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Remote control based home automation usability evaluation

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ABSTRACT

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Remote control based home automation usability evaluation

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Building automation (BA) has been knocking at the front doors of domestic and commercial buildings for many years. Its relevance continues to grow due to the benefits it can creates across the three pillars of sustainability: environmental, economic and social. BA enable both residential and commercial buildings to improve energy efficiency. In doing this, it can significantly contribute to saving costs, reducing CO_2 emissions and providing enhanced living and working environments. In spite of these benefits and that different types of systems are available, BA has not been widely adopted yet. This lack of adoption is more notorious in homes, i.e. home automation (HA). A major barrier to this adoption is the complexity and poor usability of systems user interfaces (UI). The aim of this study is to enhance usability of home automation systems (HAS), thus contributing to a better adoption of HA, based on the inclusion of conventional remote controls into systems that are usable only via web-user interfaces or smartphone applications. Online surveys are first conducted in order to discover if users tend to control their home appliances typically with conventional remote controls or more advanced techniques. A HAS is also implemented in such a way that it can be controlled by remote controls, in addition to typical UIs. Lastly, the usability of the system is evaluated using three usability evaluation methods: Usability Testing, System Usability Scale (SUS) and Heuristics Evaluation.

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Go...

To God who guided me to and through this journey...

To my girlfriend whose love and devotion gave me strength...

To my family who were there despite everything...

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LIST OF SYMBOLS AND ABBREVIATIONS

BA	Building Automation
CO_2	Carbon dioxide
CUL	CC1101 USB Lite
DHS	Digital Human Services
DIY	Do-it-yourself
FHEM	Friendly House automation and Energy Measurement
GUI	Graphical User Interface
HA	Home Automation
HAS	Home Automation System(s)
Ir	Infrared
ISO	International Organization for Standardization
M	Mean
PC	Personal computer
RF	Radio frequency
RF4CE	Radio Frequency for Consumer Electronics
SUS	System Usability Scale
TV	Television
UCD	User-Centered Design
URC	Universal Remote Controller
UI	User Interface
VUI	Vocal User Interface

1. INTRODUCTION

Building automation (BA) is an important field of research that has been knocking at the front doors of domestic and commercial buildings for many years. The wide range of services it offers to inhabitants, such as security, comfort, or energy efficiency, to mention just a few, has caught the attention of many. But it does not ends there, its relevance continues to grow due to the benefits it can create across the three pillar of sustainability: environmental, economic, and social. Today, both residential and commercial buildings have a large environmental footprint using around 40 percentage of all energy consumed worldwide (GeSI, 2017). BA technologies enable both type of buildings to improve energy and resource efficiency by automating actions the user himself should do, tearing down appliances or switching off the lights are some examples of it. By doing this they can significantly contribute to saving costs, reducing CO_2 emissions and providing enhanced living and working environments (GeSI, 2017).

Despite all these benefits and that several types of systems have been available for over four decades, BA technologies have not been widely adopted yet. This lack of adoption is even more notorious in homes, i.e. home automation (HA). There are still some barriers that need to be addressed before a major adoption of home automation systems (HAS) takes place.

1.1. Motivation

The literature has identified several barriers for the adoption of HAS technologies, ranging from technicals to socials. Reliability, interoperability and manageability are the major technical barriers towards its adoption (Meyers et al., 2010; Brush et al, 2011; Balta-Ozkan et al., 2013). Manageability refers mainly to complex user interfaces (UIs). The difficulty of creating intuitive and easy-to-use UIs is mainly due to the level of complexity that represents bringing together excessive numbers of user control options and features under a single interface (Wilson et al., 2014; Manilal and Carreira, 2014). Most current systems are more concerned with gathering functional requirements rather than improving the interfaces resulting in confusing, overwhelming and hard to operate UIs for the average user. Thus, affecting usability and ease-of-use rather than improving them (Manilal and Carreira, 2014). Even users who already have some type of HAS in their homes said that complexity of user interfaces is one of the things they most dislike about home automation and they agreed that there is a need to reduce its complexity (Brush et al., 2011; Balta-Ozkan et al., 2013). The systems must be as simple to use as possible, complex interfaces and difficulty of systems create a cognitive barrier that, even if social or additional technical barriers are overcome, the diffusion could continue to be slow (Meyers et al., 2010).

Most users are used to manually controlling their home appliances and some of them may not be totally ready to control their daily familiar environment through sophisticated interaction techniques (Van de Sluis et al., 2001). To achieve a more convenient user interaction, familiar information devices can be used to execute common home functions (Koskela and Väänänen-Vainio-Mattila, 2004). Therefore, common ways of interacting with typical appliances or other devices at home could be utilised as a complementary alternative to interact and control both common appliances and more advanced technologies such as HAS. There is a well-known interaction tool that is present in the vast majority of homes and with which most users are already familiar, the conventional remote control. There is the belief that the usability of home automation systems, at least for typical tasks, might be improved by reusing the remote controls adequately.

1.2. Goals and delimitations

The aim of this research is to enhance the usability of HAS through the inclusion of a familiar interaction tool —the conventional remote control— into home automation systems that are usable only via web-user interfaces or smartphone applications, thus contributing to a better adoption of HA itself. In doing this, a complementary or alternative way of interaction with this type of system is provided. This solution does not pretend to replace but to complement existing interaction techniques, since the remote control must be seen as an input tool not as a UI. Therefore, it is expected that the proposed system only controls typical household energy-saving tasks. The study contributes to the literature by providing a comparative usability study between traditional interaction techniques and conventional remote controls, as a study with these characteristics still missing.

An online survey in the form of questionnaires is firstly conducted in order to discover if users tend to interact or control their home appliances and technical devices typically with conventional remote controls or more advanced techniques. The survey is intended to everyone but international or exchange students since the vast majority of them usually live in students dorms where there are no more home appliances than the basics refrigerator, stove and radiator that are often not controlled other than manually. Simultaneously, a HAS tat can also be controlled by conventional remote controls, in addition to their typical users interfaces, is tailored. It is important to note that the remote control integrated into the system already exists and is reused for the purpose of this study, meaning that no new control is developed nor designed during this research. The usability of three interaction tool, including a conventional remote control, is then assessed by test subjects and the results are lastly compared using proven usability evaluation techniques. Apart from the remote control, the other evaluated tools are a personal computer and a smartphone.

That being said, the main research question to be addressed in this research is:

1. Do the inclusion of conventional remote controls into home automation systems increase their adoption?

In order to answer the main question, a number of sub-questions have to be responded first. The sub-questions are:

2. What tools are typically used to interact with home appliances?
3. How to integrate conventional remote controls into current home automation systems?
4. Do conventional remote controls improve the usability of home automation systems?

5. Do conventional remote controls on home automation systems are aimed to a specific audience?

1.3. Structure of the thesis

The thesis report is structured as follows:

- Chapter 2 provides a background and reviews the literature regarding the research questions;
- Research process aimed at responding all sub-questions but question number 3 is described in Chapter 3;
- Chapter 4 explains the technical approach that gives response to research question number 3;
- Evaluation and results that give response to the research questions are presented in Chapter 5;
- Chapter 6 analyzes and discusses the response to each research question including the main one;
- At last, a brief summary of the research and future works are presented in Chapter 7.

2. BACKGROUND AND RELATED WORK

The literature review in here is related to the research questions defined above. It focuses mainly in the different efforts that has been done to enhance the usability in home automation systems. Remote controls usability evaluation in other fields is also reviewed. But before going into that, a background of usability itself and the evaluation methods used in this research is given.

2.1. Usability and its evaluation

In its standard, ISO-9241-11, the International Organization for Standardization (ISO) defines the term usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO, 1998), meaning that both the intended users and the tasks they will perform with a given product, as well as the characteristics of the environment in which it will be used, should be defined before the usability of the product or system can be specified. ISO-9241-11 standard also suggests that for an assessment of usability to be successful it needs to consider the three following metrics: effectiveness, defined as the ability of the users to complete tasks and the quality of the output of those tasks; efficiency, known as the quantity of resources utilized in tasks; and finally, satisfaction, that can be understood as the subjective reactions of a user when using the product or system (Brooke, 1996).

The System Usability Scale (SUS) is born in response to the needs for a broad general method. SUS can be used to compare usability across a range of contexts in a "quick and dirty" manner to allow low cost assessments of usability in systems evaluation. SUS does this by providing ten simple items (Table 1) using 5-point Likert scale.

Table 1. SUS 10 items questionnaire (Brooke, 1996)

#	Item
1	I think that I would like to use this system frequently
2	I found the system unnecessarily complex
3	I thought the system was easy to use
4	I think that I would need the support of a technical person to be able to use this system
5	I found the various functions in this system were well integrated
6	I thought there was too much inconsistency in this system
7	I would imagine that most people would learn to use this system very quickly
8	I found the system very cumbersome to use
9	I felt very confident using the system
10	I needed to learn a lot of things before I could get going with this system

Over the years, SUS has demonstrated to be a robust and reliable, low-cost usability scale that can be used in both academic and industrial research for a general assessment of systems usability (Brooke, 1996).

Same as SUS, the heuristic evaluation is an easy to use technique utilized to evaluate usability in a timely manner with a reasonable cost (Nielsen, 1994). Heuristic evaluation is a type of usability evaluation method applied to identify usability problems of a product. The technique consists of a set of evaluators that apply a set of ten usability heuristics to a product, identify any violations of the heuristics, and asses the severity according to a severity rating scale. Heuristics are (Usability.gov, 2017):

- Visibility of system status- The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

- Match between system and the real world- The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system-oriented terms. Follow real-world conventions, making information appear in a natural and logical order.
- User control and freedom- Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.
- Consistency and standards- Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.
- Error prevention- Even better than good error messages is a careful design which prevents a problem from occurring in the first place. Either eliminate error-prone conditions or check for them and present users with a confirmation option before they commit to the action.
- Recognition rather than recall- Minimize the user's memory load by making objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.
- Flexibility and efficiency of use- Accelerators—unseen by the novice user—may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
- Aesthetic and minimalist design- Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.
- Help users recognize, diagnose, and recover from errors- Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.
- Help and documentation- Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large

Heuristic evaluation method is mainly used to evaluate websites, graphical user interfaces and software applications. Regularly, the evaluators go through the interface in order to identify problems violating the usability heuristics. In order for the method to be effective enough, at least 3 evaluators should participate in the evaluation since it has been demonstrated that 3-5 evaluators detect 60-75 percentage of the usability problems while an individual evaluator only catch 35%. (Zhang et al., 2003).

Usability testing, in turn, is referred as the most fundamental method for usability evaluation, and therefore irreplaceable since it involves real users that provides direct information about participant's satisfaction with the product (Nielsen, 1993). During a test, typically, the subject users are requested to complete a series of tasks while observers watch and takes notes. Usability testing permits to collect qualitative and quantitative data in the form of metrics such as time on tasks or successful task completion (Usability.gov, 2007).

2.2. Home automation usability studies

The present research is not the first study on usability of home automation systems that has been written. Little more than a decade ago, an ethnologic study in Koskela et al. (2004) stressed the potential of using familiar appliances as UIs to achieve a better user experience. Three familiar information appliances were evaluated and utilised as UIs: a personal computer (PC), a media terminal, and a mobile phone. The results identified two main types of activity patterns, pattern control and instant control, each of which required a different type of UI. The PC acted as a central control unit for activity patterns that can be planned and determined in advance. The mobile phone, on the other hand, was well suited for instant control. The mobile phone turned out to be the primary and most frequently used UI during the 6 months trial period. Thus, mobile phones seemed to be the main devices to both control smart homes and interact with intelligent spaces and smart appliances.

The study in Roduner et al. (2007) investigated further on mobile phones as a prototypical system to interact with a number of appliances in a range of different task settings. While the results show that appliances operation can be simplify in uncommon circumstances, the idea of a universal interaction device is less convenient for everyday appliance control. More recently, the study in Manilal and Carreira (2014) assessed existing UIs for HAS supported by accepted heuristics on UIs design. Main aspects of UIs for interaction with HAS devices were systematised and validated, thus defining a set of device behavior requirements. Three UI mockups were then designed based on the findings. Furthermore, the mockups' usability and ease of use were evaluated with usability evaluation techniques. The results demonstrate that the UI that most satisfied users was the one that respected more layout requirements.

An online survey conducted in Schiffhauer (2016) investigated which type of interface users would choose for interaction with a smart apartment. The participants rated their preferred way of interaction among speech, touchscreen, robotic assistance, or conventionally ways of doing tasks (e.g., turning the light on manually by using the wall switch). While the results indicate that the type of interaction with the smart apartment is context dependent, they also show that in most of the proposed scenarios the conventional way of interaction is preferred.

