Usability – Key Factor of Future Smart Home Systems

Gerhard Leitner, David Ahlström and Martin Hitz
Department for Informatics Systems, Klagenfurt University, Austria

Abstract. A framework of usability factors is presented which serves as a basis for the thorough research of usability issues in the context of smart home systems. Based on well accepted approaches taken from the literature, various aspects related to usability are identified as significant for the implementation and future development of smart home systems. Finally, the partly existing prototypical installation of a smart home system is discussed and scenarios for future investigations are presented.

1 Introduction

The widespread of smart home devices has increased within the last few years and has now reached the level of a mass market. The increased application of such systems will probably lead to problems well known from other areas – problems related to bad usability. Personal computers, websites or VCRs are intensively discussed examples of sub-optimal usability. Smart home systems include multiple factors which are potentially relevant in relation to usability, both as singular aspects and in a combination. Besides simple functionality, such as switching the lights on or off, smart home systems also support networked operation, the definition of macros, and the usage of diverse, mostly GUI-based devices. All these components may cause severe problems when usability is not considered.

In this paper, integration of important usability aspects which could be relevant in relation to smart home appliances in future is attempted. After an overview of the theoretical background and related work in the field, a framework comprising aspects derived from various usability models and theories is discussed which may serve as a conceptual basis for future research activities. Examples of possible research topics and research methods are given afterwards, followed by a description of relevant parts of the prototypical installation of a smart home system which serves as an infrastructure for usability investigations. The paper concludes with a discussion on future research topics.

Please use the following format when citing this chapter:

Leitner, G., Ahlström, D., Hitz, M., 2007, in IFIP International Federation for Information Processing, Volume 241, Home Informatics and Telematics: ICT for the Next Billion, eds. Venkatesh, A., Gonsalves, T., Monk, A., Buckner, K., (Boston: Springer), pp. 269-278.

2 Background

The times have passed when smart appliances have been seen merely as either a hobby of persons fascinated by technical gimmicks, or as necessary tools for the maintenance of public or company buildings. The electronic industry has already focussed on the private person as a potential mass consumer of smart home technology. There are many indicators showing that smart home appliances are already an issue for the broad public. For instance, almost each do-it-yourself store has at least one system available, and advertising in television or magazines is also intensively dealing with that subject. The offered smart home systems range from stand-alone switching components to networked systems (either wired or wireless), depending on the intended purpose of the system. Because of the high availability, solutions had to be found to support a side-by-side operation of different devices. This has been accomplished by the definition of standards, like the U.S. X10 standard and the EIB/KNX standard developed in Europe, cf. e.g. [1]. These standards provide an infrastructure including detailed interface specifications on the basis of which different manufacturers can develop and release devices.

An important development came with the widespread of smart home appliances: the users of devices are no more only specialists with technical skills, like company technicians responsible for the electrical equipment in an enterprise. Moreover, training of end users, which is usual e.g. when a new system for building automation is deployed, seems not to be very realistic. The other possibility to overcome usage problems would be to provide guidelines and specifications for the design of the user interfaces, available for different computer platforms and operating systems. However, such documentation is only partly considered in standards like X10 and EIB/KNX.

The missing consideration of issues of the user interface and the neglect of end user needs is very similar to situations consumers have been confronted with in the past. When VCRs came on the market, consumers had to struggle with bad usability. The next hurdles came with the appearance of the personal computer and more recently with the widespread of the Internet.

In relation to usability, smart home appliances add new dimensions to our lives which are important to consider, because complex smart home systems include a combination of devices and, therefore, a combination of potentially severe usability problems. Indeed, it had been annoying when recording a movie had not been possible with the new VCR, or bad usability of websites or software programs led to aborted online purchases or cumbersome text processing, but these symptoms do not have critical impact on our lives. Considering smart home appliances, bad usability could have more severe effects, e.g., if one cannot switch on the heating in winter, cannot get into one's apartment, or – even worse – is trapped inside a building. Especially novice users or elder persons are a target group for smart device marketing and the benefits of an increased ease of life when everything works by pushing a button on a remote control are illustrated in high-gloss brochures. But how realistic are these scenarios when considering all the usability problems related just to single devices such as mobile phones?

