Smart Assistive User Interfaces in Private Living Environments: Challenges and Perspectives

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Abstract: The paper outlines a vision of how smart assistive user interfaces in private living environments could exceed the current state of the art. In particular, it is shown how a virtual assistant capable of evolution and capable of absorption is beneficial and a step towards an entity that is able to identify and make accessible through a user interface as many suitable services of the smart home environment as possible that fit the individual needs and interests of its users. Challenges such as the coherence challenge, the design challenge, the user acceptance challenge, and the security and privacy challenge are identified that are significant obstacles in realizing the vision. Based on this, approaches that provide a perspective to overcome these obstacles are presented. Here, the paper looks at advanced UI technology, robotics, user profiling and smart reasoning, software architectures, the internet of things, organic computing, and advanced security methodologies. Finally, the paper discusses a blueprint for a smart assistive user interface and the peculiarities in the application field of private living environments.

Keywords: Human-Computer Interaction; Smart Homes; Virtual Assistants

1 Introduction

Virtual assistants that are able to communicate with users naturally and provide IT services are not only found in car navigation systems or on mobile phones (e.g. Apple's Siri or Samsung's Bixby) but made the step into the homes of the users successfully. Google Home or Amazon's Alexa assistant that can be accessed by a specific device (Amazon Echo) are prominent examples. For instance, according to Forbes Magazine the Amazon's Echo device has been the best-selling device on amazon.com in 2016 and thousands of skills for the assistant are available from third party providers on a specific market place. Still, current virtual assistants have only a limited scope of actions and are not able to act as a single point of contact to a smart home. Already 25 years ago, ideas of a personal assistant have been discussed that has a very broad scope and even accompanies people during their whole life [No93]. In our vision which can be perceived as a step towards more overarching concepts for virtual assistants, there should at least be a coherent UI in a private living environment that offers a broad range of comfort functions. In this paper, we identify and examine challenges in reaching this vision of a smart assistive UI and present perspectives

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how to work towards it. The paper is organized as follows. In the next section, we start with outlining a vision for the capabilities of future virtual assistants in order to clarify goals one could be working towards. Next, we identify current obstacles and challenges that are relevant for reaching these goals. In the following section, we look at approaches that provide a perspective to overcome these obstacles. Before we conclude, we discuss a blueprint for a future smart assistive user interface and examine its peculiarities with regard to it being placed in private living environments.

2 Vision

In this section, we outline a vision for a virtual assistant that goes beyond the current state of the art. Assistants at home could offer more services than controlling the basic infrastructure of a home and its household appliances (e.g. switching light on or controlling heating). Most of these more far-reaching services have been investigated in the context of ambient assisted living where assistants address the needs of vulnerable users [YK12]. While taking care of the elderly or the ill are important features, there are many more functions that can be offered, for instance

- comfort functions (e.g. reminders, entertainment offers, reporting, home automation features, concierge services, wearable assistance),
- coordination with the assistants of other homes and the building in total as well as other stakeholders (janitors, building owner, security guards, concierges),
- advice on how to best facilitate the IT infrastructure, e.g. in order to save energy,
- protection against real and virtual security breaches of the building environment,
- observation of the tenants should the need arise (e.g. due to illness, disabilities or age-related restrictions) and support of the healthy aging of the home's inhabitants.