2.3. Enhancing the usability of home automation

Ways to naturally interact with the systems such as voice or gestures have been proposed over the last years, many of them primarily inspired for use by the elderly or disabled. The Gesture Pendant proposed in Starner and Gandy (2000) is an example of it. The solution is a wearable gesture recognition system for control of home automation that can be used by the disabled, thus bringing some advantages over traditional home automation interfaces. The Gesture Pendant can define the devices under its control and limit the number of gestures necessary for control. Another example is the voice-controlled UI presented in Liu and Xian (2007). The interface is designed in such a manner that the user could utilise it in addition to standard keyboard and mouse for control home environments including lights, air conditioner and other home appliances. This interface was designed for the disabled, in order to enhance user experience. However, usability decreases when used by people with non-stander speech. To address this problem, a fully adaptive vocal user interface (VUI) capable to learn both vocabulary and grammar directly from interaction is pursued in Ons et al. (2014). However, the mismatch between several user concepts and designer concepts represented a weakness of this framework. For its part, eye interaction approaches have been tried as well. An example of this is DOGeye, a multimodal eye-based application capable of enabling people with motor disabilities to control and administrate their homes is introduced and evaluated in Bonino et al. (2011). The interface is based on the eye tracking technology. The evaluation demonstrated that the interface is quite effective and usable by people with almost regular eye movement control.

Different types of UIs aimed to improve usability of HAS has been developed. As in Gamba et al. (2015), a modern UI is created by taking advantage of multi-platform programming frameworks. Furthermore, an approach of a "bottom-up" design which focuses on the user rather than the system is briefly presented. The approach intends to provide a different and easier way of handling a HAS. The key is to start from the idea of what the user is intended to finally accomplish and action, thus providing less levels in the UI resulting in a simpler system and a good user experience. The "visible-and-controllable" smart home system introduced in Zhang and Meng (2014) pretends to eliminate the tedious search for the appliance to be controlled in the complicated menu by providing a system that uses the mobile smart terminal to recognise the appliance based on the real-time image captured. Then the terminal generates a UI according to the recognized appliance, meaning that as long as the appliance is visible, it can be controlled.

In recent years, other approaches have been brought to light. The do-it-yourself (DIY)-style is an example of these. The DIY are a style of smart home products created for users, including those not familiar with professional programming, to install their own HAS. Although DIY products can be more difficult to use than other home automation products, they are a potential solution to the problem of inflexible user controls. A recent study provides a new understanding of DIY products, including their usage cycle and contribution to upcoming smart home product design to improve user experiences at home (Woo and Lim, 2015).

Prediction of the user behaviour is another alternative to improve usability of smart devices. The importance of this approach is highlighted in Vavilov et al. (2013). The need for simple algorithms, such as that developed for prediction of TV viewers activities, that can be easily adapted to smart home devices is also pointed out. Similarly, the "offline" smart home solution presented in Milykh et al. (2016) pretends to improve usability of smart home products by predicting user needs. The term "offline" refers to the state of the solution to remain partly or completely disconnected from external environments.

2.4. Usability evaluation of remote controls

The usability of two types of remote controls (conventional vs. multimodal) for an entertainment system is evaluated and then compared in Wechsung et al. (2009). Sixteen individuals tested each remote control by performing nine timed tasks to acquired objective data. For the evaluation of subjective ratings, both AttrakDiff (Hassenzahl et al., 2003) and System Usability Scale (SUS) questionnaires are employed. The outcome of the study did not produce a clear winner as far as usability is concerned, since each remote control has its own advantages and disadvantages. The questionnaire results pointed to the multimodal remote to be somewhat more usable. While the tasks completion time indicated a slightly better usability for the conventional remote control.

In Bjerke (2011) a modified heuristic evaluation method for rapid inspection of non-Graphical User Interface (GUI) interaction devices such as remote controls is presented. Personas method is also evaluated. Moreover, the modified heuristic method is successfully tested on remote controls prototypes in ongoing development. Eight rewritten heuristics remained from the ten heuristic of the traditional method: match between device and the real world; user control and freedom; consistency and standards; error prevention; recognition rather than recall; flexibility and efficiency of use; aesthetic and minimalist design; and help and documentation. Just the two system-oriented heuristics are omitted (visibility of system status; and help users recognize, diagnose, and recover from errors). The result suggests that it is possible to use the modified heuristics to identified usability problem in non-GUI devices in an effective manner.

Apart from that of the remote control, the usability of other input devices have also been evaluated. As in Zhang et al. (2003), where the traditional heuristic evaluation method is modified so it can be applied to medical devices. In here, the ten heuristics are increased rather than simplified by combining them with the eight golden rules of user interfaces (Schneiderman et al., 1998), resulting in fourteen heuristics with semantic tags (Consistency; Visibility, Match; Minimalist; Memory; Feedback; Flexibility; Message; Error; Closure; Undo; Language; Control; and Document), to what is later called the Nielsen—Schneiderman Heuristics. The outcome provide an useful, efficient, and low cost method for evaluation of medical devices.

2.5. Remote controls in home automation

Remote controls have been integrated into home automation in lots of flavors and colors. Earlier this decade, an advanced universal remote controller (URC) for home automation capable to control all type of digital home appliance is presented. The URC incorporates a built-in touch panel and communicates with the appliances via receivers with wired and wireless communications methods (Kim et al., 2010). Lai et al. (2013) introduced a bidirectional communication GUI built-in a URC. It communicates with the appliances through Radio Frequency for Consumer Electronics (RF4CE) to automatically paired with each other. Another smart URC is proposed in Roy and Roy (2014) with the novelty of efficient self-adaptive capabilities, meaning that the remote is capable to self-learn new devices and functions from any vendor. It demonstrates a better performance when compared to a commercially available mobile based remote with similar characteristics. More recently, a smarter URC system called Point-n-Press was presented in Lee et al. (2016). The system shows in the display of the remote control the specific interface of the targeted device, meaning that only relevant buttons are utilized. Point-n-Press is intended to reduce the confusion that some users might have when using a remote control with dozens of buttons.

3. RESEARCH PROCESS

The research process is intended to give response to the research questions defined earlier. The process utilizes user research methods based on the User-Centered Design (UCD) process. The used methods are: online survey, usability testing, heuristics evaluation and system usability scale.

3.1. User-centered design

The user-centered design (UCD) process is an approach that involves intended users in the development of a new product, software or web site, or in the evaluation of an existing one. The degree of user involvement depends on the type of methods being used (Abras et al., 2004). International usability standard, ISO 13407 underlines the process principles but it does not specify exact methods for each stage in the process, therefore it is up to the research and/or development team to define them. This approach has demonstrated that user involvement leads to an improvement in user satisfaction (Abras et al., 2004; Travis, 2017).

Four methods are employed on this research. Starting from online survey, continuing with usability testing and system usability scale, and ending with heuristics evaluation (Fig. 1).

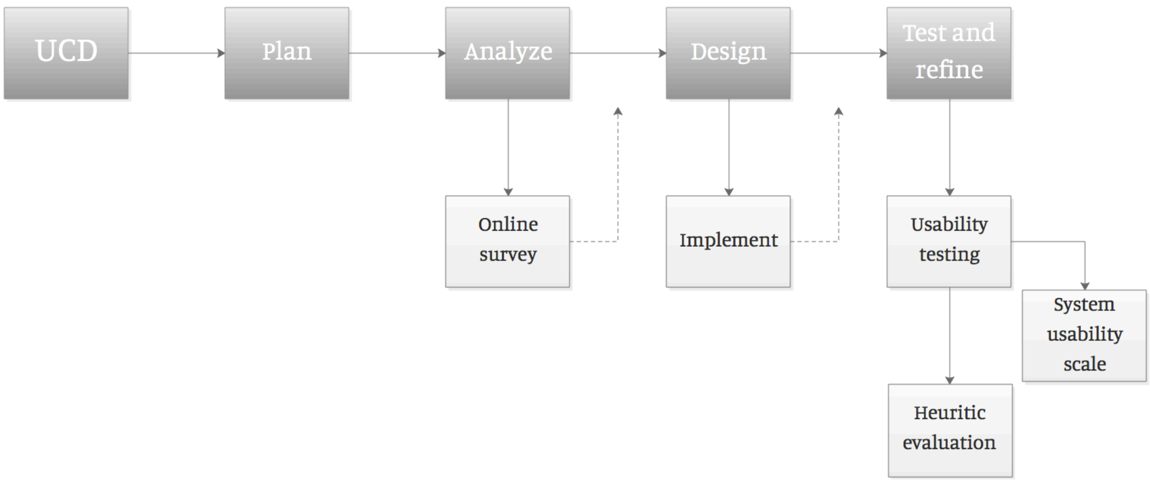


Figure 1. Phases and methods employed on the research UCD process

3.2. Online survey

At the beginning of this research, an online survey is conducted with the purpose of discovering if users tend to control their home appliances and technical devices typically with conventional remotes controls or more advanced techniques, expecting remote controls to be the main way of interaction. Additionally, some questions about home automation are also included in order to obtain an insight into respondents current position regarding the topic. Online surveys consist of distributing structured questionnaires through the Internet, thus offering a way to collect information from a broad audience for a low or almost insignificant cost (Usability.gov, 2017).

Table 2 illustrates the outcome of the process to determine the focus for individual questions, which includes the establishment of the key link between the research issues that pertain to this stage of the process and the focus of the individual question to be asked that are then designed in detail. (Burgess, 2001). Later, the questions sequence and the overall questionnaire layout is designed according to some good practices including: ensuring that it has title and a brief introductory statement, using as few questions types as possible, or leaving easier questions at the end, e.g. questions about personal data, when the respondents are less likely to object to giving information,

Once the questionnaire is generated, the online survey is designed and distributed using Google Forms (See Appendix 1). The questionnaires are originally written in English and sent it to both professors and students of Harz University of Applied Sciences and distributed through a Facebook local group. Subsequently, to broaden the scope of the survey, the questionnaires are translated into German and forwarded to the same distribution list. Similarly, a printed version of the German questionnaire is also made available and distributed through post mail in order to reach older audiences who normally do not use the Internet.

Table 2. Outcome of process to generate issues and focus of questions (Burgess, 2001)

Issue	Focus of the question
What tools does the respondents use to interact with their home appliances?	Do the respondent uses: remote control, smartphone, personal computer, other?
With what home appliances does the respondents interact using a tool?	Do the respondent interacts with: TV, audio or video player, fridge, thermostat, other?
In what room does the respondents use an interaction tool to interact with their home appliances?	Do the respondent uses it in: living room, bedroom, dining room, bathroom, kitchen?
How many conventional remote controls does the respondents have at home?	Do the respondent has: 1, 2, 3 or more?
Do the respondents have any universal remote control at home?	Do the respondent has or not?
Do the respondents have any type of home automation system at home?	Do the respondent have or not?
How interested are the respondents in home automation systems for their homes?	Is the respondent: extremely, very, somewhat, slightly or not at all interested?
To what extent does the use of remote controls in home automation systems influence the respondents preference?	Is the respondent: more, less or equally interested?
Could gender differences affect the interaction tool?	Is the respondent male or female?
Could age differences affect the interaction tool?	Is the respondent under 30, between 30-40 or older than 40 years old?
Could background differences affect the interaction tool?	Do the respondent has a technical or non-technical background?
Could living situation differences affect the interaction tool?	Do the respondent lives alone, with children, elderly, or someone else?
Could income differences affect the interaction tool?	Is the respondent's annual income under or over €30,000?

3.3. Usability testing

Upon the completion of the online survey, an onsite usability testing is run using the tailored home automation system. Usability testings are intended to determine the extent to which a product or system facilitates the ability of a user to perform routine tasks. Typically the test is conducted with a group of potential users either in a usability lab, remotely, or on-site with portable equipment. To ensure stable results, usually a total of 8-10 participants are involved in a usability testing. Participants are asked to complete a series of routine tasks. Session are recorded and analyzed to identify potential areas for improvement to the product (Usability.gov, 2017). The purpose of the usability testing is to assess and compared the usability of three interaction tool: a personal computer, a smartphone and a remote control.

The participants who provided their contact information through the online survey as well as others personally contacted are invited to the usability testing. The testing occurred in a computer adapted laboratory where participants are seated in front of the home automation system and the three different interaction tool. Each individual session lasted approximately 15 minutes. During the session, both the testing session itself and the functionality of each interaction tool is explained to the participants that are not already familiarized with it. The participants could then briefly explore all of the interaction tools. Later, the participants are requested to complete the 5 real-life tasks listed in Table 3.

