speakers' conversational or social capabilities: P38 said, "It tells witty jokes," and P127 said, "Treating her like she's part of the family." The most prevalent frustration was the speakers' inability to reliably hear and understand users: not responding when spoken to (e.g., "Sometimes it doesn't pick up on its cue,"–P47), erroneously hearing a wake word and speaking out of turn (e.g., "activates at random times"–P108), and failing to understand utterances in different accents and languages (several participants). A few participants commented on speakers' limited functionality or a general dislike of using voice interaction in certain contexts, e.g., when home alone (P22).

Robots. Across all participants, 23 robots were owned. Most of these (14) were iRobot Roomba vacuum cleaners. Others were other types of vacuum cleaners (6), impossible for us to identify (2), or not robots (an Amazon Fire Stick) (1). No participant owned anything that we identified as a social robot. Participants liked that robots were easy to use and did their jobs well (e.g., "It cleans well and easily", P18; "I like that it gets the job done," P76). Nearly all frustrations with robots (which were effectively all vacuum cleaners) were about them getting stuck, encountering obstacles, or needing maintenance and cleaning. P100 noted inaccurate voice recognition, and P6 noted their pet's and baby's averse reactions. Five participants reported that they connected their robots to either a smart speaker (3), a smartphone (1), or smart home devices (1).

Other smart home devices. The number of other smart home devices totaled 77 and fell into 5 categories: doorbell or security camera (20), lighting (16), power outlet/plug/switch (11), thermostat (13), and TV (6). Eleven device types either occurred only once or twice (e.g., smart lock, smart fitness scale, laptop) or were impossible for us to identify and were labeled as other. Because several different kinds of devices were reported, responses to the question about what participants liked varied. In general, responses reflected appreciation for the device's intended functionality, ease of use, reliability, and simplicity. Many participants had no frustrations with these smart home devices. Those who did focused largely on occasional signal and noise confusion (e.g., "Sometimes picks up movement on the street"–P132 in reference to a home security system) and connectivity issues (e.g., "unpairs itself from my bluetooth phone"–P64). Other frustrations included slowness and limited power capacity. Participants reported controlling their smart home devices via an app or widget on a smartphone (50), a smart speaker (14), and an interface on the device itself (13).

4.2 Use of virtual assistants

100 participants reported interacting with at least one virtual assistant (VA), and no participant interacted with more than 3 VAs. The assistants that participants reported using included Apple's Siri (57) Amazon's Alexa (28), Google's Assistant (31), Microsoft's Cortana (9), Samsung's Bixby (2), and Yandex's Alisa (1).

People gave a variety of answers to our questions about what they liked and found frustrating about their interactions with VAs. Overall, likes and frustrations looked similar to those for smart speakers. This is likely because "interactions with VAs" and "interactions with smart speakers" similarly refer to speaking using voice as an input and output modality for interacting with non-embodied interfaces. The similarity was evidenced further by the fact that many participants discussed VAs in the smart speakers section and vice versa. In general, people liked VAs for their ease of use and for the convenience of hands-free interactions. As with smart speakers, they were frustrated by having to repeat things multiple times for VAs to correctly interpret them.

The most common uses for VAs were finding out the weather, playing music, and getting answers to specific factual questions (see Figure 1 for details). The least common reported use of VAs was controlling other devices. We also asked participants if their interactions with VAs changed when using different physical devices. Nineteen responses indicated that participants interacted through more than one device, and only five of those responses reported that interactions differed across different devices.

We asked three free-response questions about what participants' interactions with virtual assistants usually look like in specific contexts. The first prompt was, "You arrive home in the evening after running errands and need to ask your virtual assistant something. What will you ask?" Participants mostly answered with specific requests, like asking for the time (30 participants; the most common answer), for entertainment (e.g., playing music or a podcast) (22), and for the weather (21). Many participants said that they would ask for information about their schedules (14), information about food (13), or items on their to-do lists (12). A few requested physical tasks like cooking a meal or cleaning. The second prompt said, "You get in the car to start a 20 minute drive. What will you say to your virtual assistant?" Participants asked for directions or navigation (70), asked for entertainment (42), requested information about traffic (16), gave commands related to starting or controlling the car itself (8), and asked to send messages or get updates regarding other people (6). A few participants' responses were of a purely conversational nature (e.g., "Did you miss me?", P28). Twenty responses were labeled as "other". The third question asked, "You arrive home in the evening after work, and your virtual assistant has a notification for you. What will it be?" Many responses were not actually answers to the question, perhaps due to difficulty in understanding the prompt. The remaining responses were about package deliveries (12); status updates about their homes (e.g., who had stopped by) (11); event, product, or media recommendations (7); event reminders (6); and status updates about other people (2).

