Measuring User Experiences of Prototypical Autonomous Products in a Simulated Home Environment

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Abstract. Advances in sensor technology, embedded processing power, and modeling and reasoning software, have created the possibility for everyday products to sense the environment and pro-actively anticipate user needs. There is however a risk of creating environments in which people experience a lack of control. The aim of this study is to explore the degree in which people are willing to delegate control to a pro-active home atmosphere control system. The findings suggest that participants are willing to delegate control to easy-to-use systems, and they do not want to delegate control to complex and unpredictable systems. It is argued that the willingness to delegate should not be considered as a fixed degree, rather system initiative might depend on the situation at hand or on changes in time. Design research on mixed initiative systems faces a methodological challenge, in terms of measuring user experience of autonomous prototypes in a controlled way, while still preserving the sense of a realistic experience. The paper describes advantages and disadvantages of testing in a simulated home environment versus testing in the field.

Keywords: Smart environments, user studies, intelligent interfaces, mixed initiative, interaction design, user adaptivity.

1 Introduction

Increasingly, people are being confronted with products in the home that can automatically adapt to the context of use. Advances in sensor technology, embedded processing power, and modeling and reasoning software, have enabled everyday products to sense their environment and pro-actively anticipate user needs [13]. For example, stair lights can be activated in the home by movement at night using commercially available domotics systems. Context-aware and autonomous services might eventually automatically anticipate user needs, and accurately fit into domestic routines [1,16]. There is however a risk of creating an environment in which people experience a lack of control [1,3]. In a worst case scenario, instead of feeling understood and supported by the environment, the future home user might feel as if the environment is out of control.

To design controllable and pleasurable semi-autonomous products for the home, designers need to know how prototypes of these products may be experienced by people [4,5,8]. In existing studies, user experiences with autonomous products are sometimes based solely on product descriptions on paper. For example, in a study by Barkhuus and Dey [2] on autonomous applications for mobile phones, participants were asked to imagine using autonomous services based on a written service description. Using a five-day diary, participants indicated how often they would have used the service, and then rated the usefulness of the service. Since the participants had never used autonomous services on their phones before, the degree to which people were able to imagine these services is unknown. The study showed that users are willing to partially give up user control if only the application's usefulness is greater than the cost of limited control. Apparently, the limited user control as implied by product autonomy can be compensated by product advantages. Barkhuus and Dey agree that a logical next step would be to develop and test working prototypes.

Product descriptions on paper also played a central role in a study by Rijsdijk and Hultink [10], which focused on consumer appreciation of autonomous products. Participants were not given the opportunity to actually experience the autonomous products; in the study, only a short description of the product was given. The user experience invoked by the product descriptions might not correspond with the experience of real products. The study reveals that consumers perceive highly autonomous products as more risky and complex than less autonomous products. Relative advantage, i.e., the degree to which an innovation is perceived as superior to the idea that it supersedes [11], was however found to compensate for the negative effect of perceived risk. It would be interesting to see if the user experience changes in time, an aspect which could not be examined in the Rijsdijk and Hultink study.

From an ecological perspective, the home is the obvious place to study and evaluate domestic products and to collect experience-based feedback [1,12]. Current practice is however such that most studies take place in lab environments [6,9]. Many practical obstacles prevent researchers from doing research in the field, including: 1) *time constraints*; it generally takes more time to get the product to the user than vice versa; 2) *deployment issues*; most autonomous products are still under development, and product behavior is often wizard-of-oz based. Deployment in the field would require a huge implementation effort; 3) *controllability issues*; although the living patterns of people would be more natural inside their homes, [e.g., 14,15], creating a controlled environment can help in focusing in on relevant aspects of the product; 4) *ethical issues*, including privacy concerns, make it hard to monitor users at home. Laboratory studies might not suffice, since it can be hard to mimic the natural setting in the lab, and long term product use cannot be studied in the lab. Researchers are faced with a methodological challenge in terms of measuring the user experience of autonomous prototypes in a controlled way, while still preserving the naturalness of the experience. In many cases, however, most relevant aspects of the home situation can be recreated in the lab. In a comparative study, Kjeldskov et al. found that both a lab evaluation and a field evaluation of a context-aware mobile system resulted in the same list of issues [9], thereby demonstrating the practical use of the laboratory for studying autonomous products.

This paper is organized as follows. Section 2 presents a user study, in which the degree of system initiative as preferred by the users was studied in a simulated home environment. The findings of the user study are described in section 3, followed by a discussion and conclusions in section 4, and suggestions for future work in section 5.