Table 3. Usability testing tasks

#	Task
1	Turning on the light
2	Adjusting the temperature to 20 ºC
3	Turning on the television
4	Dimming down the light to 50%
5	Turning everything off (light, temperature and television)

The participants are instructed to perform the tasks in a systematically manner in each and every one of the interaction tools. The task completion rates are captured and registered. By the end of each round, the participants are asked to rate the tool they just tested using the

System Usability Scale. Individual differences such as age and background are considered to investigate if there are variations between the types of users.

3.4. System Usability Scale

To assess subjective ratings regarding usability, the System Usability Scale (SUS) (Brooke, 1996) is employed. SUS is chosen for this research due to: its very easy to administer scale; it is usable on small sample sizes with reliable results; it can effectively differentiate between usable and unusable products; and it allows to equally evaluate both hardware and software products. Apart form the 10 items, ranging from "strongly agree" to "strongly disagree", that comprises SUS questionnaire, some personal questions are included in the form in order to identify the type of users (see Appendix 4). For our purposes, the items are modified by changing the term "system" to "interaction tool" in each of the items as shown in Table 4.

Table 4. SUS 10 items questionnaire modified

#	Item
1	I think that I would like to use this interaction tool frequently
2	I found the interaction tool unnecessarily complex
3	I thought the interaction tool was easy to use
4	I think that I would need the support of a technical person to be able to use this interaction tool
5	I found the various functions in this interaction tool were well integrated
6	I thought there was too much inconsistency in this interaction tool
7	I would imagine that most people would learn to use this interaction tool very quickly
8	I found the interaction tool very cumbersome to use
9	I felt very confident using the interaction tool
10	I needed to learn a lot of things before I could get going with this interaction tool

SU scale is used after the subjects tested each interaction tool, in such a manner that a tool is first tested then evaluated, and then the same with the rest of them. Respondents are asked to record their responses to each of the 10 items using the Likert scale.

To calculate the SUS score, the score contribution from each item is first summed. For the odd items (1, 3, 5, 7, 9) the score contribution is the position in 5-point scale (1-5) minus 1. For the pairs items (2,4,6,8, 10) the contribution is 5 minus the position in 5-point scale. Next, the sum of the scores is multiplied by 2.5 to obtain the SU overall value.

SUS score can ranges from 0 to 100. In accordance to (Bangor et. al, 2009; Usability.gov, 2017), scores greater than 68 are considered above average and any score under 68 is below average (Fig. 2).

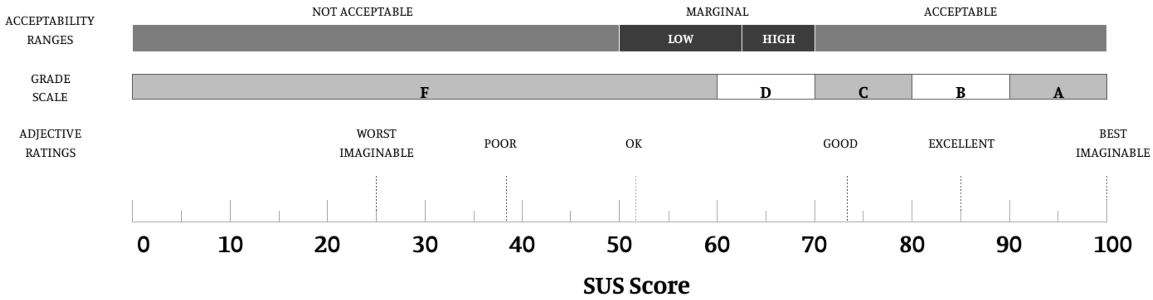


Figure 2. A comparison of the adjective ratings, acceptability scores, and school grading scales, in relation to the average SUS score (Bangor et. al, 2009).

3.5. Heuristic evaluation

As an additional measure for usability also the heuristic evaluation is employed (Nielsen, 1994), but only for the remote control. The heuristic evaluation is an easy to use technique that can be conducted in a timely manner with a reasonable cost and as such is suitable for this study (Zhang et al., 2003).

Since the traditional heuristic evaluation is conceived to assess systems with UIs, the method is tailored based on Bjerke (2011) and Zhang et al. (2003) so that it can be applied to the evaluation of a conventional remote control. The modification results in the reduction from the original ten heuristics to only eight. The pair of omitted heuristics are those highly targeted to software systems (i.e. visibility of system status and help users recognize, diagnose, and recover from errors). The heuristics that remained are then tailored to be specific for evaluation of the remote control. The resulting eight heuristics are shown in Table 5.

Table 5. Eight modified heuristics (Bjerke, 2011)

Heuristic (tag)	Description
Match between tool and the real world (Match)	The tool should speak the user language, with icons, labels and concepts familiar to the user, rather than tool-oriented terms; follow real-world conventions by making information appear in a natural and logical order
User control and freedom (Control)	Users often choose functions by mistake and will need a clearly marked “emergency exit” button to leave the unwanted scene without having to go through and extended dialogue; support undo and redo
Consistency and standards (Consistency)	Users should not have to wonder whether different labels, icons, or buttons mean the same thing
Error prevention (Error)	Is the tool designed carefully to prevent problems from occurring? Are all buttons placed in such way users cannot press them by mistake? Is each buttons’ intended function clear? Is each buttons’ label placed intuitively?
Recognition rather than recall (Recognition)	Minimize the users’ memory load by labeling buttons and making actions and options visible
Flexibility and efficiency of use (Flexibility)	Allow users to tailor frequent actions; shortcuts may often speed up the interaction for the experienced user and make the device suit both inexperienced and experienced users
Aesthetic and minimalist design (Aesthetic)	The tool should not contain labels, icons, or buttons that are irrelevant or rarely needed; every extra unit of information competes with the relevant units of information and diminishes their relative visibility
Help and documentation (Help)	Even though it is better if the tool can be used without manual, it may be necessary to provide help and documentation; any such information should be easy to search, focused on the users’ task, list concrete steps to be carried out, and not be too large

In contrast to the heuristics, severity rating scales are not modified at all, hence each problem is evaluated according to the severity rating on the following scales:

- 0— not a usability problem at all
- 1— cosmetic problem only; does not need to be fixed unless extra time is available
- 2— minor usability problem; fixing this should be given low priority
- 3— major usability problem; important to fix, should be given high priority
- 4— usability catastrophe; imperative to fix this before product can be released

The severity rating of a usability problem is a combination of the frequency with which a problem occurs, is it common or rare?; the impact of the problem if it occurs, will it be easy or difficult to overcome?; and the persistence of the problem, is it a one-time problem that users can overcome once they know about it or will users repeatedly be bothered by the problem? (Bjerke, 2011).

4. IMPLEMENTATION

Research question 3 —How to integrate conventional remote controls into current home automation systems?— is here responded, meaning that the implementation of the home automation system is described. The aspects included as part of the implementation are components, architecture and configuration.

4.1. System overview

A home automation system is tailored so that it can be controlled by any conventional remote control. Fig. 3 illustrates the universal remote control utilized during the implementation of the system.

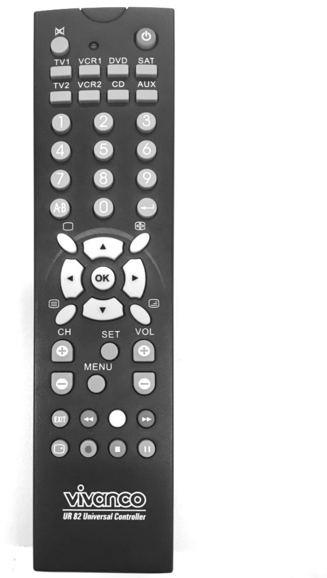


Figure 3. Remote control used in implementation.

Some basic daily tasks are implemented. The implementation consists in the configuration of single buttons of the remote control to carry out either a single action or a number of simultaneous actions. Additionally, the remote control is accompanied by an explanatory sheet illustrating the new functionalities for each of the modified buttons (Table 6).

Table 6. Explanatory sheet

Button	New functionality
	Turn everything (home appliances, lights and temperature) off
	Switch on and off the TV
	Set the comfort temperature (20 $^{\circ}$C)
	Turn the light on and off
	Dim up the light (in 50 percentage increments)
	Dim down the light (in 50 percentage decrements)

4.2. System components

The Friendly House automation and Energy Measurement (FHEM) solution is used in the implementation of the system. FHEM is a home automation system based on GPL'd perl. The program runs as a server that can be controlled via web or smartphone frontends, telnet or TCP/IP directly (Fhem.de, 2017).

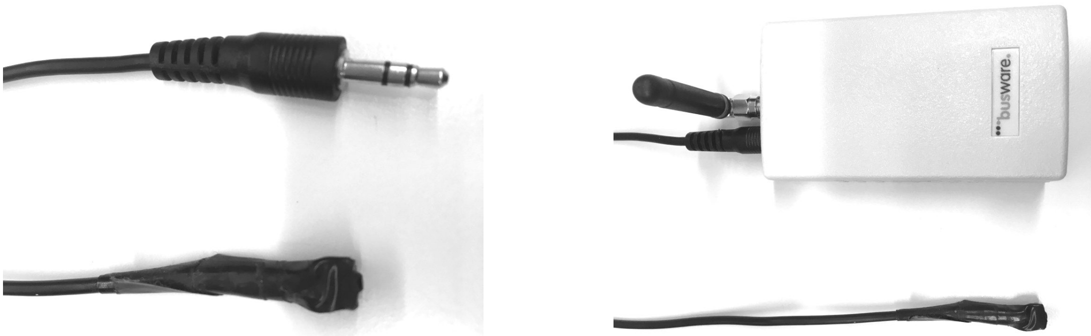
The server runs in a DHS HomeManager developed by Digital Human Services (DHS) - Computertechnik Gmbh, with 4GB flash, 1GB RAM, dual core 1GHz processor, 100Mbit LAN, HDMI, USB host, 2x RF link and a 2.8" touchscreen illustrated in Fig. 4.a. Perl is available in 5.20.2 (Dhs-computertechnik.de, 2017).

(a) (b)

Figure 4. System components a) DHS HomeManager; b) CUL.

As for the home center, it is an CC1101 USB Lite (CUL) version 1.43 CUNO433 a radio frequency (RF) device with external antenna sold by busware.de with the open-source firmware culfw, it is capable to send and receive different 433/868 MHz protocols (Fig. 4b).

In addition to its RF capabilities, the hardware of this version of the CUL is particularly modified in order to support an special module to interpret infrared (IR) messages (fig. 5). With this module the CUL is able to receive IR signals from practically any remote controller (Fhem.de, 2017).



(a) (b)

Figure 5. IR module: a) IR receiver; b) IR receiver connected to CUL

FHT and FS20 sensors and actuators are utilized in the implementation (Fig. 6). The components utilized are listed in Table 7.

(a) (b) (c)

Figure 6. Sensors and actuators: a) wireless switch socket; b) radio wall thermostat; c) wireless dimmer

Table 7. System components.

Product	Function	Number
FS 20 ST-4	Wireless switch socket	2
FS20 DI-5	Wireless dimmer	1
FHT 80B	Radio wall thermostat	1

4.3. System architecture

Fig. 7 illustrates the home network diagram. Everything, including both the FHEM server (HomeManager) and home center (CUL), is interconnected through an Ethernet modem with wireless capabilities. FHEM is accessed through either a web-front end from a computer or a smartphone utilizing FHEMremote application. The home center communicates wirelessly to the sensor and actuators and receives infrared command from the remote control through the IR receiver.

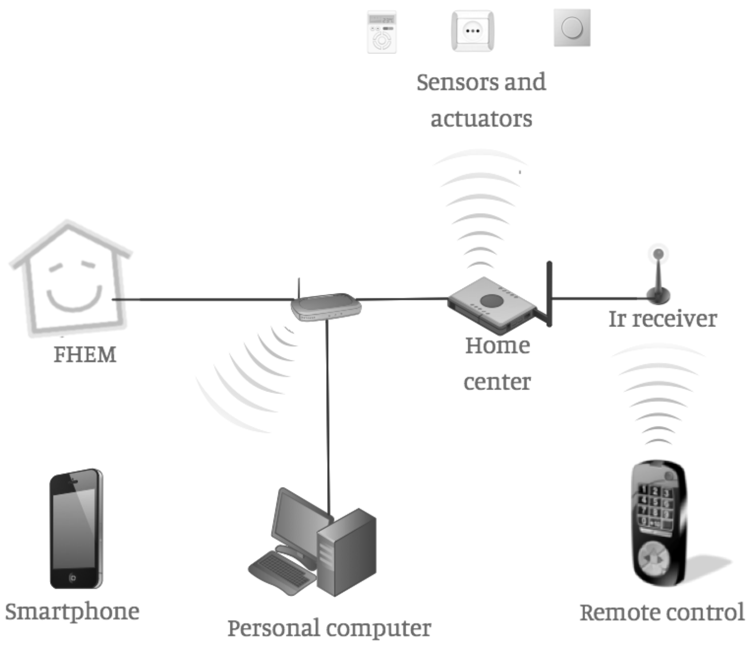


Figure 7. HAS architecture.

