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Vision: Shining Light on Smart Homes – Supporting Informed Decision-Making of End Users

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***Abstract*—Smart Home technologies are promising to enhance quality of life, autonomous living of elderly people and home security. Yet, uncertainty in terms of personal benefits, functionality, cost, privacy and security features influences potential users' decision processes. The vision of this research thus is to support end users' informed decision-making in terms of Smart Home technologies. We developed and tested a prototype of an interactive Smart Home configurator that provides users with targeted information according to their interests. It visualizes Smart Home processes and implications for privacy and security to increase transparency and reduce uncertainty in the decision-process. Ideas for further improving and extending the concept of the Smart Home configurator are discussed.**

Keywords—Smart Home, configurator, privacy, security

I. Introduction

Smart Home technologies offer great potential for a multitude of use cases. They can, for example, support the autonomous living of elderly people, enhance home security, and increase general comfort and quality of life. Furthermore, Smart Home technologies are increasingly available to end users. Still, even though the number of users increases, the adoption rates still fall behind [1–3]. Previous work uncovered a variety of factors that hinder adoption, among them uncertainty in terms of personal benefits, costs and the interoperability of devices [1, 4]. Moreover, fear for a loss of control [5, 6] as well as privacy and security concerns negatively impact user perceptions of Smart Home technologies [7–10].

User studies and interviews with potential users reveal that the general end users' understanding of Smart Home technologies is rather superficial [9] and influenced by uncertainty. Neither is a reasonable basis for deciding whether to adopt Smart Home technologies at all or for choosing suitable devices and functionalities from the plethora of service providers that align with the personal needs and the personal privacy and security preferences. Still, there is a lack of suitable guidance for interested but uncertain end users. Information texts or videos most often provide general information instead of individual advice. Smart Home Labs that demonstrate the practical use of certain technologies are seldom accessible for end users and information on the websites of commercial service providers often follows aims other than to provide neutral and independent information.

The vision of this research is to support end users in making informed decisions in terms of Smart Home technologies. The aim thus is not to convince people to adopt Smart Home technologies but to decrease their uncertainty in the decision process and to facilitate a good match between the user's needs and their choice of Smart Home technologies.

Following initial interviews with Smart Home experts and users to collect ideas on how to best support the decision-process we derived the following aims for our vision:

- It provides neutral information, e.g., in that it does not follow commercial interests, and provides reasons for evaluations.
- It provides concrete information, e.g., by stating the functionality of technologies, listing devices needed for a certain functionality, and the cost associated with the devices.
- It provides targeted information, e.g., by allowing users to choose use cases according to their preference.
- It supports the understanding of privacy and security implications, e.g., by increasing transparency through suitable visualization.
- It is usable, cost-free and accessible from different places.

To transform these aims into a suitable measure, we developed a prototype for an interactive and web-based Smart Home configurator following a user-centered design approach. The prototype was analyzed in a user study to evaluate the steps undertaken so far and to derive ways for further improving the vision of supporting informed decision-making of end-users. The evaluation revealed promising ratings in terms of usability, an increase in knowledge and the subjective ability to make informed decisions in terms of Smart Home technologies. As privacy and security aspects were deemed very important for the participants' decision process, future work should focus on enhancing the visualization of privacy and security implications. Another focus should be on the extension of scenarios and options included in the configurator.

The remainder of this paper is structured as follows: Section II briefly describes related work that our vision builds on. Section III describes the development process of the Smart Home configurator prototype. The method and results of the prototype evaluation are detailed in Section IV. Section V discusses the preliminary findings, limitations and ways for improving the Smart Home configurator and the visualization of privacy and security aspects.

II. Related Work

Market research and a number of user studies demonstrate great interest in Smart Home technologies, yet, adoption rates fall short [1–3] compared to the increasing availability and potential offered. One reason for low acceptance rates faced by some companies might be a general lack of addressing and involving end users [11].