2 Methodology

A user study was conducted to find out how much initiative people may be willing to delegate to an atmosphere control system in the living room, and to study to what degree early prototypes of autonomous domestic products can be studied in a simulated home environment. The atmosphere control system used in the experiment made it possible to activate and adjust predefined atmospheres; each atmosphere consists of a combination of music, electronic wall art and light settings [15]. To determine if preferred system initiative depends on the situation at hand or on changes in time, the willingness to delegate will be studied in relation to context (user activities) and user perceived product characteristics (usefulness, confidence, ease of use, user control).

Diary Study. Diary booklets were used to personalize the experiment sessions, thereby creating a sense of attachment and familiarity. Participants were asked to log their activities at home for five evenings prior to the experiment. These logs were used to create realistic activity-based assignments that were used in the experiment.

Previous studies with the atmosphere projection system showed that although generic atmosphere presets can be used as a start, they do not fit the preferences for music, projections and colors of the individual users [15]. In preparation of the present study, participant couples were asked to indicate, for each activity, their music and ambient-color preferences. These preferences were used to create personalized atmosphere presets, i.e., predefined combinations of (colored) light settings, electronic wall art, and music.

Prototype description. A living room setting was created in a lab environment. Participants could use a touch-screen user interface, specifically developed for the experiment, to activate the preset personalized atmospheres and to control the individual lights, electronic wall art, and music separately. The prototype uses a home atmosphere control module that was developed earlier at Delft University of Technology. The atmosphere controller is based on an atmosphere control model, in which functions and features have been clustered based on how people experience their environment. Prior to the experiment, the atmosphere content was personalized according to the participants' preference for music and room light color as stated in their diaries. The predefined atmospheres could not be changed during the experiment. Preset settings of lamps and music volume were defined for selected activities. For example, when activating the activity 'watch TV', lights were dimmed and music was muted. Presets could be temporarily overridden in the user interface by users.

In a separate frame, which was visible at the lower section of the screen at all times, users could select the preferred level of system autonomy (Fig.1). The prototype offered three modes of operation, similar to the three levels of interactivity as defined by Barkhuus and Dey. In the *manual mode*, users had to take initiative to control the atmospheres, activity settings and manual overrides. In the *semi-automatic mode*, the system would suggest a change of setting to the users. The suggestion was presented on the touch screen, which could be viewed from most positions in the room, and a bell sound was played. Suggestions were accepted or rejected by uttering ‘yes’ or ‘no’. In the *automatic mode*, the system would pro-actively change settings; users were still able to override the automatic settings. For example, when a user would pick up a book, in the automatic mode the reading lamp would be switched on automatically, whereas in the semi-automatic mode the system would suggest turning on the reading lamp. Both automatic and semi-automatic system behavior were wizard-of-oz; the operator observed the participants via a camera, and activated settings and suggestions when appropriate.

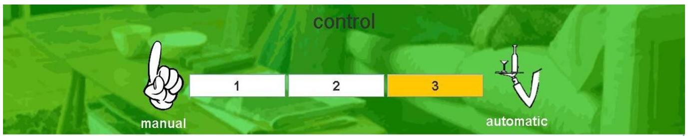

Fig. 1. Using the touch-screen, users could select the preferred level of system autonomy: manual control, semi-automatic, and automatic.

Procedure. Data was collected over ten 2.5 hour-sessions. Ten participating couples (10 women, 10 men) aged between 23 and 30 (mean 26.7, SD 1.9) participated in the study. There were 4 students and 16 non-student adults with diverse backgrounds. Participants had no prior experience with the control system used in the experiment. Couples were selected based on their home situation, i.e., household, no children.

One week prior to the experiment, the couples were visited and were given a diary to collect personal data for the experiment. The completed diaries were collected the day before the experiment, and were used to create a personalized atmosphere model, as well as to create eight activity assignments for the experiment.

The study was carried out in the living room laboratory at the Faculty of Industrial Design Engineering at Delft University of Technology. An introduction to the system was given, in which the functional use of the system was demonstrated. Participants were given some time to try out the interface, and were encouraged to ask any questions relating to product usage. Participants were asked to try out the various system initiative settings; they were explicitly told that they could not do anything wrong. During the experiment, the participants were left alone in the living room lab. Each session took approximately three hours per couple.