4.4. System configuration

In order to adapt the remote control to home automation systems, the functionalities of the desired buttons must be implemented within the configuration of the system. This subsection walks through the part in the configuration file (see Appendix 3) that implements the functionality of the IR module.

The CUL_IR module is created by defining the device name of the IR receiving device, i.e. CUL1:

```
defmod IR_Dev CUL_IR CUL1
```

After the CUL_IR device is successfully created, it is set in IR-Code learning mode for the given seconds, e.g. 30 sec:

```
set IR_Dev irLearnForSec 30
```

In order for the device to learn IR-Codes, the CUL_IR devices is set in IR-Receiving mode beforehand by modifying the irReceive attribute:

```
attr IR_Dev irReceive ON_NR
```

Hence, the CUL_IR generates a new button-attribute for each new IR-Code received which are later on modified by adding a command as attribute value so that the buttons from where the code is received are ready to execute the defined functionality.

The functionality of switching on and off the television is defined:

```
attr IR_Dev ButtonA001 I02AF50001900 IF ([homeappliance_1:&STATE] eq "off")
        (set homeappliance_1 on) ELSE (set homeappliance_1 off)
```

The functionality of adjusting the temperature to 20ºC is defined:

```
attr IR_Dev ButtonA002 I02AF50001A00 set FHT_2d31 desired-temp 20.0
```

The functionality of turning everything (light, television and temperature) on and off is defined:

```
attr IR_Dev ButtonA003 I02AF50000800 set FHT_2d31 desired-temp off;;
          set light_1 off;; set homeappliance_1 off;; set dimmer_1 off
```

The functionality of switching on and off the light is defined:

```
attr IR_Dev ButtonA004 I02AF50001B00 IF ([dimmer_1:&STATE] eq "off")
          (set dimmer_1 dim100%) ELSE (set dimmer_1 off)
```

The functionality of dimming down the light in 25 percentage decrements is defined:

```
attr IR_Dev ButtonA008 I02AF50000200 IF ([dimmer_1:&STATE] eq "off")
          ((set dimmer_1 dim25%) IF ([dimmer_1:&STATE] eq "dim25%")
                    ((set dimmer_1 dim50%) IF ([dimmer_1:&STATE] eq "dim50%")
                              ((set dimmer_1 dim25%)))) ELSE (set dimmer_1 dim100%)
```

The functionality of dimming up the light in 25 percentage increments is defined:

```
attr IR_Dev ButtonA009 I02AF50000300 IF ([dimmer_1:&STATE] eq "dim100%")
          ((set dimmer_1 dim75%) IF ([dimmer_1:&STATE] eq "dim75%")
                    ((set dimmer_1 dim50%) IF ([dimmer_1:&STATE] eq "dim50%")
                              ((set  dimmer_1 dim25%)))) ELSE (set dimmer_1 off)
```

Next button-code-number to be learned, i.e. 10:

```
attr IR_Dev learncount 10
```

String added to every button-attribute-name, i.e. A:

```
attr IR_Dev learnprefix A
```

5. EVALUATION AND RESULTS

Results issued by the research process are presented in here, thus responding research questions 2, 4 and 5: What tools are typically used to interact with home appliances? Do conventional remote controls improve the usability of HAS? and Do conventional remote controls on HAS are aimed to a specific audience?

5.1. Typical interaction tools

Forty-two respondents participated in the online survey, 30 of whom are male and 12 female. Twenty-five aged over 40 years, 11 between 30-40 years, and six of them are 29 years or younger. Nineteen replied that their background is technical, while the others 23 that theirs is not.

As illustrated in Figure 8, the remote control is the main interaction tool most respondents use to interact with televisions (90%), audio (45%) and video (63%) players, and home theatre (55%). The remaining home appliances are mainly controlled manually, microwave (96%), refrigerator (100%), thermostat (83%) and air conditioner (86%). In contrast, tablet and speech or gesture command are not the main ways of interaction with any home appliances.

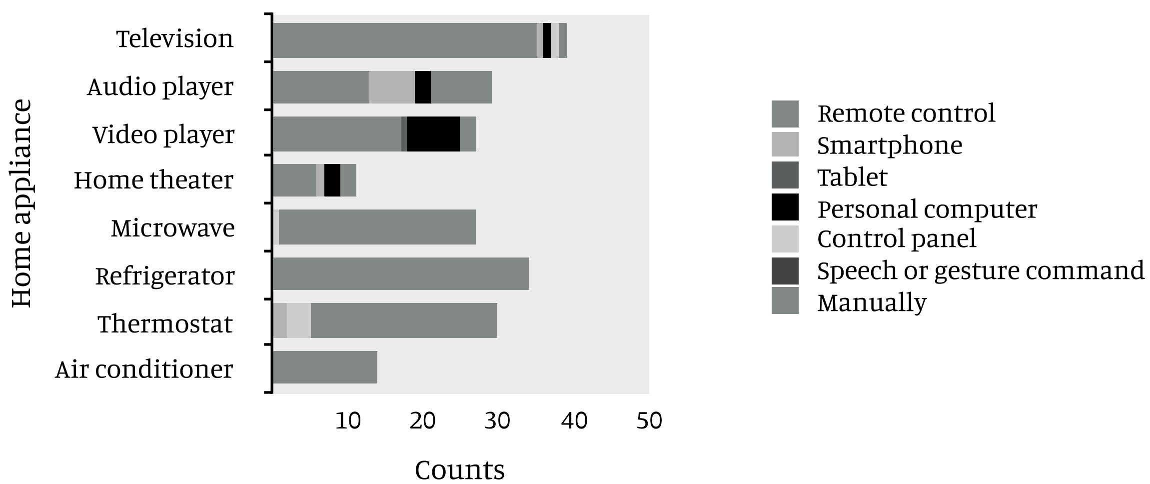


Figure 8. Main interaction tool per home appliance.

Similarly, the remote control is the interaction tool most frequently used to interact with home appliances (79%), since it is used at least once a day (i.e., more than once a day or everyday). Smartphone and personal computer comes next with 55% and 50% of daily use, respectively. In contrast, tablet (29%), control panel (32%) and speech or gesture control (15%) are daily used by less than 50% of respondents (Figure 9).

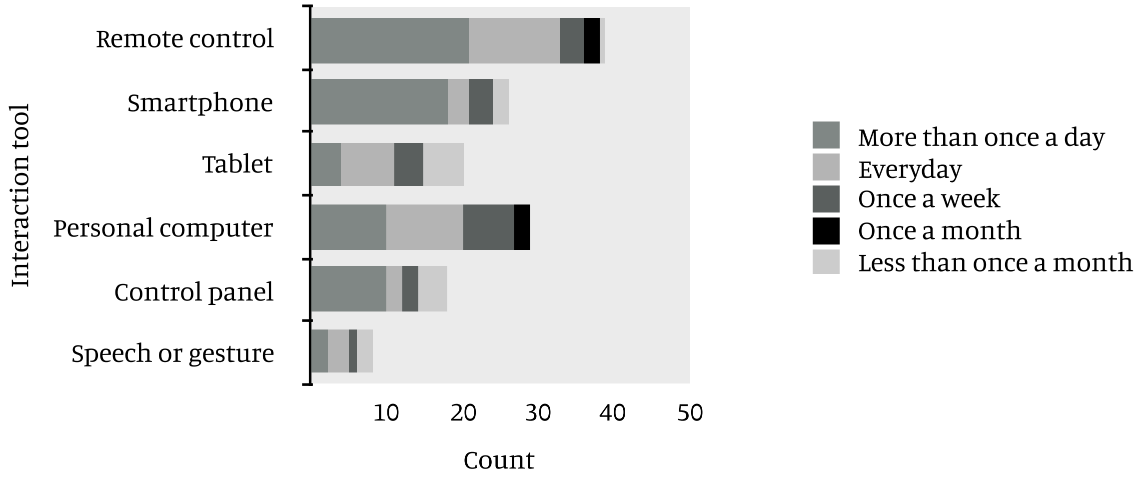


Figure 9. Frequency of use per tool to interact with home appliances.

For almost 100% of the interviewed (98%), the living room is the place of the house in where they use an interaction tool to control some sort of home appliance while the second place in the house is the kitchen (43%). Bed (26%) and dining (24%) room are right behind the kitchen. In contrast, the room where users least interact whit home appliances is the bathroom (Fig. 10).

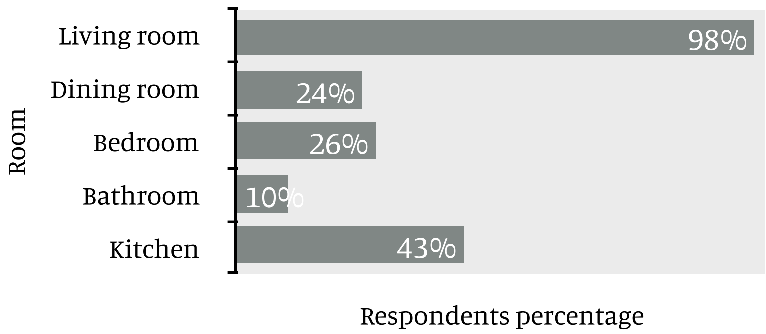


Figure 10. Rooms in where interaction tools are being used to control home appliances.

On average, there are 4 conventional remote controls per household. However, in most households, there are 2 or 3 of them. In some houses there are up to 10 remote controls, while in the remaining homes there is at least 1 (Fig 11).

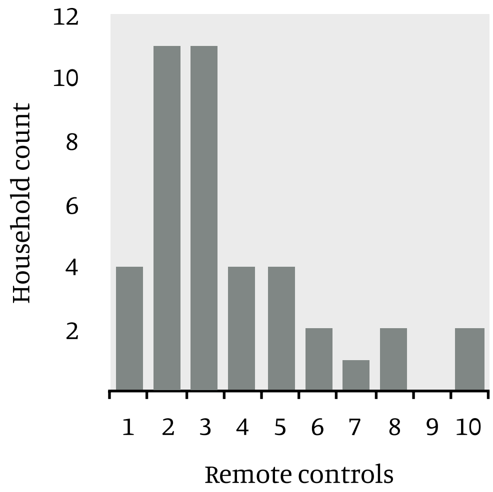


Figure 11. Remote controls per household.

Fig. 12 illustrates current interest level of respondents in incorporating home automation into their homes. 5% of respondents already have a sort of HAS at home. 71% are at least slightly interested in acquire some (i.e., very interested, somewhat interested or slightly interested), and 29% are not interested at all.

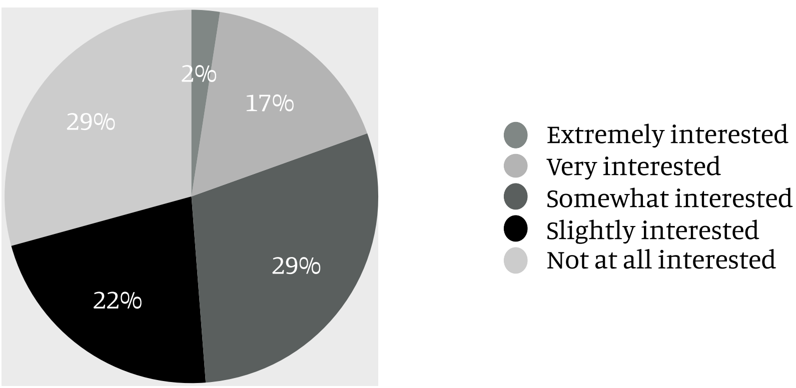


Figure 12. Interest level in incorporating home automation

Furthermore, 33% replied that a system with a conventional remote control involved, would increase their interest in HAS. 27% responded that it would made no difference, and the remaining 40% implied that it would actually decrease their interest.

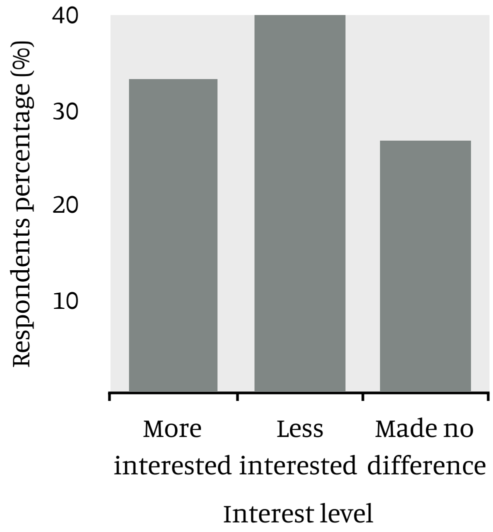


Figure 13. Remote control influence on interest level

Effects of personal differences of respondents are considered. Effects between age and: frequency of use of interaction tools, main tool of interaction, and remote control influence on interest level are considered. For both frequency of use (Fig. 14a) and main interaction tool (Fig. 15b) no significant differences are observed.