One benefit of taking a broader perspective is that the assistant is not associated with negative circumstances in life such as illness. It could accompany users for a large time span and offer other valuable services before it also gradually acts as an assistant in the sense of ambient assisted living. For this, it is crucial that the assistant is a metaphor for a single point of a contact to a complex and evolving federation of IT systems present in the user's home. The central goal of the virtual assistant is to identify and make accessible through a user interface as many suitable services of the smart home environment as possible that fit the individual needs and interests of the home's inhabitants. Moreover, the virtual assistant administrates and maintains the smart home environment following the users' demands and being able to report its actions and their implications in a way that is understandable by the users. For this, the whole private living environment becomes the fundament for realizing the assistant, i.e. the assistant is not tied to a specific device or location within the private home. The virtual assistant is a ghost-like entity that can inhabit virtual spaces but can also "possess"real objects in the home, e.g. using all loudspeakers in the private living environment (e.g. on a television set, an alarm clock, a user's tablet or a intercom at the door) to talk to the user. Let us illustrate the vision with a use case: *Jane D. buys a new game console that contains a 3D camera. At home, the new hardware resource is discovered by the virtual assistant and automatically configured. The virtual assistant appears on a display in Jane's kitchen and informs her that the game console is ready to be used. It makes additional suggestions, e.g. that Jane could play a health game. Jane agrees and starts playing using the 3D camera and her 50" television set whose display became automatically part of a new virtual exercising device together with the smart windows of her living room that open in order to provide enough oxygen for Jane's workout. The virtual assistant monitors her success over time and encourages Jane to continue workout and also to change her eating habits. For this, it combines the physiological data from her smart watch, her latest medical report, and nutritional information about the food she has bought that the virtual assistant can access on the Internet. Accessing data from a cloud, the virtual assistant compares her data with Jane's age group and ensures that she does not over exercise. Having a 3D camera available, Jane is able to communicate with her virtual assistant by simply pointing at objects. When she gets cold during exercise, she gestures at a window and says to the virtual assistant "close this window, please". The virtual assistant had explained to her the new exercising capabilities when it discovered that there was a quiet moment where Jane was able and willing to pay attention. While Jane gets older over the years, the virtual assistant is able to integrate the 3D camera of the game console in many useful virtual devices, some of them offering the amenities of assisted living, e.g. directing her household robots or monitoring of her movements and alerting help when necessary.*

There are two major characteristics of the user interface. First, the user interface is capable of evolution. The virtual assistant can take advantage of new devices introduced to the IT infrastructure and is able to forego devices that are removed or replaced in the private living environment over a long period of time. Moreover, the virtual assistant is able to adapt to the evolution the user undergoes when becoming older – and as a result the user interface also evolves. For example, by collecting and processing information from a user over several years or even decades the virtual assistant evolves in its user profiling and user adaptation. Second, the user interface is capable of absorption. It absorbs novel hardware capabilities and is pro-actively capable of turning them into affordances for user interaction. Similarly, the user interface is able to absorb advances on the software side, e.g. novel algorithms for reasoning or novel standards to access devices. Moreover, the virtual assistant is able to absorb information that is either collected from user observation or can stem from various resources in the Internet.

3 Challenges

After sketching a vision for smart assistive user interfaces of the future, we take a look at some of the challenges that need to be addressed for working towards realizing this vision.

We identify four major challenges: the coherence challenge, the design challenge, the user acceptance challenge, and the security and privacy challenge.

Coherence Challenge. Early ethnographic studies in the area of smart homes [KVVM04] showed that neither a stationary device such as PC nor a mobile device (e.g. a mobile phone) alone are sufficient to interact with a smart home environment well. [KVVM04] attribute this to the different characteristics of tasks, e.g. tasks that are concerned with planning (e.g. setting up a schedule for heating) vs. tasks that aim at instant control (e.g. turning a light off). Also, all real devices found in private home (e.g. household appliances) come equipped with their own user interface. Thus, there exist many different user interfaces to a smart home. The challenge is that these isolated user interfaces show a degree of coherence and consistency in order to satisfy fundamental usability demands. The assistant should not be yet another user interface for the smart home environment next to all other user interfaces or a user interface on a higher hierarchical level above them but rather serve as glue that integrates all separate user interfaces to a single point of contact and mitigates inconsistencies. In particular, the virtual assistant needs to use interaction modalities consistently. Research work such as [SJ15] shows that making an interactive assistant relying on tightly-coupled multimodal dialog advances the usability of the assistive system.