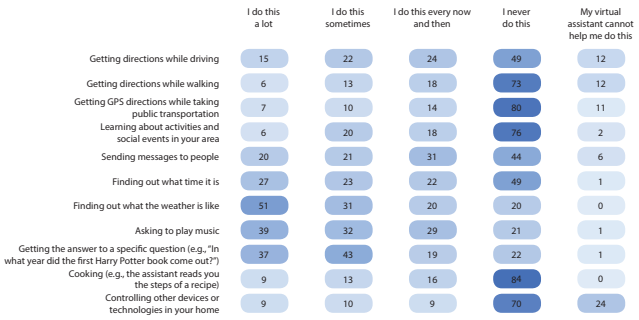

Figure 1: Number of participants who used virtual assistants for each of eleven tasks. Higher counts have darker shades.

4.3 Desires for future systems

Several aspects of our study examined what people desire and dislike in terms of how future smart home technologies should be designed to behave and interact (RQ2). We organized and analyzed the qualitative and quantitative results from these different sections of the survey in light of one another around broad themes.

Our analysis of data from the question, "What would you like to be able to do with your smart home devices that you cannot do today?", generated 158 comments across all responses. The largest category (aside from *other/unknown* (34)) was *controlling the environment* (30), followed by *better functionality for existing tasks* (25). Slightly less common were *physical chores* (23), *"nothing"* (17), *life management/personalized recommendations* (13), *socializing* (8), *privacy controls* (4), *driving* (3), *and voice interaction* (1). A few notable responses reflected new uses and functions, such as "bath [sic] with it" (P50) and "interact with other people's google home" (P101). Coders moderately agreed on labels, Cohen's $\kappa = 0.582$.

The opposite question, "What do you NOT want your smart home devices to be able to do in the future?", generated 175 comments. Most were about data sharing and privacy. We broke this down into *data collection/monitoring* (e.g., "record private conversations", P10) (71) and *data sharing* (23) (e.g., "give my information/data to the company that created it", P63). The *other/unknown* category was also fairly large (29); responses included lifelike behavior (P99), having only a single function (P65), and forced upgrades (P80). Medium-sized categories were *being proactive* (e.g., placing orders, calling people on the user's behalf, acting with autonomy) (22); *having social power* (15); *controlling the environment* (10); *advertising* (2); and *uncanny/humanlike behavior, being a single function item*, and *forced upgrading/lockouts* (1 each). Coders moderately agreed on labels, Cohen's $\kappa = 0.523$. Answers on whom or what they believed smart home device data should not be shared included: *anybody without express consent* (59), *third-party companies* (51), *other third parties* (34), *law enforcement or government* (32), *the maker company* (16), and *other/unknown* (8). Coders moderately agreed on labels, Cohen's $\kappa = 0.497$.

5 DISCUSSION

In our study, smart speakers and virtual assistants were mostly used to find out the weather, play music, and answer specific factual questions. Rarely, they were used to control other devices. Robot vacuum cleaners did not interface with other technologies or interact with their users beyond turning on and off as commanded. They were mostly judged according to their ability to get the job done. Impressions of non-robot, non-speaker smart home devices (e.g., thermostats, lights, security cameras) were formed mostly on the basis of their intended functionality rather than on their performance or design. These devices primarily were controlled by apps rather than through voice or on-board input devices.

It should be no surprise that people's interactions with their smart home devices do not usually comprise more than a single request and response. Our work is only one of many reporting this (e.g. [23, 26]). However, we also found several indications that people anticipate a future that goes beyond these short, single-task interactions. In some cases, people also anticipate technology as being more than a tool, such as behaving as a pet or serving as a companion; many participants wanted to interact with their smart speakers socially. Importantly, the most common desire for future smart home interactions was the ability to control the environment. While this capability exists to an extent in many products that are on the market today, it was prominent in our study as a *desire* and not as a *current use*. This may mean that the control afforded by currently available products is not discoverable, not useful, or not worth its own setup cost (in time, money, and learning).

Many people wanted voice added to future iterations of smart home devices that do not currently use voice interaction. When asked to freely express what they liked about smart speakers and virtual assistants, many people mentioned that they appreciated when the voice recognition worked. Conversely, when participants in our study had frustrations with their smart speakers and VAs, an enormous number of their grievances centered on the AIs' inability to understand them. Several studies have similarly surfaced users' aggravation with the impacts of bias in voice recognition technology ([19–21] are only a few examples). This is a potential caveat of the suggestion to embed voice into the design of more devices. It also underscores quality of function—which requires training voice UIs on diverse set human speech data—as the most important priority in the design of future smart home devices that use voice.

We also found that data collection and monitoring, especially when undisclosed, was the most significant concern about the advancement of smart home technology. When asked to reflect freely on how data *shouldn't* be shared, the second-largest category that participants' responses fell into (behind "anybody without consent") was "third-party companies". These findings reinforce the need for transparency about what data is being collected when, and with whom it is being shared.

Our work is limited in that several of our survey questions were about how people imagine themselves using and wanting to use devices. People are not always be able to accurately predict their own behavior, so the findings about predicted future use may not translate to what we can expect to actually see from users. Prolific users were also required to be in the U.S. and Canada to participate, so our findings are culturally representative of those two countries.

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