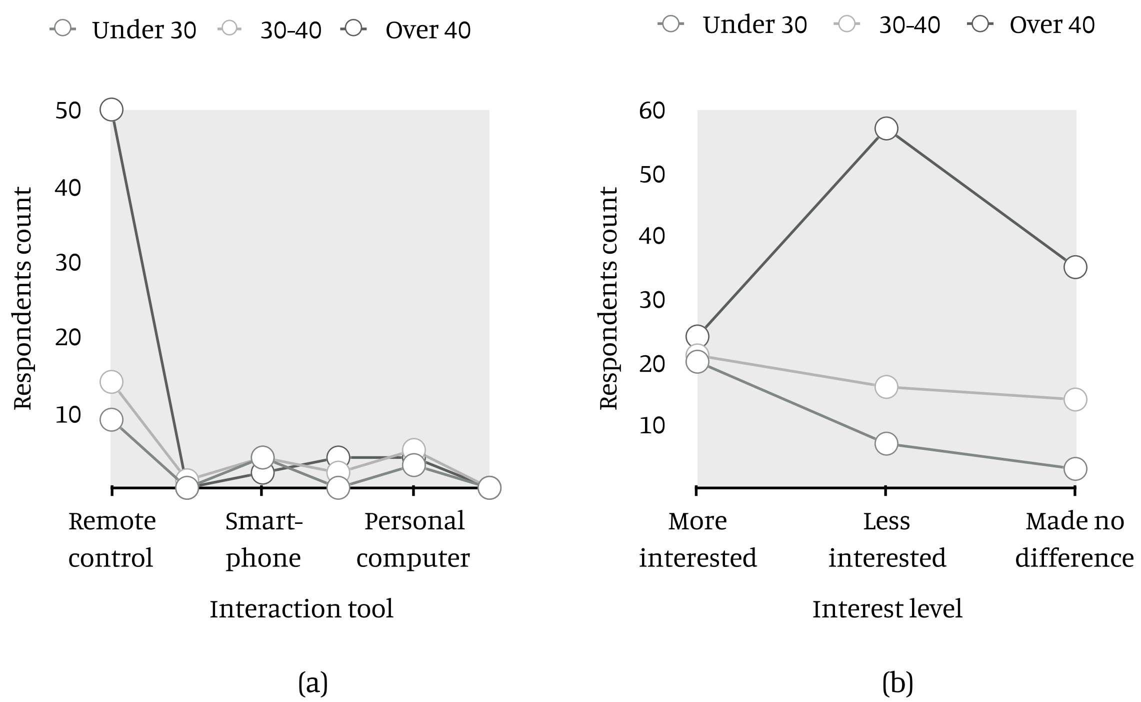


Figure 14. Effects between age and: a) frequency of use; b) interest level.

Respondents background and living situation are also considered. For background, no major effect is observed in any case (Fig. 15a; 16a; 16b).

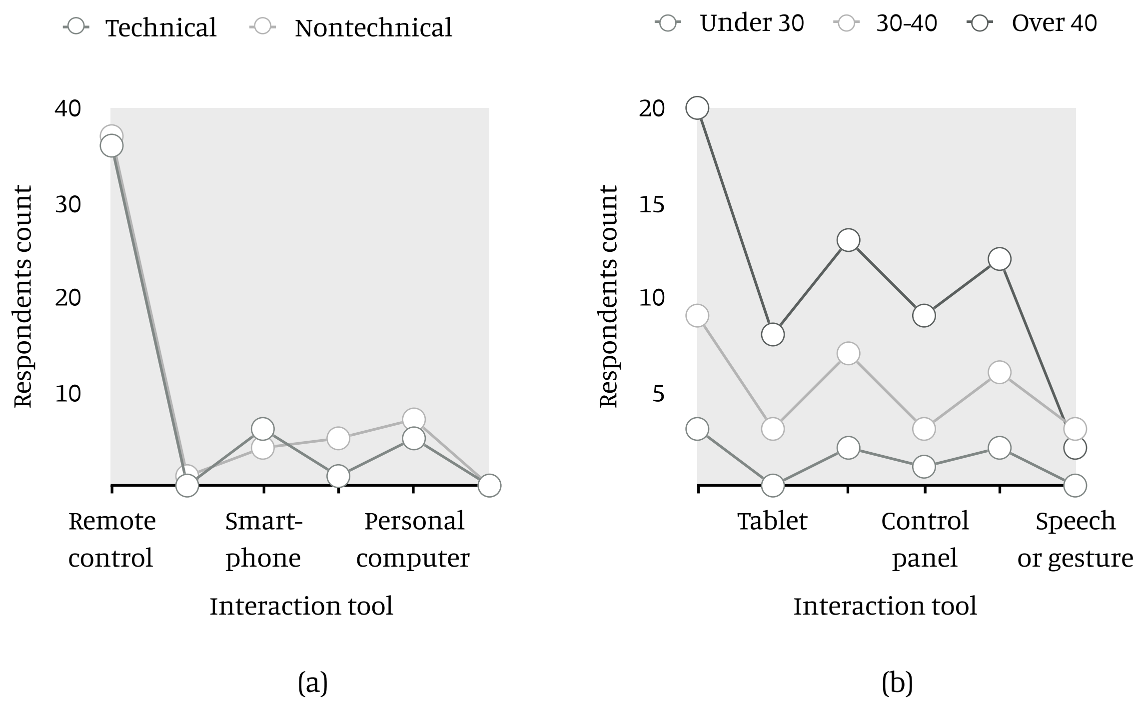


Figure 15. Effects between: a) background and frequency of use; b) age and interaction tool.

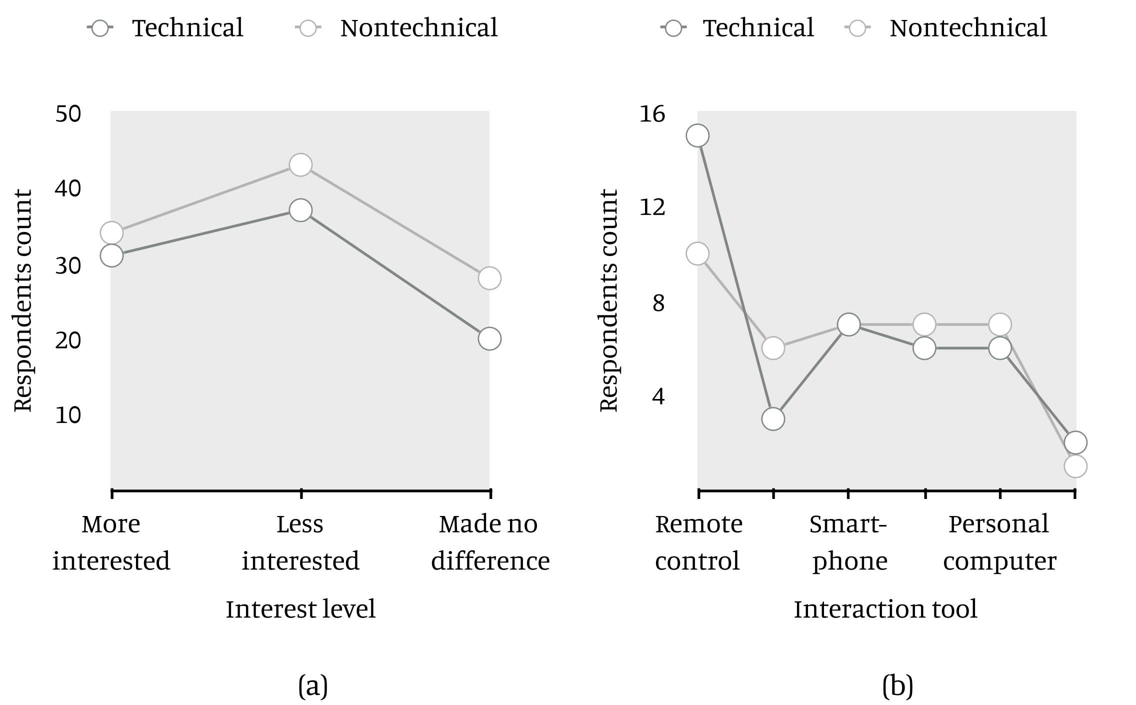


Figure 16. Effects between background and: a) interest level; b) interaction tool.

In regard to living situation and interest level, respondents living with elderlies are more interested whereas those living either with children, both or none, are less interested (Fig. 17a). Neither frequency of use (Fig. 17b) nor interaction tool (Fig. 18) are affected by the living situation.

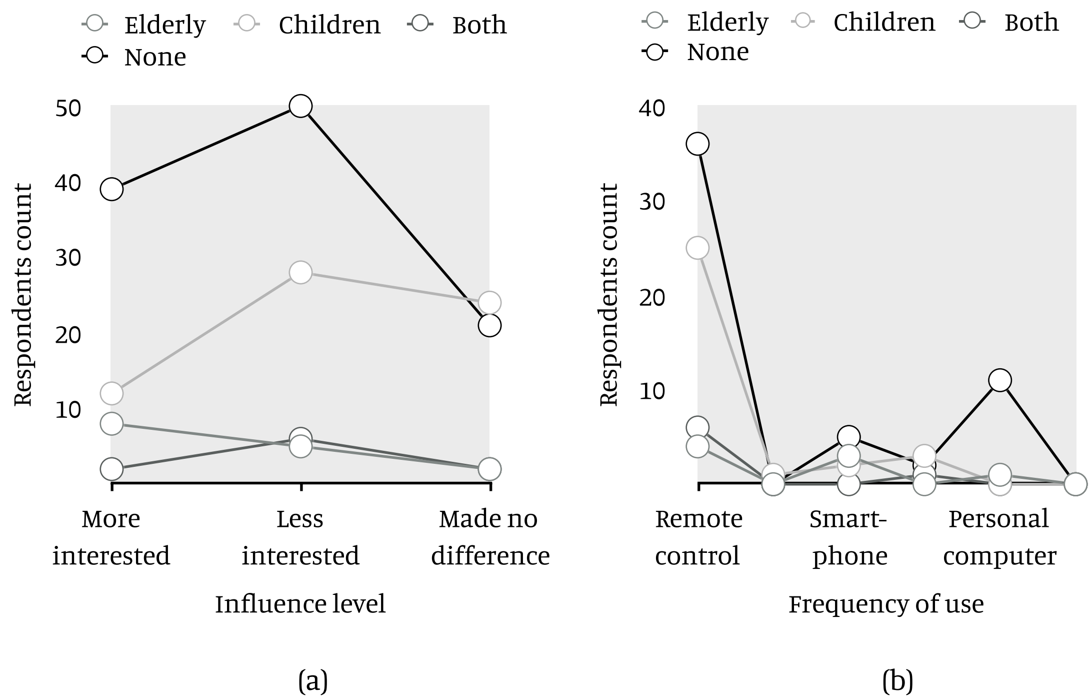


Figure 17. Effects between living situation and: a) interest level; b) frequency of use.

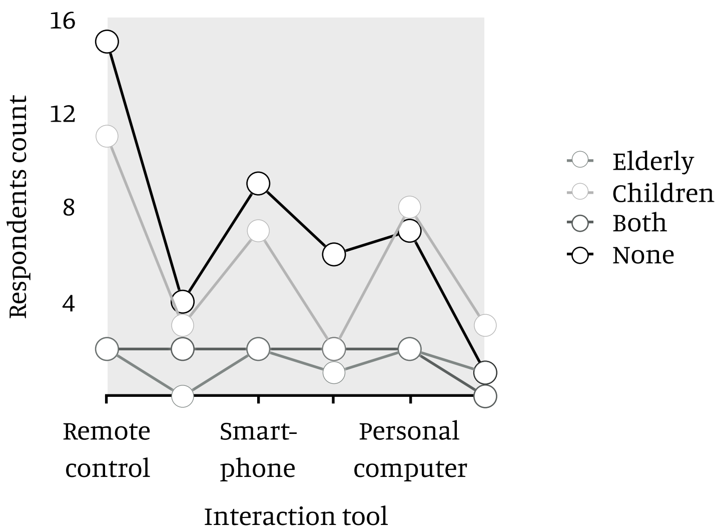


Figure 18. Effects between living situation and interaction tool.