Design Challenge. Designing a user interface that is expected to evolve over a long period of time is particularly challenging as it is design with incomplete information. Future development in hardware and software are unclear as well as future user requirements. Evolution over a long time period also includes rapid adaptation to changing requirements, e.g. a user who suffered a stroke or had an accident might need a radically different user interface within a short period of time. Approaches to tackle this challenge are scarce. Moreover, the design challenge does not only touch on difficulties in designing user interface concepts but also on architectural design of the IT system that implements the user interface. Literature such as [PE10] shows that even when user interfaces follow modern component-based design approaches it is still challenging to seamlessly integrate heterogeneous UI components that can lead to basic implementation problems such as loss of modularity or tangled code.

User Acceptance Challenge. The virtual assistant in our vision has far reaching power and can influence people's lives heavily. Many users not versed in technology find it difficult to recognize the state and to understand the actions of a virtual assistant. Moreover, they find it difficult to assess and to evaluate a virtual assistant's decisions and performance. This opaqueness of the virtual assistant, its actions and their rationale, makes it challenging for users to accept and trust a virtual assistant. Research [Ts14] indicates that for an acceptable virtual assistant humanlike communication and behavior is appreciated and ßocial skillsäre requested. This is a challenge in itself. Moreover, users expressed mixed opinions according to [Ts14] whether the virtual assistant should possess a humanlike appearance. The term üncanny valley"describes a phenomenon that a humanlike assistant needs to be perfect and especially small deviations elicit revulsion in humans. This poses a challenge to realistically simulate a virtual human character that is acceptable for humans. But even the strategy to not strive for perfect humanlike appearance and clearly make the virtual assistant not humanlike, e.g. by using Cartoon-like animated characters, may not lead to user acceptance. A prominent example is the Microsoft's Office Assistant "Clippy", an animated paperclip, who invoked mostly negative strong emotional responses. Besides appearance, an important aspect for user acceptance is the mode of communication between user and smart home. In the literature, researchers advocated for end-user programming, i.e. the goal to enable users to express themselves in a formal language (e.g. rule-based approaches where users specify actions to be triggered as a result of the occurrence of events or visual programming approaches). This has not been successful [DRC15] as inhabitants of smart homes keep having problems in understanding or troubleshooting. Developing end-user programming that is acceptable for users in private living environments or finding adequate alternative is still an open research task.

Security and Privacy Challenge. Related to user acceptance is the challenge to not only ensure that the virtual assistant is a secure IT system but also that it is perceived as trustworthy. Users in their private homes are particularly vulnerable and guaranteeing privacy is a challenge. Only few work in the literature such as [Ch11] examine and classify private moments of inhabitants in their home or the effects on social life when inhabitants are vitreous humans from the virtual assistant's perspective.

4 Perspectives

The previous sections demonstrated how varied the challenges are for realizing our vision of a virtual assistant. Hence, solutions need to draw on different approaches that offer perspectives to work towards the vision. One perspective lies in advanced user interface technology. For example, Augmented Reality and Tangible User Interfaces [Is08] allow all real objects in a smart home to become part of the user interface. [HLH15] gives an example how a direct combination of digital interfaces and physical affordances can foster usability. [Ha11] shows how this can lead to seamless multimodal interaction in 2D and 3D. For instance, this can be used to allow for interaction over a distance range and allow users to interact with user interface elements in direct reach but also remotely. [Cl11] examines such a proximity-based interface in the context of private living environments. Robotics provides the perspective to have a proxy that acts in a distance. [RS15] describes a smart home where a user and robot together operate physical devices. Moreover, a virtual assistant can be embodied in a robot and novel forms of human-computer interaction or human-robot interaction can be created. In this way the action capabilities of the virtual assistant will also increase. This perspective has already been visualized in movies such as Iron Man, where the smart assistant Jarvis acts through robots.