2.1 Related Work

Usability aspects of smart home appliances have been investigated under different viewpoints. Beginning with the very early discussion of "the psychology of everyday things" as Norman [2] terms it, where bad usability of quite simple devices was critically observed, long before smart home systems reached the market. Usability aspects of smart home devices have been researched, e.g. by [3] who investigated usability problems related to the user interface of a smart home system. Schoeffel [4] describes a usability engineering oriented design approach for a smart home end user interface. Ringbauer & Hovfenschioeld [5] investigated the emotional aspects related to the usage of such systems. Investigations regarding the utility and usability of smart home systems for the elderly were done e.g. by [6] and long term usability observations have been conducted at the Philips Homelab [7].

The work in this area is characterized by punctual investigations which do make sense in answering specific questions. However, as discussed, smart home systems include very different components which could show interaction effects. These effects cannot be considered and measured with singular methods. Therefore, a comprehensive model including the most relevant dimensions seems necessary. Such a model is presented in the following.

3 Usability Oriented Framework of Smart Home Interaction

The investigation of usability aspects related to smart home appliances is difficult because several areas of usability research are linked together in one problem domain. One common shortcoming of the related work presented in the previous section is that only singular aspects have been addressed, focused on the user interface. However, smart home appliances affect at least two areas of usability: real world usability issues, e.g. the ergonomics of door handles, wall mounted switches [8] as well as usability issues related to software or Web interfaces. Furthermore, if mobile system components are in use, additional aspects regarding mobile usability have to be considered.

Thus, ensuring usability in smart home environments is a difficult and multidimensional task. To address all relevant dimensions, it is necessary to specify a framework which serves as the basic structure for usability research related to smart home appliances. Complex smart home systems are integrating distinct paths of manipulation and feedback, e.g., one user is switching a device with a power switch while another user who is accessing the system via Internet is retrieving feedback on the current system status. Figure 1 illustrates the possibilities of interaction between a user and a smart home system. To keep the model simple, only the most immediate switching and feedback loops are presented.

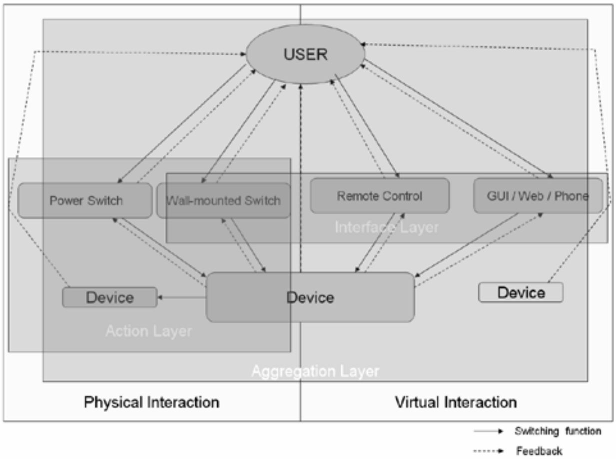

Fig. 1. Smart Home Interaction Framework

Physical Interaction:

A user can switch a device by activating a control directly on the device or a wall-mounted switch which e.g. closes a circuit to an attached device. Feedback is given by the device itself (e.g., the light goes on), or by the switch – which is giving tactile and/or visual feedback. In some cases the feedback is given by some indirect feedback mechanisms, e.g., when the central heating in the basement is switched on, feedback can be observed via the increasing temperature of the radiators.

Virtual Interaction:

A user can press a button on a remote control, and feedback is given by the switched device (if the user is in the same room he sees that the lights went on). This case seems to be similar to physical interaction, but due to the involvement of at least two parts of the system (electrical wiring and remote system) the situation is categorized as virtual. If the user is pressing a button on the remote control, but is not in the same room, he cannot see the status of the switched devices and has to rely on feedback given by the remote control or on feedback provided by other devices, e.g., a building layout equipped with status LEDs.

When a user is accessing the system over a desktop computer, a handheld device or a mobile phone, the device is switched indirectly. The system involved in this switching process can include diverse technical and interaction related dimensions, e.g., wireless or wired infrastructure, interface features of the used device (PC, handheld or mobile phone). As the manipulation is performed remotely, the switched devices themselves cannot provide feedback to the user, therefore feedback representation is given by software components like graphical symbols or similar means. Another possibility would be that a system-independent device can provide feedback, e.g. the user can observe over a webcam whether the lights are on.

The three layers (Action Layer, Interface Layer and Aggregation Layer) in the framework are symbolising the usability dimensions of relevance are discussed below.

Action Layer – In the context of physical interaction, many aspects play a role. The interaction model of Norman [2] and the model of Abowd & Beale [9] define different aspects of interaction between a user and a system. The two models include functional- and feedback components. Additionally, of interest are the characteristics of the interaction with "everyday things" postulated by Norman:

- Visibility – The system should not hide important interface components.
- Affordance – Controls should animate the user to use them (the right way).
- Mapping – The system should have a representation with affinity to the real world.
- Feedback – The user should be able to observe if and how the system is working.
- Constraints – The system should be adapted to the users' capabilities and circumstances of the usage.
- Conceptual model – This characteristic is considered within the Aggregation Layer (cf. below).

Additional aspects of relevance can be taken from the theory of action regulation (cf. e.g. [10]) which adds e.g. unconscious or automated actions, or "habits", as Raskin [11] terms it. To give an example what could be a relevant problem on the level of action is the switching of a wall switch which is designed as a standard switch (affordances) – but is wirelessly steering a remote device. In such situations questions are to be answered, like: "Which usability aspects do play a role? Does the switch give tactile or optical feedback regarding the status of the switched component?" When more than one switch is there – which switch belongs to which device (see Figure 2 containing illustrations of smart home switching components)? More difficult is the analysis of the device represented on the right side of the figure. Tactile components like buttons are used for the regulation of the device, a character based display is giving information on the chosen values. These components of a smart home system have to be analysed in relation to both the Action and the Interface Layer.

Fig. 2. Examples of smart home switching components (sources: http://www.moeller.at, http://www.eib-home.de/gepro_knx-eib-tableau_2006.htm, 2007-03-17)

Interface Layer – This can be conceived as the layer containing classical usability issues. Singular aspects of the interface are of relevance, but also the interaction of different interface components has to be considered. This is the most researched segment of the model. An abundance of literature exists, ranging from different collections of usability heuristics to relevant standards and norms, e.g. the ISO 9241 series. The characteristics to be analysed within this level are, e.g., usability factors of the ISO 9241-11 Guidance on Usability [12] , i.e.:

- Effectiveness – Can a user accomplish a task?
- Efficiency – Can the task be accomplished with acceptable effort in acceptable time?
- Satisfaction – Is the performance of the task satisfactorily?

As these factors are parts of a theoretical construct which cannot be observed directly, measurable attributes have to be identified. Literature regarding factors influencing usability is rich, models are discussed e.g. by [13,14,15]. One of the newest and therefore most complete list of basic principles for interface design is the one published by Tognazzini [16] shown in Table 1.

Table 1. Usability Principles in Interaction Design

Anticipation	Fitts´ Law
Autonomy	Human Interface Objects
Color Blindness	Latency Reduction
Consistency	Learnability
Defaults	Metaphors
Efficiency of Use	Protect Users work
Explorable Interface	Readability

An example question regarding the Interface Layer could be: "Are the criteria of usability fulfilled in an existing interface? What can be improved?". Figure 3 shows a layout of a smart home control desktop software on the left, and another example of a GUI interface based on a tablet PC on the right.

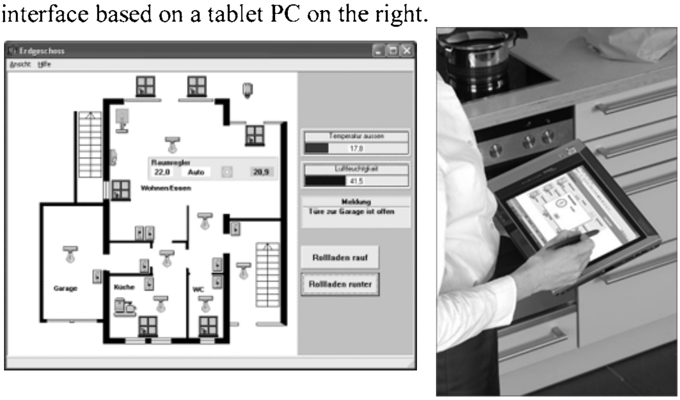

Fig. 3. GUI based systems of smart home appliances (sources: Contronics and Siemens).

Aggregation Layer – This level contains aspects related to different components of the multi-tasking, multi-device interaction (as shown in the interaction framework). The content of this layer is least known at the moment. The idea behind the Aggregation Layer is a kind of "Gestalt" in the nomenclature of psychological

Gestalt Theory. The central postulation of this theory is that the whole is more than the sum of its parts. The central question to be addressed within this level is how the different aspects of interaction in smart homes influence each other, what are the criteria which influence the "homeostasis" of the system. Is it the chosen technology, be it human factors like personality, age or gender.

3.1 Research Methods

As difficult as the development of a conceptual model is the selection of appropriate methods to investigate the different aspects of usability of smart home appliances. Our approach is to use a set of methods pertinent to the different layers. Physical action can be observed and investigated with usage analysis protocols used in industrial psychology, e.g. VERA [17], but also methods usually applied in the analysis of ergonomics are considered. The outcome of the investigations based on such methods is information regarding the tactile sensory features of the devices.

For the investigation of aspects related to the Interface Layer, a broad range of user interface analysis methods is available. These contain focus groups, structured interviews, contextual inquiries, usability questionnaires, usability expert methods and usability tests (an overview is given e.g. by [14] and [18]). Questions to be answered by the applications of these methods are e.g. to what degree the interfaces investigated reach the requirements of standards, fulfil the user needs and are satisfactory for the users regarding design and functionality.

The methods mentioned in relation to the Action Layer and the Interface Layer have been used in different other contexts and can be successfully adapted to the new domain of smart home systems. The investigation of aspects related to the Aggregation Layer is a bigger challenge. The major difficulty is that a punctual evaluation of factors related to single actions or the singular usage of an interface is not suitable for the identification of relevant aspects influencing a continuous usage of a smart home system. Therefore, longitudinal observation methods have to be used. Such longitudinal observations have already been successfully used, e.g. by [7], however in artificial environments. Other approaches were based on the observation of groups of people for a short time period combined with questionnaire data [5]. Thus, the most suitable approach to investigate long-term usage aspects seems to be based on the participant observation method (often applied in psychology and sociology) which is characterized by the fact that the researcher is concurrently observer and part of the topic of investigation. This approach has both advantages and disadvantages. The major advantage is that it is possible to conduct observations in a natural environment if the investigations are performed in the home of the participants (one of which is the researcher himself) which guarantees realistic situations and surrounding conditions. A second advantage is that the researcher, as part of the setting, can therefore perform the observation without massively influencing the behavior of the observed persons. However, the latter advantage can also be a major disadvantage since the participation of the researcher can highly influence the study outcome.

3.2 Prototypical Installation

Currently, a prototypical implementation of a system of smart home appliances is installed at two different locations. The first location is an experimental lab, where punctual investigations can be performed. The second location is a one-family house, where the longitudinal studies can be carried out. In the latter location a test set has already been installed and first investigations were already carried out. These first investigations served the purpose of a pilot study to collect more detailed and complete requirements for a realistic implementation of the system in use. The outcome resulted e.g. in the decision for a system which is open for the integration of different devices and – more importantly – provides an interface for the development of customized software components. Figures 4 and 5 show a sketch of the test installation. Figure 4 shows a set of devices already in use in relation to the presented framework. For instance, a remote control can be used to switch attached devices (like a garage door or a lamp). With a desktop computer or a smart phone the status of the system can be observed. The camera shown in the figure serves as an additional feedback channel. All the devices mentioned are part of the Interface Layer. Other devices like wall mounted switches or switches on the device itself can be used to switch devices more directly. These devices are part of the Action Layer.

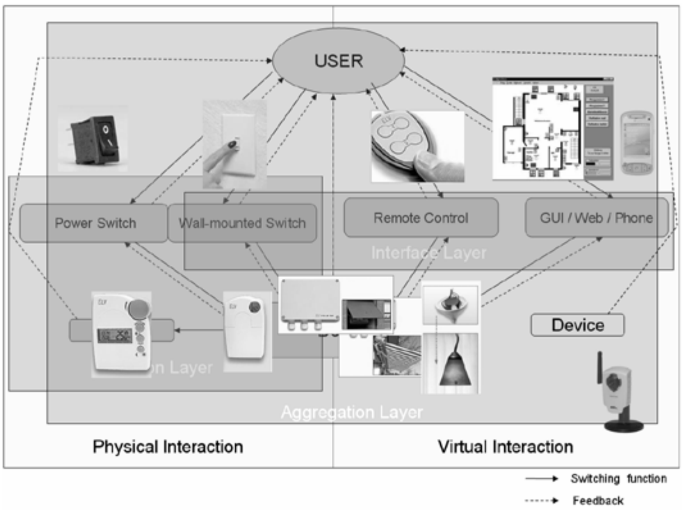

Fig. 4. Example Devices in relation to the Layers of the Framework

Figure 5 on the next page includes an overview of the whole infrastructure installed so far on the basis of a floor plan.

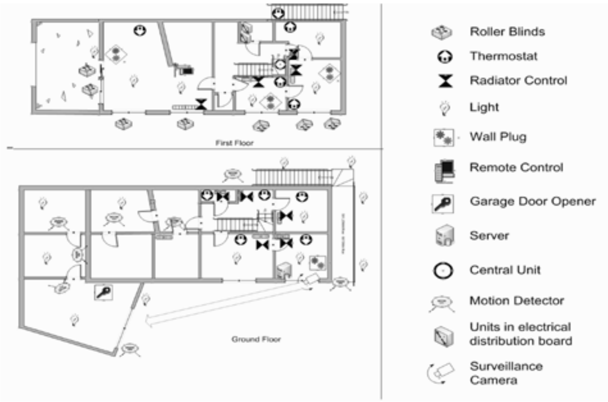

Fig. 5. Installed Devices on the One-family House Floorplan

4 Future Work

The framework for the investigation of usability of smart home appliances which has been put forward in this paper will serve as the basis of our future research projects. The very next step is to complete the prototypical installation and implement software components, like logging tools or statistics programs which provide the possibility of detailed analysis of the behaviour of the users interacting with the system. Several research questions on different levels are planned to be addressed,. The following list represents some of the questions formulated so far:

- Ergonomic factors of switching components – e.g., how can feedback be realised when the switched device is not visible?
- User Interface Factors – is it possible to apply standardized GUI-widgets or is the primary user group not familiar with computers?
- How do smart homes change habits, rituals or behaviours of the persons using them?

5 References

1. G. Westermeir, Der Europäische Installation Bus EIB, http://www.hfs.e-technik.tu-muenchen.de/ext/d12/eib2.pdf (March 17, 2007).

2. D.A. Norman, The Design of Everyday Things (Doubleday, New York, 1988).

3. B. Ringbauer, F. Heidmann and J. Biesterfeldt, When a House Controls its Master - Universal Design for Smart Living Environments", in: Proceedings of HCI International, Vol. 1, pp. 1228 – 1232. (2003).

4. R. Schoeffel, Usability Engineering am Beispiel des Home Electronic System von Siemens und Bosch. in: Software-Ergonomie '97. Usability Engineering: Integration von Mensch-Computer-Interaktion und Software-Entwicklung, pp. 37–53. (1997).

5. B. Ringbauer and E. Hofvenschiöld, Was macht es denn jetzt? - Emotionale Faktoren bei der Akzeptanz von Smart Home Lösungen, in: Usability Professsionals 2004, Tagungsband des 2. Workshops des German Chapters der UPA, pp. 87-89. (2004).

6. T. Erkert, T and A. Koenig, Neue Medien zur Alltagserleichterung von Seniorinnen und Senioren. http://www.swz-net.de/infoserver/download/index.htm (March 17, 2007).

7. B. de Ryter, 356 Days – Ambient Intelligence in HomeLab, http://www.research.philips.com/technologies/misc/homelab/downloads/homelab_356.pdf (March 17, 2007).

8. M.J. Darnell, http://www.baddesigns.com (March 17, 2007).

9. G.D. Abowd and R. Beale, Users systems and interfaces: a unifying framework for interaction'. In: HCI'91: People and Computers VI., pp. 73-87. (1991).

10. M. Frese and D. Zapf, Action as the Core of work psychology – a german approach. in: Handbook of industrial and organizational psychology. Vol. 4 (Consulting Psychologists Press, Palo Alto, CA, 1994).

11. J. Raskin, The Humane Interface: New Directions for Designing Interactive Systems. (ACM Press/Addison-Wesley Publishing Co, New York, 2000).

12. ISO 9241-11, Ergonomic requirements for the work with visual display terminals (VDT) ± Part 11 Guidance on usability. (1998).

13. M. van Welie, G. C. van der Veer and A. Eliens, Breaking Down Usability, in: Proceedings of INTERACT 99, pp.613-620.(1999).

14. J. Nielsen, Usability Engineering. (AP Professional, Boston, MA, 1993).

15. B. Shneiderman, Designing the User Interface. (Reading: Addison-Wesley, 1987).

16. B. Tognazzini, First Principles in Interaction Design. http://www.asktog.com/basics/firstPrinciples.html (March 17, 2007).

17. E. Ulich, Arbeitspsychologie. (Poeschel, Stuttgart, 1991).

18. M. G. Helander, T. K. Landauer, P. Prabhu, and P. V. Prabhu, Eds. Handbook of Human-Computer Interaction. (Elsevier Science Inc., North-Holland, 1997).