5.2. Comparative usability evaluation

In-situ usability testing happened in an adapted laboratory. Eight individuals attended. From the total, seven are male and only one is female. The time on tasks is recorded and registered for each participant.

Table 8 contains individual tasks completion time with the PC. Task 5 took the longest time to complete (M=24.148 seconds) to all but one participant. However, completion times ranges from 10.235 to 59.090 seconds with most times less than 20 seconds. Overall, task 4 is the task that took the second longest time to complete (M=22.131). Completion times ranges from 5.403 to 58.171 seconds. Task 2 comes third which is reflected in the average completion time of 10.158 seconds and with completion times between 2.488 and 32.760 seconds. Tasks 1 and 3 (M=4.126 and M=4.496, respectively) took the shortest times to complete, with more consistent completion times ranging from 1.688 to 6.718 seconds.

Table 8. Tasks completion time (in sec.) for personal computer (U = User, M = Mean)

Task #	I1	I2	I3	I4	I5	I6	I7	I8	M
Task 1	6.460	2.142	2.432	1.688	4.333	6.718	5.106	3.549	4.053
Task 2	32.760	5.837	2.488	5.296	6.672	9.632	8.418	12.120	10.403
Task 3	6.590	4.336	3.913	2.108	5.936	4.769	3.818	3.367	4.355
Task 4	13.160	24.664	7.791	36.319	9.408	58.171	5.403	8.307	20.403
Task 5	49.220	17.573	10.235	59.090	11.438	10.775	10.706	9.505	22.318

In Table 9 are comprised the time the participants took to complete the tasks using the smartphone. In this occasion, the task that took the longest time to be completed is Task 1 (M=21.618). A couple of average times (48.984 and 46.310 seconds) rise the average, since the other times ranges from 5.504 to 19.575 seconds. With 19.505 task 2 runs a close second, with completion times going from 6.544 to 53.710. Task 3, 4, 5 are very close to each other (M=9.235, M=10.450 and M=13.322), being task 3 the shortest task with time ranging from 3.803 to 17.729.

Table 9. Tasks completion time (in sec.) for smartphone (U = User, M = Mean)

Task #	I1	I2	I3	I4	I5	I6	I7	I8	M
Task 1	46.310	11.185	19.575	10.043	10.165	5.504	48.984	3.640	19.426
Task 2	53.710	26.926	6.544	12.759	9.655	12.992	13.949	12.894	18.679
Task 3	13.790	9.105	3.803	4.444	17.729	11.900	3.875	4.039	8.586
Task 4	12.624	0.705	7.688	11.119	9.604	18.524	5.889	7.855	10.126
Task 5	1.550	13.260	7.373	14.361	20.095	26.128	10.486	25.153	14.801

Table 10 arranges tasks completion times for the third and last interaction tool, the remote control. Longest task to complete is Task 5 (M=4.100), its completion times ranges from 2.976 to 11.764 seconds. All the other tasks completion times, ranges from 2.392 to 3.706 seconds. In addition to that of 11.764 sec, there is no other completion time, for any task, greater than 10 seconds and there are only three other higher than 5 seconds (6.565, 8.103 and 8.319 seconds). Task 4 is the task that took the shortest time to complete (M=2.392). Completion times for user no. 3 were not registered correctly.

Table 10. Tasks completion time (in sec.) for remote control (U = User, M = Mean)

Task #	I1	I2	I3	I4	I5	I6	I7	I8	M
Task 1	4.180	3.751	-	8.319	3.543	3.764	2.032	2.951	3.567
Task 2	4.289	3.404	-	4.029	4.088	6.565	3.568	2.656	3.575
Task 3	3.100	4.483	-	2.848	3.200	8.103	2.153	3.847	3.467
Task 4	4.255	2.185	-	1.860	3.009	3.579	1.856	2.624	2.421
Task 5	11.764	3.168	-	2.976	3.567	3.797	3.428	10.071	4.846

Overall, task 5 took the longest average time to complete for both personal computer and remote control (24.148 and 4.100, respectively). For smartphone, the most time consuming task is Task 1 (21.681). In contrast, remote control and smartphone matched task 4 as the shortest least time consuming task. The remote control surpassed both the personal computer and the smartphone in each and every task. Moreover, it significantly outperformed the smartphone in all of the tasks and the personal computer in three of the five tasks. All of which is exhibited in Table 11.

Table 11. Summary of mean tasks completion time (in sec.) per interaction tool

Task #	Personal computer	Smartphone	Remote control
Task 1	4.053	19.426	3.567
Task 2	10.403	18.679	3.575
Task 3	4.355	8.586	3.467
Task 4	20.403	10.126	2.421
Task 5	22.318	14.801	4.846

At the end of each round of tasks, the participants are requested to evaluate the interaction tool they just tested using the system usability scale (SUS).

Individual SUS scores for the personal computer are contained in Table 12. SUS scores above 68 are considered above average and anything below that number is below average. For the personal computer, most of the scores (6) are below average (30, 35, 42.5, 45, 45, 55) and just 1 (75) is above.

Table 12. Individual SUS scores for PC (I = Individual)

Item #	I1	I2	I3	I4	I5	I6	I7	I8
Item 1	1	2	1	3	1	1	5	5
Item 2	3	3	3	3	4	4	3	2
Item 3	1	2	3	4	3	2	4	4
Item 4	5	3	1	2	1	1	1	1
Item 5	3	2	1	4	2	2	3	4
Item 6	3	4	2	3	3	3	2	1

Item 7	1	2	1	2	1	3	2	2
Item 8	1	3	4	4	2	4	2	3
Item 9	2	2	4	3	2	3	5	5
Item 10	4	3	2	2	2	1	1	2
SUS score	30	35	45	55	42.5	45	75	77.5

Table 13 illustrates the individual SUS scores for smartphone. Although above average scores increase compared to those of PC, below average scores (50, 57.5, 65, 67.5) remain under half (4). Therefore, there are 3 scores (90, 92.5, 95) above average.

Table 13. Individual SUS scores for smartphone

Item #	I1	I2	I3	I4	I5	I6	I7	I8
Item 1	2	4	5	4	3	5	5	5
Item 2	3	3	1	3	2	1	2	2
Item 3	4	4	5	4	4	5	4	3
Item 4	1	2	1	1	1	1	1	1
Item 5	3	4	4	3	2	4	4	3
Item 6	2	3	2	3	4	2	1	2
Item 7	2	4	5	4	3	5	4	4
Item 8	2	3	1	3	4	1	1	3
Item 9	2	3	4	4	3	5	5	4
Item 10	5	2	1	2	1	1	1	2
SUS score	50	65	92.5	67.5	57.5	95	90	72.5

In Table 14, SUS scores for remote control are exhibited . Unlike previous interaction tools, most scores for the remote control (5) are above average (77.5, 85, 2x87.5 and 100) and only a couple are below (2x57.5).

Table 14. Individual SUS scores for remote control

Item #	I1	I2	I3	I4	I5	I6	I7	I8
Item 1	5	4	5	3	4	2	5	3
Item 2	1	3	1	1	1	2	1	2
Item 3	5	5	5	5	5	5	5	4
Item 4	1	1	1	3	1	1	1	1
Item 5	4	4	2	4	5	3	5	4
Item 6	1	2	2	5	1	5	1	1
Item 7	5	4	5	4	5	2	5	4
Item 8	5	3	1	4	4	3	1	3
Item 9	5	4	3	4	5	5	5	5
Item 10	1	1	1	4	2	3	1	3
SUS score	87.5	77.5	85	57.5	87.5	57.5	100	75

Table 15 summarizes and compares individual SUS scores of the three interaction tool.

Table 15. Individual SUS scores comparison between interaction tools

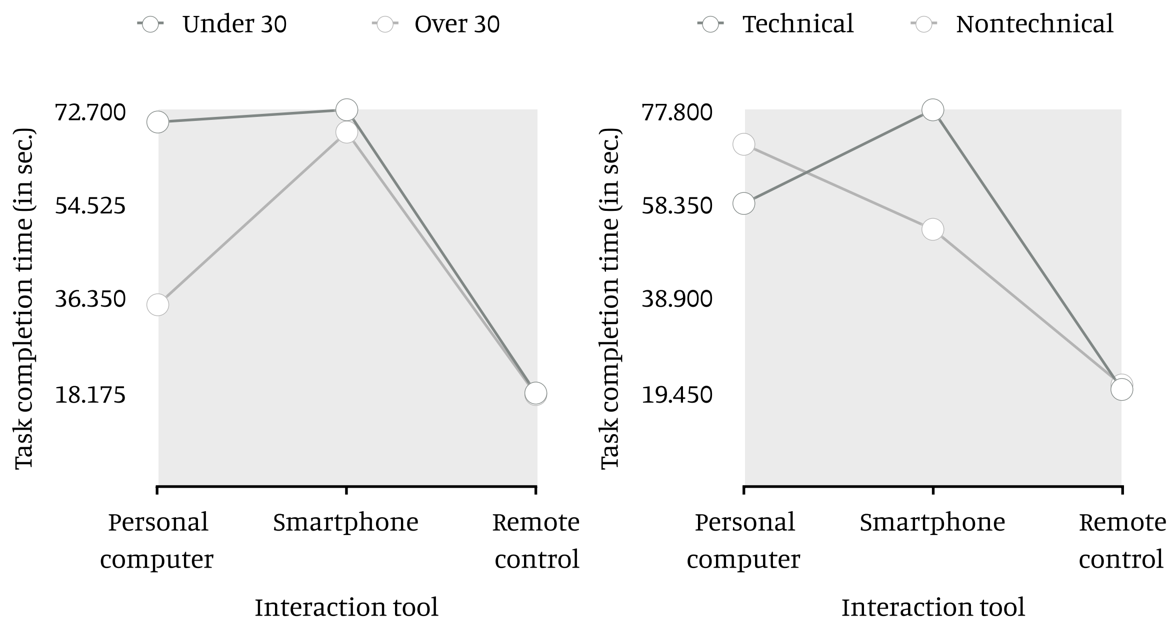
	Personal computer	Smartphone	Remote control
Individual 1	30	50	87.5
Individual 2	35	65	77.5
Individual 3	45	92.5	85
Individual 4	55	67.5	57.5
Individual 5	42.5	57.5	87.5
Individual 6	45	95	57.5
Individual 7	75	90	100
Individual 8	77.5	72.5	75

Table 16 contains the average SUS scores for each interaction tool. The remote control achieved the highest core of 78.93 and significantly outperformed the personal computer which averaged a SUS score of 46.79. In contrast, the smartphone score do not significantly differs from that of the remote control, which is reflected in an average SUS score of 73.93.

Table 16. Average SUS scores per interaction tool

	SUS score
Personal computer	50.63
Smartphone	73.75
Remote control	78.44

Interplay between individual differences (age and background) and both task completion times and the scale scores are considered. Task completion time is not affected by the respondents age (19a). Their background, on the other hand, did produce some effects. The nontechnical users are supported by the personal computer whereas the technical users were faster with the smartphones, both performed better with the remote control (Fig. 19b).



(a) (b)

Figure 19. Effects between task completion time and: a) age; b) background

Just as in the previous case, the scores are unaffected by the age (Fig. 20a) while the background seems to influence them somehow. Fig. 20b illustrates how technical participants rated the remote control better, while nontechnical gave a higher score to the smartphone. Personal computer was the worst rated by both groups.