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An interview study with 42 end users showed that end users have rather superficial mental models of Smart Home processes [9]. They are more interested in the functionality of the system than the technical processes behind the functionality [5]. In contrast, Mennicken and Huang found that common Smart Home technologies require profound technical skills for accessing and controlling all functions provided [12]. A field study by Jakobi et al. revealed that users are overwhelmed by the plethora of available devices and have difficulties to translate their preferences into required products [4]. Also Jakobi et al. suggest to address the "disconnect between what users desired and how to map this to the system" [4, p. 1628]. Further factors contributing to uncertainty might be the lack of interoperability between devices from different service-providers, missing clarity in terms of the long-term security and functionality of this fast-developing technology and high initial costs for the devices and their installation [1, 4]. Apart from that, current technologies often lack illustrations of the benefits they provide so that users remain uncertain about the personal added value of the technology [1, 4].

Finally, several studies revealed privacy and security concerns in terms of Smart Home technologies. Gerber et al. and Emami-Naeini et al. conducted online studies and found general privacy concerns [13] and privacy concerns related to specific scenarios and types of data collected [7]. In the interviews conducted by Zimmermann et al. nearly all non- or little-experienced participants believed that their data were not secure in a Smart Home [9]. In contrast, the Smart Home administrators interviewed by Zeng et al. expressed less concerns [8] indicating that pprivacy and security concerns might be especially relevant in potential as compared to current users.

The findings described above suggest a lack of orientation in terms of use cases and missing support in translating the users' needs and preferences into a technological setup. Also, there seem to be concerns and uncertainty in terms security and privacy implications of Smart Home technologies.

The next section thus describes a potential measure to bridge this gap and foster informed decision-making by end users: an interactive Smart Home configurator [14].

III. Smart Home Configurator

The section first describes the development process and then describes the resulting prototype.

A. Development Process

The development process of the Smart Home configurator prototype followed the user-centered product development process according to ISO 9241-210:2010 [14]. The aims described in the introduction were formulated as requirements for the product development process. Apart from that guidelines for the presentation of information and dialogue principles were followed [15, 16]. In six iterations using sketches and HTML-mock-ups, user feedback of nine participants was integrated into the prototype.

B. Description of the Prototype

Fig. 1. shows an exemplary screenshot of the Smart Home configurator prototype. The prototype can be accessed via the Online Appendix [17]. Users aiming to interact with the Smart Home configurator are guided through several steps:

(1) After a brief introduction on Smart Homes in general, users can choose areas they are interested in, e.g., smart lighting or smart heating, to allow users to limit the selection according to their preferences. Again, brief information is