Another perspective is the use of methodologies from organic computing. These comprise the so-called self-X properties such as self-organization, self-awareness, self-configuration, self-healing, self-protection and self-optimization. These methodologies allow the underlying IT infrastructure to organize itself being triggered by the virtual assistant. This way the virtual assistant is able to act and to adapt to changing environments and requirements. The virtual assistant sets standards and constraints in this process adhering to policies given by its user. Possible methods used here from the research field of organic computing include bio-inspired methods like artificial hormones or DNA or an artificial immune system. These methodologies can be complemented by novel approaches in reasoning such as deep learning or methodologies from multi agent systems. Network access and access to databases or a cloud can provide the necessary basis information for reasoning together with information gathered by the sensor network in the smart home as well as a history of user interactions. This information can be harvested in order to improve user profiling. Flexible connections of sensors and actuators can be achieved by using the Internet of Things (IoT). The Internet of Things (IoT) is a huge and still expanding network of connected "things", i.e. devices that are (1) connected to the internet and exchange data, (2) able to collect data through embedded sensors, and (3) remotely monitored and controlled. It is estimated [GC15] that the number of IoT devices will increase worldwide from 4.2 billion (2015) to 24 billion (2020) from which 5 billion will be installed in consumer settings. The lack of interoperability of the IoT [STJ14] extends to the difficulty to provide consistently designed user interfaces. Here, virtualization of sensor and actuators nodes can be a perspective to remedy these problems.

Several approaches to tackle the security challenge are under research such as smart contracts and block chains that are successfully used in peer-to-peer electronic cash systems e.g. Bitcoin. Another interesting source for perspectives is entertainment computing [Dö16]. For example, gamification can be used to motivate users to undergo some training in order to improve interaction with the virtual assistant or to realize balancing mechanisms between sophistication of services rendered by the virtual assistant and user expertise in dealing with smart home technology in order not to frustrate the user.

5 Discussion

In Figure 1 we depict an overview of an architecture that combines approaches presented in the previous section. There is no single user interface layer with dedicated hardware but the whole IT infrastructure serves also to support the realization of the user interface. A knowledge base and the deduction of contexts provide the basis for smart capabilities of the virtual assistant. These are supported by Self-X mechanisms from organic computing as well as security mechanisms. Having abilities such as self-organization and reasoning in the core of the system, allows addressing the peculiarity of a smart home that there is no administrator and the user cannot be expected to handle complex IT-related tasks such as end-user programming. Distributing user interface functionality over the whole system offer the degrees of freedom needed to flexibly realize and adapt a user interface with high usability. Another peculiarity of smart homes are that their users do not plan to develop and maintain the infrastructure. As a result, the smart home needs to cope with system failures and the introduction of novel devices in a completely automated way.

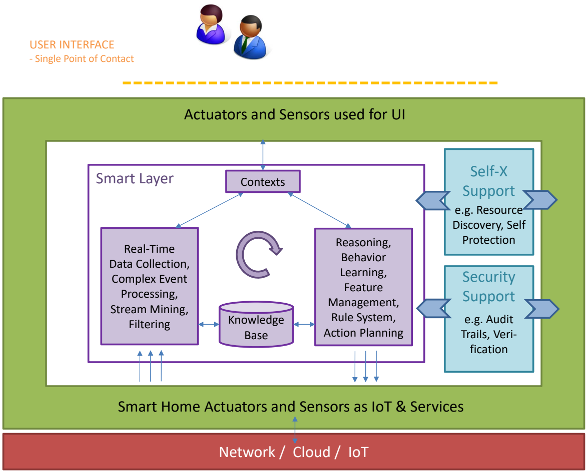

Fig. 1: Blueprint of a system architecture for a virtual assistant and a smart home system

6 Conclusion

This paper contributes to the discussion of future directions of research in user interfaces that are highly relevant for innovative private living environments. The vision for user interfaces in a smart home is a virtual assistant that serves as a single point of contact and is capable of evolution and absorption. Major challenges for realizing this vision but also promising approaches to overcome these challenges exist. System architectures and research efforts are needed that take vertical integration into account. Hence, user interfaces in a smart home environment need to be designed and implemented with basic infrastructures such as the IoT as well as middleware such as a smart layer for reasoning in mind.

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