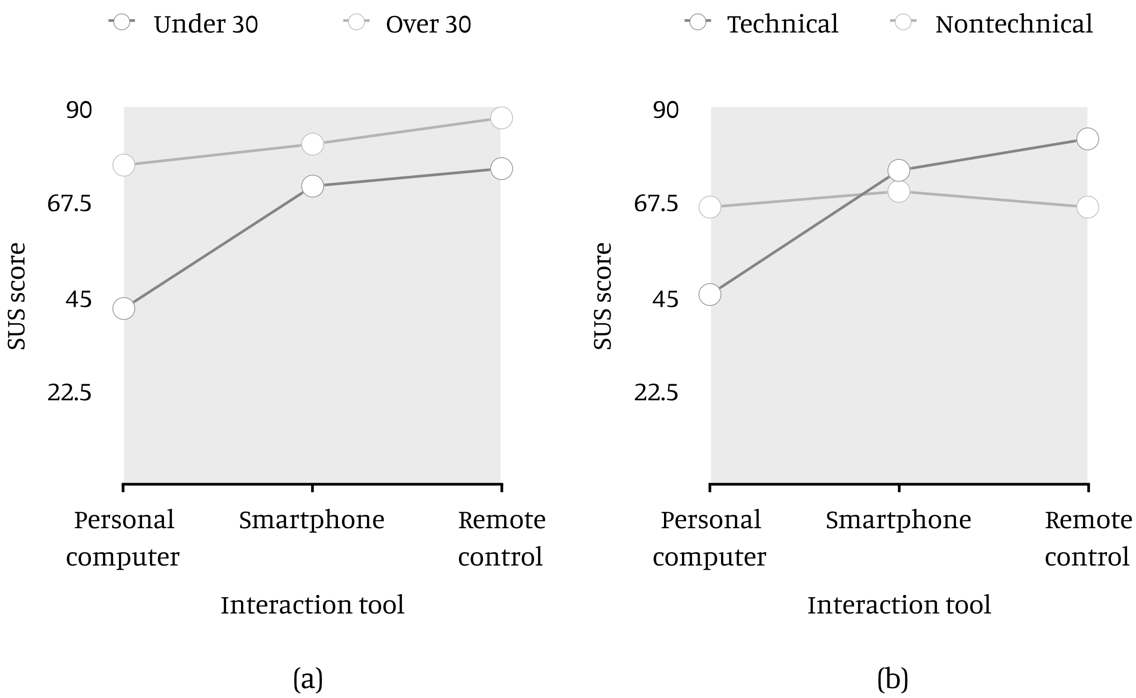


Figure 20. Effects between usability scale scores and: a) age; b) background

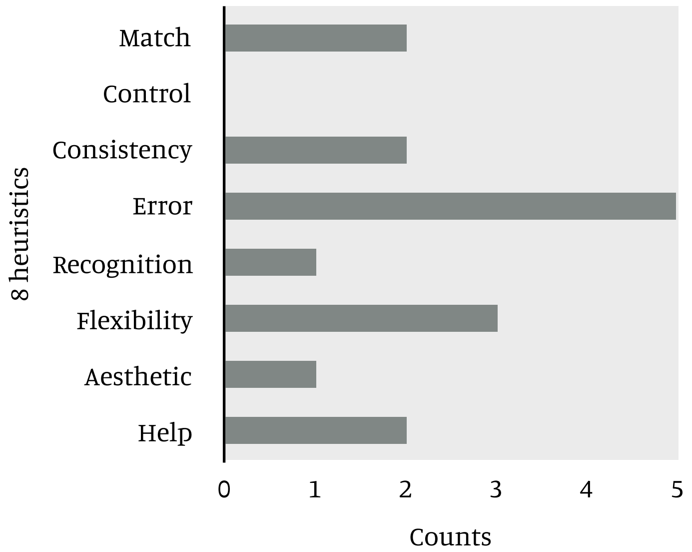
5.3. Remote control usability problems

The heuristic evaluation is conducted in order to identify potential usability problems of the remote control. In Table 17, each row contains a brief description of the identified usability problem, the heuristic violated, and the severity rating assigned. The number of heuristic violations is higher than the number of usability problems identified since a single usability problem may violate multiple heuristics (Zhang et al., 2003).

Table 17. Usability problems and heuristic violations for remote control

Problem description	Heuristic violated	Severity rating
The symbols do not always represent the button functionality	Match, Consistency, Error	3
There is no opportunity to add new functionalities	Flexibility	1
There is no opportunity to modify functionalities	Flexibility	1
There may be difficulties to remember the functionalities of each and every button	Recognition	1.7
The explanatory sheet may not always be available	Help	1
There may be buttons placed too tight	Error	1.3
There may be buttons that are too small	Error	1.3
There may be lots of unused buttons	Aesthetic	1.3
There is no more documentation available than the explanatory sheet	Help	0.7
There may be insufficient buttons	Flexibility	2.3
There may be confusion between old and new buttons functionalities	Match, Consistency, Error	2.7
There may be confusion about not conventional feedback	Error	2

Fig. 19 illustrates the number of heuristic violations for the conventional remote control across the 8 modified heuristics. Heuristics are violated a total of 16 times. Error and Flexibility are the two most frequently violated heuristics (5 and 3, respectively). These two heuristics sum up 50% of the violations. Match, Control and Help are come in second place with 2. Recognition and Aesthetic are violated only once each, while Control is not violated at all.



The problems found in the remote control are summarized in Fig. 20. The severity rating is divided in four categories. There are 7 cosmetic, 3 minor and 2 major and not a single catastrophic usability problem.

Figure 19. Remote control heuristics violations.

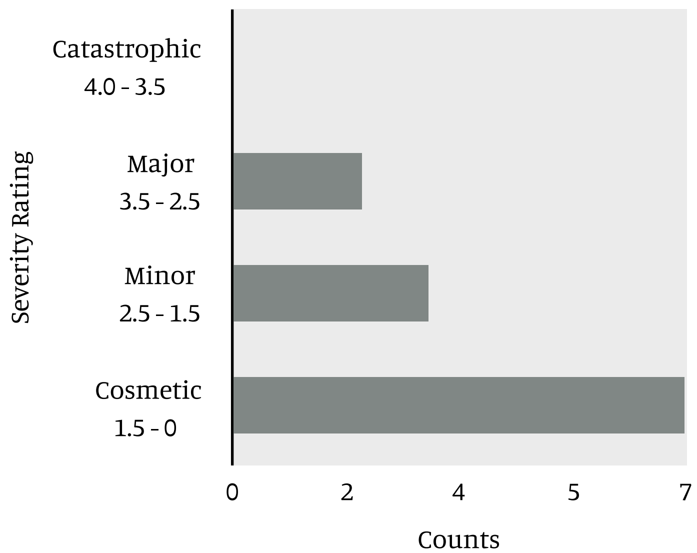


Figure 20. Problems severity rating.

6. ANALYSIS AND DISCUSSION

Each and every research question is responded and discussed one by one below, starting with the sub-questions (two-five) and ending with the main research question (one).

Research question number two, firs sub-research question, regarding the interaction tools typically used to control home appliances is responded with the online survey outcome. Answer, as expected, is that remote controls are the main interaction tool with entertainment appliances (audio and video players, including television and home theaters). However, kitchen, heating and cooling devices are still mainly controlled manually, since these types of equipment are not known for being controlled at a distance, even when there are already real alternatives. In regard to new ways of interaction such as speech or gesture command, the penetration still negligible. While the survey revealed some useful information that helped to give answer to one of the sub-research questions, during the survey application it was identified that it could have provided a better outcome if, for example, some extra question would have been included. Some questions that could have been included are the number of remotes controls in home that are actually used, or whether all or most buttons (and perhaps which ones) of those remotes are used. Both question would have assisted in the configuration of the new functionalities in the remote.

Any approach in the literature review already implementing a sort of remote control in home automation systems could have been used to respond the second sub-research question, three overall, about the way to integrate remote controls into home automation systems. Nevertheless, the majority involved the development of a specific remote control, which are not public available. An additional way based on standard remote controls is therefore implemented, thus giving response to second sub-research question by explaining how conventional remote control is integrated. Ir capabilities need to be activated (if available), in the first place, or implemented if are not yet available in the given system. Ir must be accompanied with the relevant hardware capable to received Ir signals. This should be followed with the definition of the new buttons functionalities in the remote control according to predefined requirements. In practice, it is up to the user and its availability where the button configuration is done, whether a full unused remote control is used or only a certain group of unused buttons on a remote that is actually used.

Sub-research question number four, fifth overall, in regard to systems usability improvement is successfully responded by usability evaluation results, meaning that initial belief that conventional remote control leads to a better usability compared to that of traditional interaction techniques is supported, at least for typical daily tasks. The usability measures did provide clear evidence for a superior usability of the remote control over both the personal computer and the smartphone. The quantitative data (task completion time) indicated a better usability for the conventional remote control in each and every task. Similarly, the qualitative data from the system usability scale indicated a higher usability for the remote control followed by the smartphone. According to the scale, both the remote control and the smartphone demonstrate above-average usability (78.44 and 73.75, respectively), while the personal computer shows below-average usability (50.63). The heuristic evaluation, on the other hand, revealed thirteen usability problems for the remote control. However, none of the problems falls under the catastrophic category. Moreover, almost half of them are just cosmetic (not really usability problems). With respect to the two majors (symbols do not always represent the buttons functionality, and confusion between old and new buttons functionalities) and three minors (difficulties to remember the functionalities of each and every button, insufficient buttons, and confusion about not conventional feedback), it can be expected that users will acquaint themselves with the new functionalities in the remote control through the natural process of familiarization with new technologies, thus improving or totally removing all of the problems overtime. As for the remaining ones, it is hoped that all of them can be avoided by means of an efficient configuration of the new functionalities on the remote control.

Contrary to preceding questions, the fourth and last sub-research question about whether conventional remotes controls in home automation systems are aimed at a specific audience is not totally answered, since the sample is not large enough to provide conclusive results. Effects between participants attributes (age and background), and usability evaluation results (usability testing and SUS) were observed. Whereas no effect was shown on the usability testing results, the SU scale demonstrated slightly better usability with remote controls for respondents with technical background while nontechnical participants exhibited a greater usability with the smartphone. This does not mean that the usability is not good in either interaction tool, since the two of them are above average for both technical and nontechnical users. Remote controls are apparently intended to all, since no meaningful differences were identified. Nonetheless, further study is needed. as stated above, sample is not large enough, nor representative.

Once all sub-questions are responded, the main research question about wether inclusion of conventional remote controls into home automation systems increases its adoption can be answered. While the actual increase in the adoption of home automation systems can only be demonstrated overtime, by clearly proving a better usability of home automation systems, it is expected that its adoption within the residential sector is likely to increase.

6.1. Sustainability benefits

If adoption of home automation in homes increases as expected due to better usability in home automation systems, it would result in sustainability benefits across the three pillar of sustainable development: environmental, economical, and social. Environmental impact of a better adoption of home automation systems would be reflected in a contribution to climate change related goals. Building automation can generate a reduction of 1.96 Gt CO_2 emissions, save up to 5 billion MWh of energy and 261 billion liters of water. Economical benefits would be translated into cost savings of $360 billion in energy and water, and $384.6 billion in additional revenues. In regard to the social benefits, a better adoption would help to provide happier and more sustainable living (GeSI, 2017).

7. CONCLUSION

In this thesis a comparative usability evaluation study of conventional remote controls within home automation systems is presented. From the results, it can be concluded that the remote control does improve the usability of home automation systems, at least for typical daily tasks such as those included in this study. That, in addition to the fact that there are at least one and an average of four remote controls in each participating home, makes the conventional remote control worthy of further study for more complex tasks.

The results also revealed 7 real usability problems (not considering the cosmetics) for the remote control, all of which can be addressed either by the continues use of the tool or by an effectively enough configuration of the new functionalities on the remote. To observe changes in the usability problems over time a follow-up study is necessary. Similarly, a heuristics evaluation with evaluators with knowledge of both usability and home automation is needed for a more effective identification of problems. Additional concerns regarding the remote control raised in the course of this research. Potential conflict, for example, of "who has the remote control has the control of the situation" needs further investigation, but it is assumed that a general agreement should be reach, as has been happing since the introduction of the first TV remote in the earlier '50.

Considering that the usability of home automation systems with conventional remote controls have proven better, a contribution to a greater adoption of home automation systems within residential buildings can be expected, thus contributing a grain of sand to sustainable development.

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APPENDIX 1. Online survey form

Survey on Home Appliances Interaction Tools

This survey is part of a Master's thesis research being carried out at Harz University of Applied Sciences (Hochschule Harz) in Germany. The questionnaire attempts to find out common user interaction tools with home appliances. In doing this, it is intended to enhance the ease-to-use of home automation systems (such tearing down appliances or switching off the lights automatically) by using interaction tools with which the user is already familiar.

The estimated response time is less than 10 minutes.

To help protect your confidentiality, the survey will not contain information that will personally identify you at least you decide to provide it. Either way, the results of this study will be used just for scholarly purposes.

*Required

(continues)

APPENDIX 1. (continues)

1. How often do you use the following tools to interact with your home appliances? *

Mark only one oval per row.

	More than once a day	Everyday	Once a week	Once a month	Less than once a month	Not applicabl e
Remote control						
Smarphone						
Tablet						
Personal computer						
Control panel						
Speech or gesture command						

(continues)

APPENDIX 1. (continues)

2. What is your common tool of interaction with the following home appliances? *

Mark only one oval per row.

	Remote control	Smartphone	Tablet	Personal computer	Control panel (attached to wall)	Speech or gesture	Manually	Not applicable
Television	◯	◯	◯	◯	◯	◯	◯	◯
Audio player	◯	◯	◯	◯	◯	◯	◯	◯
Video player	◯	◯	◯	◯	◯	◯	◯	◯
Home theater	◯	◯	◯	◯	◯	◯	◯	◯
Fridge	◯	◯	◯	◯	◯	◯	◯	◯
Thermostat	◯	◯	◯	◯	◯	◯	◯	◯
Airconditioner	◯	◯	◯	◯	◯	◯	◯	◯

(continues)

APPENDIX 1. (continues)

3. **If you use any tool(s) of the two previous questions. What room do you use it/them in to interact with home appliances? ***

Check all that apply.