Eight activity-assignments were given. These activity-assignments were selected from the diaries such that they roughly resembled the activity pattern at home, squeezed into a 2.5 hour session**.** Some of the activities had to be performed individually, while others were at the couple level. For each assignment, the participants were asked to engage in the activity and to use the central touch screen to select the preferred product autonomy level (a single product autonomy setting for both participants); the autonomy level could be modified at any time during the activity. Participants were given the option of manually changing the room settings to accommodate a given activity whenever they wanted to. After approximately 15 minutes, the experiment supervisor asked to finish the activity and to fill in the evaluation questionnaire, as described in table 1. After finishing the questionnaire, the system was reset, and the participants started their next activity-assignment. At the end of the experiment, participants were asked for general feedback in an exit interview.

Table 1. A paper-based questionnaire was administered to measure the user experiences immediately after each activity-assignment using continuous rating scales. Participants were asked to rate I) their activities, II) their satisfaction with the enviroment settings, III) preferred mode of operation, and IV) perceived product characteristics.

Part I: user activities	**Q1a**	concentration level	(low-high)
	Q1b	physical effort level	(low-high)
	Q1c	social interaction level	(low-high)
Part II: functional and atmosphere settings	**Q2**	satisfaction with functional settings	(low-high)
	Q3	satisfaction with atmosphere settings	(low-high)
Part III: willingness to delegate control	**Q4**	user preferred system mode of operation	(manual – automatic)
Part IV-a: product scores - initial expectations	**Q5a**	confidence level	(low-high)
	Q5b	ease of use	(low-high)
	Q5c	user control	(low-high)
Part IV-b: product scores – actual experience	**Q6a**	confidence level	(low-high)
	Q6b	ease of use	(low-high)
	Q6c	user control	(low-high)

3 Preliminary findings

The total number of completed questionnaires was 148; six activity-assignments had to be skipped because the of time constraints. The experiment sessions were limited to 2.5 hours, due to limited lab availability. As a result, five couples completed eight activities, four couples seven, and one couple six.

Correlation analysis. To understand how willingness to delegate control related to the items in the questionnaire, a Pearson correlation analysis was conducted on the questionnaire results. Willingness to delegate was measured by Q4: *user preferred autonomy level*. A significant moderate-positive correlation ($r=.245$, $n=144$, $p<.005$) was found between Q4 and Q6b, being the *ease-of-use* score, taken after each assignment. Apparently, high scores on willingness to delegate control to the system were related to high product scores on confidence, ease of use and user control. Q4 was also positively correlated to the initial expectations product scores Q5a (confidence) ($r=.175$, $n=140$, $p<.05$) and Q5b (ease of use) ($r=.167$, $n=140$, $p<.05$).

General trends in time. Significant correlations were found between the activity-assignment sequence number, i.e., the time-line, and the initial expectations product scores Q5a ($r=.391$, $n=141$, $p<.0005$), Q5b ($r=.292$, $n=141$, $p<.0005$) and Q5c ($r=.306$, $n=141$, $p<.0005$), respectively. As shown in figure 2, on average, participants were neutral at the start of the experiment, and the initial expectations product scores on confidence and ease of use increased over time. It would seem that participants needed some time to familiarize themselves with the idea of product autonomy, and to gain appreciation for the prototype.

User ratings on initial expectations product scores gradually increased in time, whereas the actual experience product scores fluctuated throughout the experiment. A possible explanation would be that the initial expectations scores (Q5) were used to express an overall score in relation to the prototype, whereas the actual experience scores (Q6) were used to give feedback to the prototype performance during the previous activity.

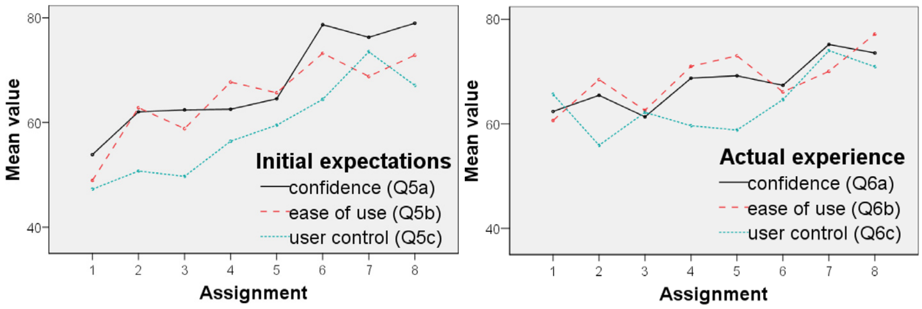

Fig. 2. Mean values for initially expected (left) and actual experienced (right) product scores in time for confidence, ease of use, and user control, on a scale from 0 (low) to 100 (high).

Factor analysis. A factor analysis on the results of the questionnaire resulted in six factors explaining a cumulative 78% of the variance (Table 2). Six factors were selected based on the percentage of variance explained. The factors were labeled 1) ease of use (expected), 2) ease of use (actual), 3) perceived user control, 4) functional lighting score, 5) physical activity, and 6) social activity, considering the factor loadings of the questions. Q4 loads on three factors: FAC1, FAC3 and FAC6, suggesting that ease of use (expected), perceived user control, and social activity contribute significantly to user preferred control.

Table 2. Rotated Principal Component Anaysis, using varimax rotation. All values <.20 suppressed. The table shows the factor loadings of the questionnaire items. User preferred control (Q4) loads on three factors: FAC1, FAC3 and FAC6, suggesting that ease of use (expected), user control, and social activity contribute significantly to user preferred control.

Factor label	ease of use (expect.)	ease of use (actual)	perceived user control	functional lighting score	physical activity	social activity
Component (% of variance)	**1 (28,9%)**	**2 (12,8%)**	**3 (10,8%)**	**4 (9,2%)**	**5 (8,1%)**	**6 (8,0%)**
Q1a concentration				,508	,548	,226
Q1b physical effort					,858	
Q1c social interaction						,916
Q2 functional lighting score				,894		
Q3 atmosphere score	,204	,246		,466	-,453	,465
Q4 user preferred control	,428		-,602			-,217
Q5a confidence (expected)	,837	,201				
Q5b ease of use (expected)	,839	,249				
Q5c control (expected)	,615		,685			
Q6a confidence (actual)	,220	,839	,209			
Q6b ease of use (actual)	,223	,897				
Q6c control (actual)	,235	,441	,745			

User preferred product autonomy. The user scores on Q4 can be visualized using the components of the factor analysis. Q4 has high factor loadings on FAC3 and FAC1. As shown in Figure 3, the willingness to delegate control to the system appears to be related to the perceived ease of use. This might suggest that participants are willing to delegate control to easy-to-use autonomous home control systems, but they do not want to delegate control to complex systems. This finding was confirmed by the user feedback in the exit interviews; participants explicitly indicated that they disliked autonomous product behavior whenever system behavior was unpredictable, i.e., not easy to use. Secondly, whenever the perceived user control is high, participants preferred manual control, and vice versa.

The effect of activity context on preferred initiative was measured using Q1a, b and c; user activities were characterized in terms of concentration, physical effort and social interaction. According to the results of the factor analysis, preferred control (Q4) has a small negative loading on social activity (FAC6), which might suggest that, in the case of autonomous home control systems, people prefer manual control whenever they are involved in social acts. However, no significant correlations were found between user activities and preferred control.

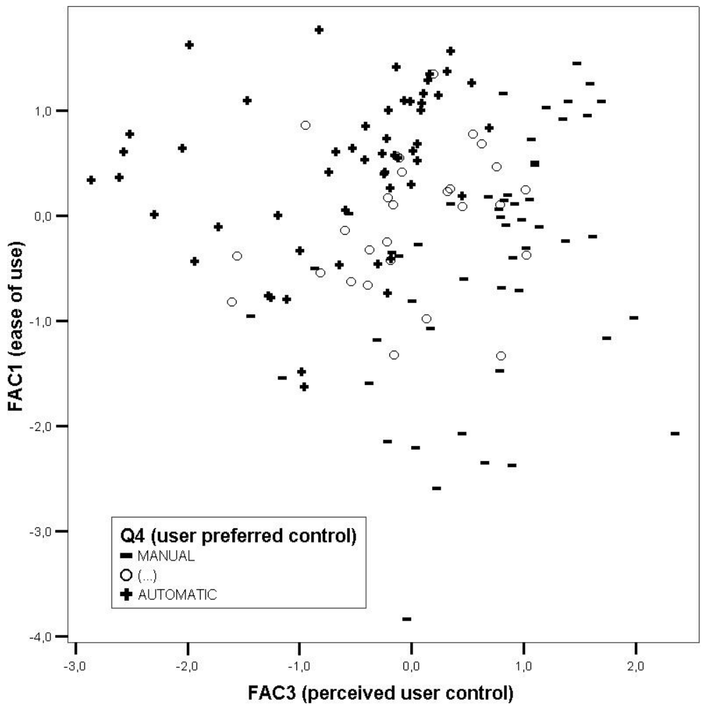

Fig. 3. User ratings of preferred mode of operation plotted against the relevant components of the factor analysis.

Observations and user reactions. Participants generally indicated in the exit interview that the experiment session resembled a normal evening at home, although most participants would conduct fewer activities at home. In the exit interview, eight out of ten couples indicated that they would like to have a similar autonomous system in their homes, whereas two couples were neutral. Seven couples indicated they enjoyed using the system.

The sense of being able to predict system actions was found to have a direct impact on confidence in the system. For example, at one point the system switched off a lamp when the participants had not moved for quite some time. The participants did not understand why the system took the initiative to change the setting, and got confused. One participant explicitly indicated that her confidence in the system dropped in reaction to each unpredictable action.

4 Discussion and Conclusions

Willingness to delegate control. Participants were willing to delegate control to the autonomous home control prototype used in the experiment. Participants did need time to familiarize with the prototype and to appreciate the product autonomy. On average, participants were neutral at the start of the experiment, and the product scores improved in time. Apparently, participants changed their expectations and first impressions based on the real experiences they had with the prototype; this issue could not have been studied with paper-based product concepts only.

Ease of use and predictability were found to be fundamental issues in creating acceptable autonomous products for the home. User feedback from the exit interviews suggests that especially the predictability of autonomous system actions needs the attention of designers of autonomous systems for home use; unpredictable system behavior had a negative effect on ease of use, and consequently on the willingness to delegate control. This type of feedback is valuable in the early phases of the design process; the design can then be improved before starting a field study.

Although high system autonomy was found to be related to low user control, the lack of user control does not necessarily have a negative influence on the willingness to delegate control, and consequently to the acceptability of autonomous products in the home. This is in line with results from earlier, similar studies [2].

Being 'at home' in the lab. Considerable time was spent rebuilding a living room in the lab. Also, input from a diary study was used to personalize the course of the experiment, resulting in user driven scenarios instead of scenarios that were fixed for all participants. Since user activities at home varied between subjects, it would not have been natural to enforce default activities. The variations in scenarios between sessions made it hard to compare results between subjects. Despite this limitation, the results do provide insight in trends in time, as well as in general acceptability of autonomous products.

The diaries proved to be a valuable source of information in terms of modeling participants' typical home activities. Activities in the lab did however differ in user experience from activities at home. First, secondary activities, such as 'putting the dishes into the dishwasher', and interruptions, such as incoming phone calls, were not captured by the diary and therefore were not part of the experiment. Subjects generally reported that the experiment session was more relaxing than an evening at home, since many such interruptions were missing. Second, there was no sense of purpose or urgency in the activities in the lab, since there were no deadlines or real consequences. Consequently, participants might have been more relaxed in the lab, resulting in neutral scores on concentration (Q1a). The user study in the lab should however be regarded as a step towards field testing; testing the effect of secondary activities and interruptions in the lab might not be feasible at all.

Personalization of atmosphere content based on the diaries turned out to be a time consuming activity that had to be redone in preparation of every session. In the exit interviews, however, participants did indicate that the personalized atmospheres helped create an experience similar to home.

Experiment design. Participants were explicitly instructed to try out various initiative settings during the experiment. The actual system settings were not consistent with the actual preferred settings, and consequently the system settings as logged in the log file could not be used in the data analysis. In the case that the actual system settings are needed for the data analysis, participants should be instructed to use the system as they would do at home.

Reflections on the methodology. Collecting realistic user feedback in the initial stages of a design process for pro-active home systems remains a challenge. Whereas many studies focus on testing concepts, without working prototypes, a simulated environment can enable researchers to measure realistic user experiences with prototypes. Preparation of the present lab study was however a time-consuming process. In general, however, the user studies in the laboratory setting did provide useful input for the field studies, thereby saving time in later stages of the design process. A flexible design approach is suggested in which early user studies in a lab environment are followed by realistic and longitudinal studies in the field.

5 Future Work

The ideal autonomous home product would probably take into account the actual context of use and adapt the system autonomy accordingly. Based on the results of the current study, autonomous products could lower system initiative whenever the user perceived ease of use is low. For example, when users implicitly show their discomfort with system actions, system initiative should be reduced; this would give the user some time to regain confidence in product behavior.

As a next step, a study is foreseen in which a similar prototype will be tested in the field. Studying the prototype for a longer period of time in the field should result in a more natural user experience, and consequently in a better understanding of the mechanisms underlying acceptability of autonomous products in the home environment. In the view of the methodological challenges as mentioned before, it might still take some time before practical and usable autonomous products find their way to the home.

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