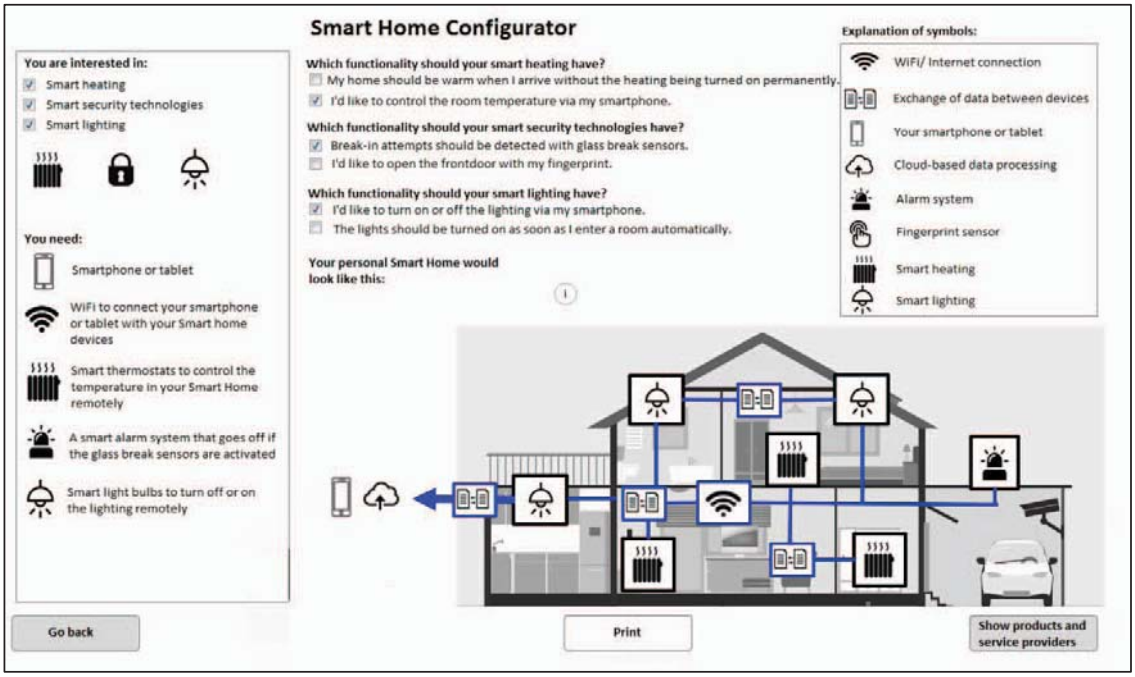

Fig. 1. Exemplary picture of the Smart Home configurator prototype (Picture of house taken from www.pixabay.com).

offered about the different areas, potential benefits and requirements.

Security and privacy implications are highlighted by a data exchange symbol that is consistently used throughout the configurator and a list stating which (personal) data needs to be processed and stored to provide a certain functionality.

(2) The users are then forwarded to the main configuration interface shown in Fig. 1. In the text box on the left the user is shown the selected areas and allowed to change these to provide users with visual feedback concerning the current state and to comply with guidelines on reversing user actions. In the middle, the user can select specific scenarios and functionalities according to their needs, e.g. "I'd like to control my room temperature via my smartphone". They are formulated in the first-person perspective to foster putting oneself in the situation, and on the level of specific use cases to enhance understanding and to highlight potential benefit.

Depending on the users' selection of scenarios, the related symbols appear in the visualization of a home. The symbols are explained in a text box on the right. To allow for the mapping of desired scenarios and the technological setup, the user receives a list of the technologies required to implement a selected functionality that is accompanied by a short explanation, e.g., "You need: Smart light bulbs to turn off or on the lighting remotely". It is shown in the text box on the left.

Security and privacy implications are visualized by blue lines and symbols that represent the data exchange between Smart Home devices. It is further depicted whether data is transferred to a cloud or stored locally. The aim of this feature is to increase transparency of Smart Home processes and to raise awareness for resulting security and privacy implications.

If the user is happy with the selection, they can print the current visualization and list of technologies and/ or continue to a comparison of products or service providers by clicking on the button on the lower right of the interface "show products and service providers".

(3) The next page compares products and service-providers that match the previous selection of scenarios by the user. The prototype used fictional providers and products just for demonstration purposes. The comparison contains prices and technological specifications to allow for a direct comparison of service providers, and for an estimation of costs.

For each fictional provider a privacy and security rating (see Fig. 1.) as well as an explanation thereof are included. It takes the form of a star-based rating similar to smartphone app ratings or online shopping services. The fictional products were awarded with a maximum of five stars for criteria such as whether only the data required for the functionality was collected or whether security measures such as encryption of the data transfer were implemented. After clicking on an "i" next to the rating, the user was provided the reasons for the number of stars, e.g. "Your data is only stored locally in your home" or "Your data is stored in the provider's cloud. You can't be entirely sure who can access the data". This feature again aimed to increase awareness for security and privacy implications and allow for an easy comparison.

Fig. 2. Examplary screenshot of the privacy and security rating.

(4) The final page again allows for printing the user' configuration and contains a farewell message for indicating the end of the configuration process.

IV. Prototype Evaluation

A total of 21 participants took part in our evaluation of the Smart Home configurator prototype. The evaluation covered three aspects: a hypothesized increase of knowledge about Smart Home technologies by using the prototype, an assumed increase in the perceived ability of the user to make an informed decision in terms of Smart Home technologies, and the usability of the prototype itself. The goal is to increase users' general knowledge and perceived ability to make an informed decision by being able to see potential benefits and usage scenarios of Smart Home technologies, by receiving information in terms of security and privacy, and by being presented potential service providers and devices needed to implement a scenario.

Due to space constraints, the reader is referred to the Online Appendix [17] for a link to the prototype, a list of all self-constructed items, and results of additional usability and user experience measures used in the study.

A. Method

1) Sample: Of the 21 participants who were recruited via snowball sampling 12 identified as female and 9 as male. The mean age was 25 years (SD = 1.89) ranging from 21 to 28 years. Six participants had a high school diploma, 15 had a university degree.

2) Material: The potential increase of knowledge was examined with a self-constructed knowledge-questionnaire that included five multiple choice items dealing with different Smart Home topics. Each question answered correctly was awarded with one point (see [17]).

The perceived ability to make an informed decision concerning Smart Home technologies was analyzed with a self-constructed questionnaire including seven items that were answered on a five-point Likert scale from "I completely disagree" to "I completely agree", e.g., "I can name risks concerning the security and privacy of Smart Home technologies." (see [17]). Usability was examined with the widely used System Usability Scale (SUS) [18].

B. Procedure:

First, the participants received information about the study and were presented an informed consent sheet. Second, they filled out questionnaires about their Smart Home knowledge and ability to make an informed decision prior to using the prototype. Afterwards, the participants tested the

prototype according to their own preferences for up to 15 minutes. Finally, the participants answered the same questionnaires as prior to the test phase to check for differences by using the prototype. Additionally, the participants answered some open questions and completed the SUS, which allows for a comparison of the results with other products.

C. Results

We compared the score of the knowledge-questionnaire before (M = 2.81, Md = 3.00, SD = 1.08) and after (M = 3.38, Md = 3.00, SD = 1.16) using the prototype with a non-parametric one-sided Wilcoxon test due to the sample size and data distribution. The scores after using the prototype were significantly higher than before the test phase with Z = -1.92, p = .03, r = .42. Similarly, a one-sided Wilcoxon test revealed that the perceived ability to make an informed decision in terms of Smart Home technologies was significantly higher after using the prototype (M = 3.65, Md = 3.57, SD = 0.63) than before (M = 2.70, Md = 2.71, SD = 0.63) with Z = -3.88, p <.01, r = .85. One item within that score targeted the perceived ability to name risks in terms of security and privacy. This item's score increased significantly from M = 3.05 (Md = 3, SD = 1.20) to M = 3.76 (Md = 4, SD = 1.04) after interacting with the prototype with Z = -2.385, p = .01, r = .52 using a one-sided Wilcoxon test. The Smart Home configurator received an average SUS-Score of M = 82.50 (SD = 12.17) of 100 possible points. The SUS score of 82.5 can be interpreted similar to an A grade in school [19].

Asked what would be especially important for a decision in terms of Smart Home technologies, 16 participants named privacy and security aspects. Other answers concerned usability (N=6), functionality (N=6), reliability (N=4), and cost (N=4) of Smart Home technologies.

V. Discussion and Future Work

In studies, end users often expressed uncertainty about the functionalities and benefits of Smart Home technologies [1, 4] and only had superficial knowledge of how Smart Home technologies work [9]. The Smart Home configurator prototype presented here aims to address this by supporting individual and interactive decision-making for or against Smart Home technologies.

The prototype described and evaluated in this research serves as a proof of concept and as a starting point for the further development of a Smart Home configurator. The functionality of the prototype is still limited, in that, e.g., few scenarios were implemented, and the comparison of products and service-providers were fictional. Still, even though the configurator is in an early stage of development, the approach appears promising. The evaluation of the prototype revealed promising results in terms of an increase in knowledge and the perceived ability to make an informed decision concerning Smart Home technologies.

A. Limitations

The Smart Home configurator prototype in its early development stage is fairly limited in terms of functionality. One of the main limitations here is the small number of Smart Home functionalities a user can choose from (compare Fig. 1). In addition, the visualization of security and privacy implications was rather sparse, e.g. data flows, although dynamic in terms of the chosen scenario, and were only visualized by blue lines without any animation. Last but not least, all products and providers were purely fictional and therefore could not be used for real decision making.

Apart from the prototype itself, our preliminary evaluation study is subject to some limitations. The sample was quite small and biased towards young and educated users. The recruitment via snowballing to allow for testing on site and with intrinsically motivated participants might also have biased the sample. Although this is appropriate for an early pilot study, we strive for a more heterogeneous, and above all, larger sample for a more advanced version of our Smart Home configurator. This could be achieved by implementing a web version that is cost-free and accessible from different places.

The items of our knowledge test also seem to need improvement and clarification, as some participants showed a decrease in knowledge after using the prototype. Although this could stem from inconsistencies or unclear content in the prototype itself, it is also possible that the measure is not ideal. For example, the wording of the questions or multiple-choice answers might have been confusing.

To gain further feedback for improving the configurator, future studies could include a short follow-up interview to gain qualitative insights.

B. Further development of the configurator

Our Smart Home configurator prototype does not yet fulfill all aims of our vision and thus provides potential for further development. The current prototype was rated as fairly usable and provides neutral, targeted and concrete information to a limited extent.

As mentioned above, one of the first steps will thus be to increase the choice of Smart Home functionalities, e.g., smart health and independent living solutions for elderly people [20], and user preferences, e.g., in terms of device or data sharing. Also, we aim to integrate more usage scenarios to better illustrate potential benefits of Smart Home technologies. To avoid commercial interest bias, integration of scenarios, products, and providers could be put into practice via crowd-sourcing. A platform that allows the extension of the database through users, researchers, and providers would allow for specifying individual use cases and could also contain feedback mechanisms to ensure correctness of the data. If the number of scenarios increases, a list as currently implemented might no longer be suitable to show all use cases. Other choice mechanisms such as decision trees or selection menus could be implemented and tested.

Another aim of the configurator was to support understanding of security and privacy implications of Smart Home technologies. The large number of participants that stated these to be especially important for a decision demonstrates the importance of this aim.

The prototype contained information about which (personal) data is required for certain functionalities and a rating of the privacy and security of fictional service providers. Still, the visibility and content of these features could be further improved. The idea of the star-based rating similar to ratings used in other online services (see Fig. 1.) was to provide the user with an easily understandable evaluation of whether the data collection is appropriate for the intended use and whether security measures to protect the data are adequately implemented. Further work is needed to determine whether the information should be included in one or several ratings, and how the score should be calculated for actual technologies. The configurator or the rating, respectively, should also allow the user to understand the implications of differences in the rating, e.g., between unencrypted and encrypted data transfer, and to develop appropriate threat models. Apart from extending scenarios and products, crowd-sourcing might also be useful to provide additional security and privacy ratings by users or experts similar to those used to evaluate smartphone apps.

The visualization of data exchange between Smart Home devices to increase the transparency of data flows currently consists of blue lines and symbols that appear or disappear depending on the choice of scenarios. Future versions of the configurator should not only contain data flows but visualize *why* the data is collected and *what* happens to it. The visualization could be further improved, e.g., by integrating dynamic elements or highlighting privacy- and security-threatening choices. We assume that visual feedback that is as individualized as possible and tailored to the specific usage scenario is especially useful compared to general information on data protection, e.g., as provided in privacy policies.

To measure whether security and privacy aspects are sufficiently addressed, future studies should include more questions especially focusing on these aspects. The few items addressing security and privacy that are currently included provide a first indication but do not allow for a final evaluation.

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