- ☐ Living rooom
- ☐ Dining room
- ☐ Bedroom
- ☐ Bathroom
- ☐ Kitchen

4. **How many conventional remote controls do you have at home? ***

____

5. **Do you have any universal remote control at home? ***

A universal remote is a type of conventional remote control used to control one or more appliances of different types and vendors (e.g. the one currently part of entertainment services offered by "German telecommunication providers").

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Maybe

(continues)

6. **Do you have any type of home automation system at home? ***

   Tearing down appliances or switching off the lights automatically are examples of home automation systems.

   Mark only one oval.

   ◯ Yes

   ◯ No

   ◯ Maybe

7. **If you answered 'No' or 'Maybe' in previous question. How interested are you to implement a home automation system in your home? ***

   Mark only one oval.

   ◯ Extremely inteersted

   ◯ Very interested

   ◯ Somewhat interested

   ◯ Slightly interested

   ◯ Not at all intereted

APPENDIX 1. (continues)

8. **To what extent do the following scenarios would influence your interest to implement a home automation system in your home? ***

Mark only one oval per row.

	More interested	Less interested	Made no difference
You switch your TV on by pushing down a button of your TV remote control, subsequently the lights in the room are dimmed and the shutters are closed	⬭	⬭	⬭
You are lying on your bed about to fall asleep with the lights still on. Suddenly, the doubt whether you switch off the television on the lower floor arises on your mind. Then you push down a button of the remote, which not also causes the lights to go off but also that the television on the lower floor to switch off (if switched on).	⬭	⬭	⬭
Spring has arrived, you are inside your home wearing t-shirt and shorts. Out of the blue, it starts to rain and the temperature drops drastically. Then you push down a button of the remote, which switch back from 'Spring mode' to 'Winter mode'. After some minutes, your home is warm enough to face the winter day in the middle of spring.	⬭	⬭	⬭
You have to leave your home in a rush. Then you push down a button of the remote control which turns off all appliances, lights, and heating of your home.	⬭	⬭	⬭
You are throwing a party in your place but you are not sure how many people will show. Then you push down a button of the remote which activates the 'Party scene'. Now you stop worrying as the temperature will be adapted accordingly to the body temperature of the number of people coming to your party.	⬭	⬭	⬭

(continues)

APPENDIX 1. (continues)

Finally please provide some more information about yourself in order to put your previous answers in right context. Please keep in mind that the responses you provide will be treated confidentially.

9. Are you male or female? *

Mark only one oval.

- ◯ Male
- ◯ Female

10. To which of the following age ranges do you belong? *

Mark only one oval.

- ◯ Under 30
- ◯ 30-40
- ◯ Over 40

11. Do you live alone or with someone else? *

Mark only one oval.

- ◯ Alone
- ◯ Someone else

(continues)

APPENDIX 1. (continues)

12. Do you live with children or elderly? *

Mark only one oval.

- ◯ Children
- ◯ Elderly
- ◯ Both
- ◯ None

13. Do you have technical or nontechnical background? *

Mark only one oval.

- ◯ Technical
- ◯ Nontechnical

14. What is your household annual income? *

Mark only one oval.

- ◯ Over 30,000 €
- ◯ Under 30,000 €

(continues)

APPENDIX 1. (continues)

15. **(Answer only if you currently reside in Wernigerode or surrounding areas) Would you be willing to participate in an on-site study?**

    The study is to take place in Harz University of Applied Sciences (Hochschule Harz) during the coming weeks. During the study, you will be asked to do several short tasks to control or interact with basic home automation system. You will also be asked questions about your experience and perceptions of the tests.

    Mark only one oval.

    ◯ Yes

    ◯ No

16. **If you answer 'Yes' in previous question, please leave your contact details below (name, mobile number and e-mail).**

    ____

This is the end of the questionnaire. Thank you for taking the time to participate in this study.

APPENDIX 2. Heuristic evaluation guidelines

For the evaluators

A home automation system (HAS) is tailored so that it can also be controlled by a conventional remote control. The remote control is accompanied by an explanatory sheet shown in Table 1, which illustrates the functionalities that each of the buttons adopted in the system.

Table 1. Example of explanatory sheet

Button	Functionality
Button 1	Switch on/off the lights
Button 2	Turn all your appliances and lights off
Button 3	Exit/undo
Button 4	Increase the temperature

Inspect a conventional remote control and compare it to the table of usability heuristics. To support your evaluation, picture yourself holding, both a conventional remote control and the explanatory sheet. Next, imagine that you use the remote control to perform some activities such as switching on the light, adjusting the temperature to 20ºC, or turning all your appliances and lights off.

(continues)

APPENDIX 2. (continues)

Table 2. The eight heuristics

Heuristic (tag)	Description
Match between tool and the real world (Match)	The tool should speak the user language, with icons, labels and concepts familiar to the user; follow real-world conventions by making information appear in a natural and logical order
User control and freedom (Control)	Users often choose functions by mistake and will need a clearly marked "emergency exit" button to leave the unwanted scene without having to go through and extended dialogue; support undo and redo
Consistency and standards (Consistency)	Users should not have to wonder whether different labels, icons, or buttons mean the same thing
Error prevention (Error)	Is the tool designed carefully to prevent problems from occurring? Are all buttons placed in such way users cannot press them by mistake? Is each buttons' intended function clear? Is each buttons' label placed intuitively?
Recognition rather than recall (Recognition)	Minimize the users' memory load by labeling buttons and making actions and options visible
Flexibility and efficiency of use (Flexibility)	Allow users to tailor frequent actions; shortcuts may often speed up the interaction for the experienced user and make the device suit both inexperienced and experienced users
Aesthetic and minimalist design (Aesthetic)	The tool should not contain labels, icons, or buttons that are irrelevant or rarely needed; every extra unit of information competes with the relevant units of information and diminishes their relative visibility
Help and documentation (Help)	Even though it is better if the tool can be used without manual, it may be necessary to provide help and documentation; any such information should be easy to search, focused on the users' task, list concrete steps to be carried out, and not be too large

(continues)

APPENDIX 2. (continues)

In Table 3 you will find the usability problems already found by others evaluators. Write down the problems you have identified and which heuristics each problem violate. In order to eliminate duplications, do not write again a problem that is already identified. If you are not sure if it is the same, then please add it. Add as many rows as you may need.

Table 3. Usability problems and heuristic violations for remote controls

#	Problem description	Tag of heuristic violated
1		
2		
3		

Now, assess the severity of each problem. The severity of a usability problem is a combination of the frequency with which a problem occurs, is it common or rare?; the impact of the problem if it occurs, will it be easy or difficult to overcome?; and the persistence of the problem, is it a one-time problem that users can overcome once they know about it or will users repeatedly be bothered by the problem?

Assess each problem using a severity rating on the following scale:

- 0— not a usability problem at all
- 1— cosmetic problem only; does not need to be fixed unless extra time is available
- 2— minor usability problem; fixing this should be given low priority
- 3— major usability problem; important to fix, should be given high priority
- 4— usability catastrophe; imperative to fix this before product can be released

Table 4. Usability problems and severity rating for remote controls

#	Problem description	Severity rating
1		
2		
3		

APPENDIX 3. Configuration file

```
defmod CUL1 CUL 192.168.41.24:2323@100000 1234
attr CUL1 addvaltrigger 1
attr CUL1 rfmode SlowRF

setstate CUL1 disconnected
setstate CUL1 2017-05-08 00:35:25 ccconf freq:868.300MHz bWidth:325KHz rAmpl:42dB sens:4dB
setstate CUL1 2017-05-24 12:52:05 cmds m B C F i I G M R T V W X O e f l t u x E c q
setstate CUL1 2017-05-08 00:23:31 credit10ms 900
setstate CUL1 2017-05-08 01:26:07 fhtbuf No answer
setstate CUL1 2017-05-25 21:28:13 raw No answer
setstate CUL1 2017-05-25 22:27:11 state disconnected
setstate CUL1 2017-05-08 00:23:42 uptime 0 02:48:52
setstate CUL1 2017-05-08 00:23:46 version V 1.43 CUNO433

defmod IR_Dev CUL_IR CUL1

attr IR_Dev ButtonA000 I02AF50001800 IF ([light_1:&STATE] eq "off")
(set light_1 on) ELSE (set light_1 off)
attr IR_Dev ButtonA001 I02AF50001900 IF ([homeappliance_1:&STATE] eq "off")
        (set homeappliance_1 on) ELSE (set homeappliance_1 off)
attr IR_Dev ButtonA002 I02AF50001A00 set FHT_2d31 desired-temp 20.0
attr IR_Dev ButtonA003 I02AF50000800 set FHT_2d31 desired-temp off;; set light_1 off;;
        set homeappliance_1 off;; set dimmer_1 off
attr IR_Dev ButtonA004 I02AF50001B00 IF ([dimmer_1:&STATE] eq "off")
        (set dimmer_1 dim100%) ELSE (set dimmer_1 off)
attr IR_Dev ButtonA008 I02AF50000200 IF ([dimmer_1:&STATE] eq "off") ((set dimmer_1 dim25%)
        IF ([dimmer_1:&STATE] eq "dim25%") ((set dimmer_1 dim50%)
                IF ([dimmer_1:&STATE] eq "dim50%") ((set dimmer_1 dim25%))))
                        ELSE (set dimmer_1 dim100%)
attr IR_Dev ButtonA009 I02AF50000300 IF ([dimmer_1:&STATE] eq "dim100%")
        ((set dimmer_1 dim75%) IF ([dimmer_1:&STATE] eq "dim75%") ((set dimmer_1 dim50%)
                IF ([dimmer_1:&STATE] eq "dim50%") ((set dimmer_1 dim25%))))
                        ELSE (set dimmer_1 off)
attr IR_Dev irReceive ON_NR
attr IR_Dev learncount 10
attr IR_Dev learnprefix A

defmod FHT_2d31 FHT 2d31
attr FHT_2d31 IODev CUL1
attr FHT_2d31 room FHT

setstate FHT_2d31 measured-temp: 23.1
setstate FHT_2d31 2017-05-24 17:51:52 actuator 0%
setstate FHT_2d31 2017-05-22 22:25:29 actuator1 pair
setstate FHT_2d31 2017-05-24 13:01:12 desired-temp 21.0
```

(continues)

APPENDIX 3. (continues)

```
setstate FHT_2d31 2017-05-24 14:25:54 measured-temp 23.1
setstate FHT_2d31 2017-05-24 14:25:54 state measured-temp: 23.1
setstate FHT_2d31 2017-05-24 14:25:54 temperature 23.1

defmod dimmer_1 FS20 0003 03
attr dimmer_1 IODev CUL1

setstate dimmer_1 off
setstate dimmer_1 2017-05-24 17:07:00 state off

defmod homeappliance_1 FS20 0011 11
attr homeappliance_1 IODev CUL1

setstate homeappliance_1 off
setstate homeappliance_1 2017-05-24 17:07:00 state off
```

APPENDIX 4. Modified SUS form

Interaction Tool Usability Scale

*Required

1. **Are you male or female? ***

   Mark only one oval.

   ◯ Male

   ◯ Female

2. **To which of the following age ranges do you belong? ***

   Mark only one oval.

   ◯ Under 30

   ◯ 30-40

   ◯ Over 40

3. **Do you have technical or nontechnical background? ***

   Mark only one oval.

   ◯ Technical

   ◯ Nontechnical

4. **Which interaction tool are you going to evaluate now? ***

   Mark only one oval.

   ◯ Remote control

   ◯ Smartphone

   ◯ Personal computer

(continues)

APPENDIX 4. (continues)

5. **I think that I would like to use this interaction tool frequently ***

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

6. **I found the interaction tool unnecessarily complex ***

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

7. **I though the interaction tool was easy to use ***

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

8. **I think that I would need the support of a technical person to be able to use this interaction tool ***

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

(continues)

APPENDIX 4. (continues)

9. **I found the various functions in this interaction tool were well integrated ***

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. **I though there was too much inconsistency in this interaction tool ***

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

11. **I would imagine that most people would learn to use this interaction tool very quickly ***

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

12. **I found the interaction tool very cumbersome to use ***

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

13. **I felt very confident using the interaction tool ***

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

(continues)

APPENDIX 4. (continues)

14. I needed to learn a lot of things before I could get going with the interaction tool *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree