A user experience-based approach to home atmosphere control

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Category: Long paper

Keywords: home atmosphere control, semantic scaling, multi-modal interaction, personalization

Abstract. The complex control problem of creating home atmospheres using light, music, and projected wall-art can be reduced by focusing on desired experience, rather than product functions and features. A case study is described in which subjective interpretations of living room atmospheres were measured and embedded into a prototype display system. A personalization mechanism is proposed to manage individual differences in atmosphere ratings, enabling a user model to evolve over time. To create a meaningful and simple control mechanism for a wide range of users, three interfaces were developed and studied, ranging from concrete to abstract control and from structured to exploratory navigation.

1. Introduction

Many of today's home products, such as lights, thermostats and CD-players, are operated manually and are typically set up sequentially, based on individual product features. To create an environment suitable to a task or range of activities, users are typically required to adjust device settings manually. To control a small number of devices, manual adjustment may not take much effort. However, the number of devices in the home is growing, as well as the number of functions per device. If a new button were added for every new function in a home control system, users would most likely be overwhelmed by system complexity. Setting all devices individually can become a tedious task. In short, a function/feature approach to user-system interaction design may result in a control problem.

The goal of this article is to demonstrate how an experience-based user model can be integrated into a potentially complex home atmosphere control system, while considering a wide range of possible user needs. Several multimodal interaction styles are explored in order to support diverse user groups. In the case study described, functional settings are clustered in states that coherently create a desired user experience. A coherent clustering of settings, based on an intuitive navigational control space, can enable the user to interact with the system at a higher level of abstraction.

This paper is organized as follows. Section 0 discusses related work. Section 0 describes a case study, in which a prototype home atmosphere controller was designed and tested in a living room laboratory, based upon an experience-based control model. The design of tangible, speech and graphic-based user interfaces as a means to interact with the atmosphere control space is described. Section 4 presents results from usability testing of the devices. Section 5 describes the need for personalization, followed by a general discussion (Section 6), and an indication of future research (Section 7).

2. Related work

Access to microwave ovens, X10 home control systems, and so forth, is often at a low hardware functional level. Although task models are commonly used in the design phase of product interfaces, most products do not utilize a task model at runtime. Computer models of user tasks and goals can permit a higher level of interaction, whereby user intentions are interpreted and used for product control. For example, Collagen [21] provides a mechanism for representing user tasks in a computer model and for creating high-level task constructs, allowing user actions to be interpreted and acted upon by the system. Using the task models, collaborative agents can talk with users about tasks and goals, and help users to achieve shared plans.

In the case of applications that support everyday activities, where the element of personal experiences and perceptions is central, experience-based models might be more appropriate than hierarchical and procedural task-based ones. New developments in hardware, including smaller electronic components and wireless networks, have enlarged the application domain of computer systems from the desktop to the environment. Consequently, computers are no longer restricted to desktop-related tasks; on the contrary, computing applications fit in a more complex mix of everyday activities [1, 4]. Weiser envisioned a world in which computational technologies weave themselves into the fabric of everyday life until they are indistinguishable from it [28]. To fit computing applications into everyday life, one should not only consider functional aspects. Social, personal and emotional engagement and expression, along with ease of use and efficiency, must be taken into account when designing interactive home systems, thus considering the total user experience [7, 24, 27].

Device clustering can be used to simplify the control of multiple devices. Van der Sluis et al. present a home control system that allows users to interact with “rooms” as a whole, instead of each device separately [24]. They propose a framework in which activities play a central role; users can be linked to activities, and the devices in the home are automatically set. Although functional settings might depend on user activities (e.g., *lights need to be switched off* when all users are asleep), activities might not be a suitable key element for experience-related applications. The desired home atmosphere, for example, probably depends primarily on the user’s mood or the time of day. Therefore, activity-based control could be used to augment an experienced-based model; however, basing control exclusively on activities would ignore experience-related user preferences. In short, clustered atmosphere settings might better be organized according to how people experience atmospheres, which could in turn be linked to an activity-aware system.

In order to create a model for home atmospheres, a mechanism is needed to determine how atmospheres are experienced. Body-based measures (e.g., gestures and physiological features) can be used to measure affect [12, 20], but although the methods for body-based measurements are generally considered able to discriminate arousal, they are not generally considered good measures of valence. Alternatively, semantic measurements can be used [5, 16]. For example, *semantic differential scaling* has been used to reduce a range of complex human phenomena such as politics, emotions, and aesthetics to low-dimensional semantic spaces [16]. Given that semantic spaces can determine how people perceive a certain phenomenon, they could be embedded in man-machine systems to support user-system interaction at a semantic level rather than at a functional level. In the case of home atmosphere, as described in this article, the generic navigational space for atmosphere control was based on semantic differential scaling.

Personal experience

Given the diversity of users, a home control system must address a host of requirements to support individual access [26]. User experiences of home atmospheres are by nature subjective, and the choice of interaction concept depends on individual preferences, the task at hand, and the context of use. Empirical research has revealed substantial differences in how individuals use computer systems [25]. Therefore, no single design solution is suitable for all users and all situations. In terms of a home atmosphere control system, the user interface should take into account differences in preferred style of interaction, as well as the role subjective experiences may play in selecting a given atmosphere.

To address the needs of a broad range of potential users, an adaptable user interface could be created, one that can be changed by the user or by the system, depending on the user, the tasks, and the context of use [14]. One could also consider offering a range of user interfaces and modalities, in order to permit users to choose their optimal interface, or combination of interfaces, at any time [17].

Automated home

The ideal home might be controlled automatically without any user intervention. Alternatively, the home user might control it using “powerful” and presumably high-level controls. Fully automated control systems, which require no explicit input from the users, are currently being considered. For example, the Adaptive Control of Home Environments (ACHE) system [15] pro-actively adapts to its inhabitants. The ACHE system aims to anticipate human needs in order to avoid manual control of the environment. The system monitors the changes users make to the environment. The basic assumption is that when users change the environment, for example when they turn the thermostat up, this is an indication that the user needs were not satisfied. The system then updates its models, so that this unwanted situation does not occur again in the future. Although the goal of anticipating needs may be commendable, the ACHE system can not support users in exploring and creating new experiences; the system tends to force users into past patterns. Additionally, since users would be required to program their environment at the appliance-function level, they could not explore combined settings of appliances.

In the case of home atmosphere, a simple-to-use control mechanism that enables people to express their desired experience might be a preferred option compared to a system that automatically selects the 'right' atmosphere. Consider SenToy [18], a tangible doll that allows a user to influence the emotions of a synthetic character in a game. Studies showed that users were able to express emotions using SenToy; in particular, elementary and high school students stated that they liked the doll as an interaction mechanism.

To conclude, existing products provide partial solutions for creating and modifying combined user experiences that fit into everyday life. A systematic approach is needed in order to create a system that supports interaction at an abstract user experience level, while still enabling individual personalization.

3. Case study

A case study was conducted to consider how knowledge of atmosphere perception and reference could be embedded in a user interface, in order to create an experience-based design. A range of possible interfaces for navigating through the knowledge and control structure were considered. A functional prototype home atmosphere controller application [10] was developed and tested in a living room laboratory. Atmosphere control was limited to combinations of music, wall art projections, and lights.

Figure 1 shows the steps in the research-through-design approach [19]. Each of the design steps is described in detail in the following sections, and the final evaluation step is described in section 0. The initial study focused on creating mood boards of living room atmospheres and asking subjects to rate the designs (steps A and B, respectively). This led to a model for scaling atmospheres (step C). Then, a projection system was developed that displays combinations of music, video art, and lighting settings (Step D), according to the dimensions developed in Step C. Next, the model was validated by users (Step E). Tangible, visual, and speech interfaces were developed to facilitate the interaction between the user and the atmosphere control system (Step F). The resulting prototype atmosphere controller was then evaluated by users (Step G).

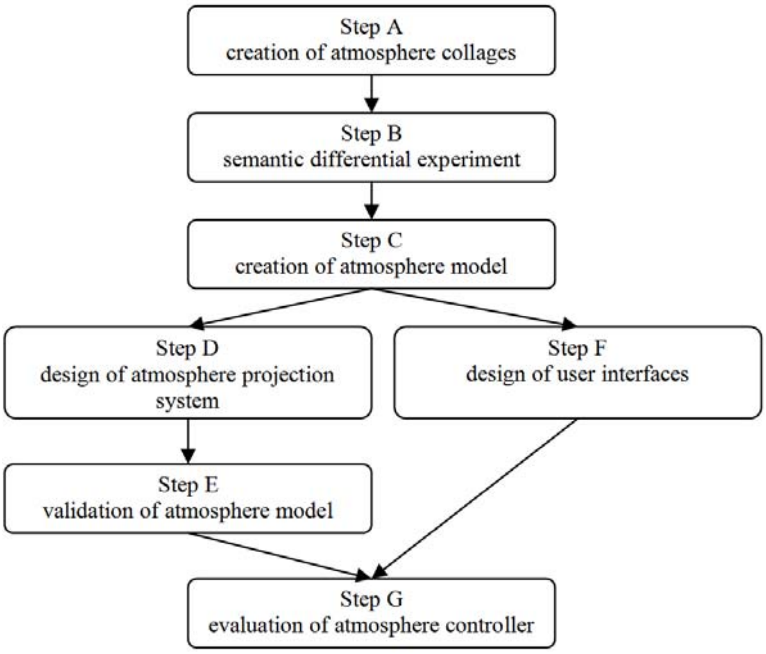

Figure 1. Overview of steps taken in the development of a functional prototype for controlling living room atmospheres

3.1 Step A: Creation of atmosphere mood boards

In order to classify home atmospheres based on how they are perceived by users, it is necessary to obtain quantitative data about the way people perceive atmospheres. In the case study, the semantic differential method [16] was applied to measure home atmospheres [22]. To consider how people judge atmospheres, a series of eight color mood boards, measuring 42 by 29.7 cm, was developed, depicting a wide range of home living contexts (see Figure 2). Six final year design students were asked to cluster the mood boards and to give each cluster a title. The students were asked to describe the differences and commonalities between each of the clusters. The most common terms were used to form 13 bipolar scales (Table 1).

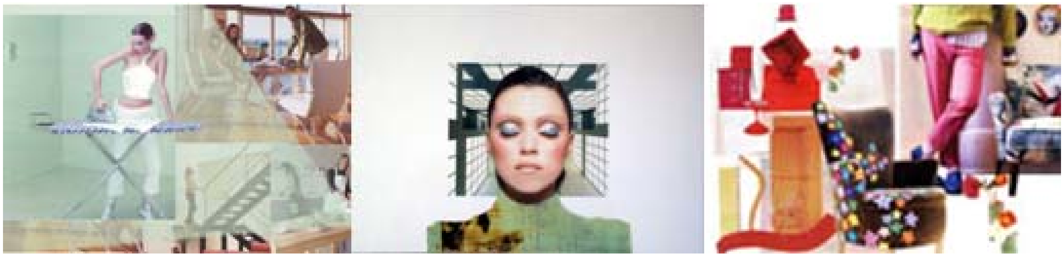

Figure 2. Three examples of mood boards used to derive bipolar scales for rating atmospheres. In an early stage of the design process, when the atmosphere control system was not available, these mood boards were used to derive bipolar scales. At a later stage, 'real' atmospheres were used to populate the atmosphere model

Table 1. The user evaluation of the mood boards resulted in 13 bipolar-scaled terms. These scales were later used to assess home atmospheres

1.	**chaotic**	**-**	**orderly**
2.	inspiring	-	uninspiring
3.	exciting	-	boring
4.	cheerful	-	sad
5.	intimate	-	distant
6.	romantic	-	work
7.	cozy	-	not cozy
8.	relaxed	-	tense
9.	active	-	passive
10.	lively	-	static
11.	natural	-	artificial
12.	restless	-	calm
13.	warm	-	cold

3.2 Step B: Semantic differential experiment

A new group of 12 senior design students were asked to rate the mood boards along the bipolar scales, using the semantic differential method [16]. A factor analysis of the results of the semantic differential resulted in three factors that accounted for approximately 77% of the variation in the rating data (Table 2). These three factors were labeled *warmth*, *activity*, and *attention,* after the common meaning of the scales that constituted them had been found. In Osgoods studies on phenomena including politics, emotions, and aesthetics, three factors appeared to be dominant for all studied concepts: evaluation, potency and activity [16, p. 326]. According to the present study, home atmospheres turn out to be no different from other phenomena: the warmth factor corresponds to Osgoods evaluation factor, activity to activity, and attention to potency.

Table 2. Results of a factor analysis with principal components, conducted on the subjective ratings along each of the 13 scales. Three factors accounted for approximately 77% of the variation in the rating data. The three factors were labeled as *warmth*, *activity*, and *attention*

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %

1	5.582	42.937	42.937	5.186	39.893	39.893
2	3.527	27.130	70.067	3.356	25.816	65.709
3	.905	6.961	77.029	1.472	11.320	77.029
4	.692	5.322	82.350			
5	.556	4.279	86.629			
6	.459	3.530	90.160			
7	.289	2.223	92.383			
8	.275	2.112	94.495			
9	.193	1.481	95.976			
10	.165	1.268	97.244			
11	.155	1.190	98.434			
12	.109	.838	99.272			
13	.095	.728	100.00			

3.3 Step C: Creation of an atmosphere model

While atmosphere ratings differed between users, common trends were found. Test results indicated that participants were consistent in their ratings, and a general commonality of ratings was found across subjects [22]. Based on the observed similarities, a generic atmosphere model was created with sample content. The *atmosphere model* can be seen as a semantic space in the shape of a cube (Figure 3). The axes *warmth, activity, and attention*, based on the factors derived from the semantic scaling study, range from -1 to 1.

The cube is populated with recorded songs, art projections, (color) light settings, and atmosphere labels. Each item in the cube is positioned within the three dimensions based upon actual rating scores from the semantic differential study. Each atmosphere term is mapped to a position in the cube, and consequently to a set of songs, art projections and light settings. The user can then navigate between labels, and the system in turn can extrapolate the relevant content as described in the next section.

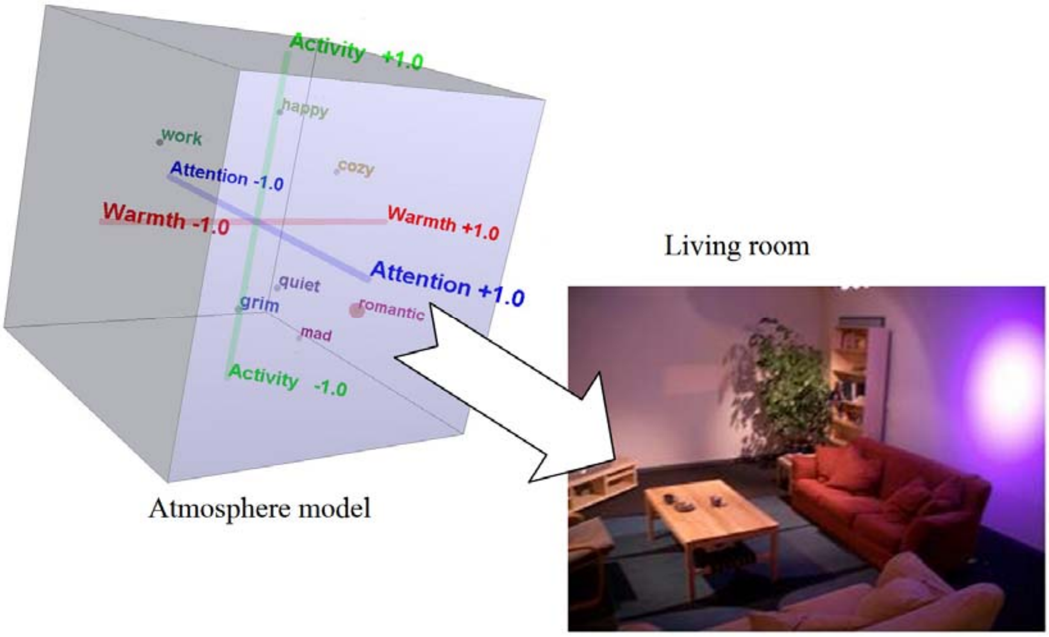

Figure 3. The atmosphere model (left view): a cubic space with the axes warmth, activity and attention. Atmosphere labels are used to navigate through the model. When a position in the cube is selected, the corresponding songs, art projections and light settings are activated (right view)

3.4 Step D: Design of atmosphere projection system

The physical atmospheres in the laboratory living room were created by generating color lighting combinations using an LED lamp (Color Kinetics™) and spot lamps driven by a customized hardware controller; music was played on a six-speaker surround system. The video art was generated in Jitter running on a Macintosh platform. A video artist was involved in creating video material for the atmosphere model. The guidelines listed in Table 3 were used to select and design the media content for the model, but they should only be considered as rules of thumb, since they are based on the results of the rating sessions for the mood boards. The resulting model space was validated by users. Examples of the generated atmospheres are shown in Figure 4.

Table 3. Guidelines for positioning atmosphere content in the three-dimensional model space of warmth, activity, and attention

Factor	**Lights**	**Audio**	**Video**
Warmth +	Warmer color (red, purple, orange), use of contrasts (spotlights rather than ambient lights)	Terms like warm, romantic, intimate apply	Warmer colors, softer shapes, smooth transitions
Warmth -	Colder color (blue, green), less use of contrasts (use of ambient lights)	Terms like cold, distant and artificial apply	Colder colors, sharp shapes, abrupt transitions
Activity +	Higher brightness	Higher tempo, complex rhythms	Higher tempo, complex rhythms, more objects
Activity -	Lower brightness	Lower tempo, simple rhythms	Lower tempo, simple rhythms, fewer objects
Attention +	Dynamic lights	High Volume	Higher brightness, more surface used
Attention -	Static lights	Low volume	Lower brightness, less surface used

Figure 4. With the prototype atmosphere control system, the ambience of a room (including music, wall art projection and lights) can be changed using a personalized atmosphere model. Left picture: a 'quiet' atmosphere, created by a subtly animated blue figure on the wall. Middle picture: an 'active' atmosphere, created by bright lights, and moving blocks on the wall. Right: a 'cozy' atmosphere, created by warm colored lights, warm colored video art, and use of spotlights

3.5 Step E: Validation of the atmosphere model

Up to this point, the atmosphere model had not been tested for live projected atmospheres. To see if the model still held for live atmospheres, a new rating session was organized. Seven basic atmospheres and 14 variants were presented to the participants in random order. Subjects were asked to rate the projected atmospheres along the same 13 scales that were used in the mood board study (Step B). A factor analysis of the data showed the original three factors emerging again, explaining 73 % of the variance. As expected, there were differences between subjects in the rating of the atmospheres (Figure 5). However, the commonality of ratings across participants indicated that the atmosphere model was also suitable for describing live atmospheres.

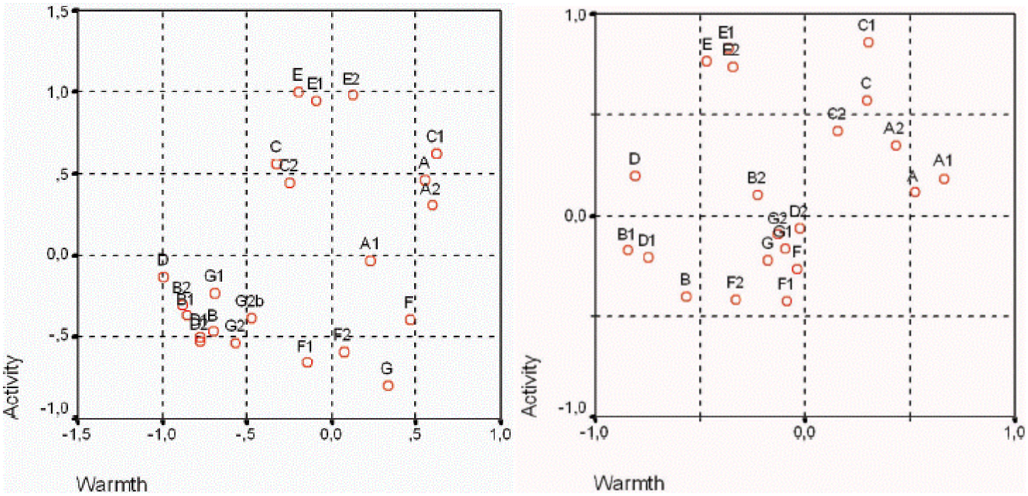

Figure 5. Graphs of the subjective ratings of live atmospheres for two participants depicted on the scales for warmth and activity. Participants were asked to rate seven atmospheres, cozy ('A'), grim ('B'), happy ('C'), work ('D'), mad ('E'), romantic ('F'), quiet ('G'), and two variants of each atmosphere, 'x1' and 'x2'. Although some ratings differ, e.g., of the 'happy' atmosphere, both participants rate the atmosphere reasonably high on activity and warmth

3.6 Step F: Design of user interfaces

Three alternative interfaces for access to the atmosphere control system were developed: namely, a tangible, a speech, and a graphic interface (Figure 6). The goal was to accommodate a wide range of user interaction styles from structured to exploratory navigation, and from concrete to more abstract control. It was also assumed that user preferences for a given interface could change over time or be related to events in the immediate environment. Generally speaking, the tangible interface can be considered as a more expressive and interpretive design, which tends to stimulate exploratory behavior given the wide range of control dimensions, while the graphic interface is more structured and can be manipulated more directly. The speech interface, while more flexible than the graphic interface, is perhaps less exploratory than the tangible interface, with fewer degrees of expression. Although the interfaces differed in look and feel, it was decided that users should be able to switch between interfaces easily. Conflicts could arise if two or more interfaces were used simultaneously, but these potential conflicts were not studied in the experiment reported in this paper.

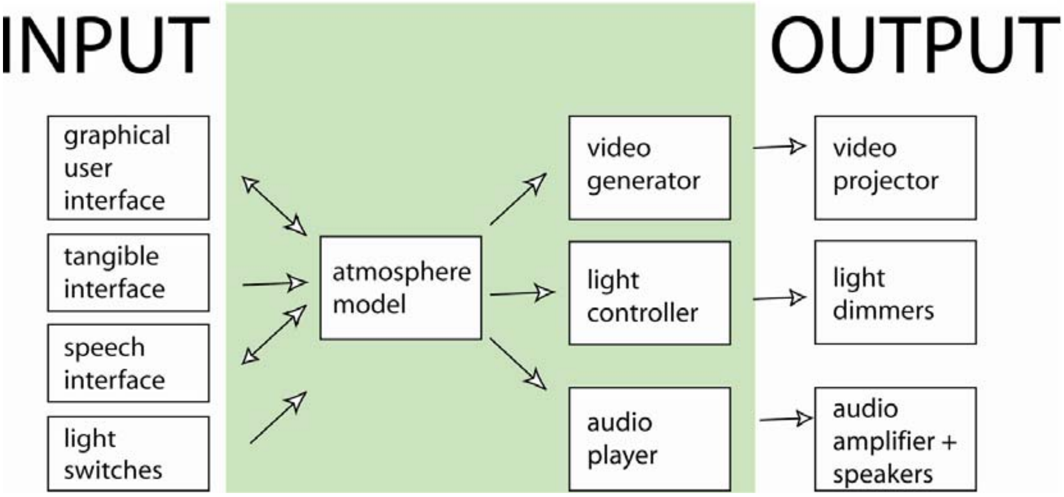

Figure 6. A component view of the system layout used in the case study. A graphical user interface, a tangible interface, a speech interface, and local light controls can all be used to navigate through and manipulate the atmosphere control system. The atmosphere output consists of wall art projection, light settings, and audio

3.6.1 Tangible interface

The Carrousel (Figure 7), a **tangible interface** developed principally by Ross [23], offers a natural, intuitive way of expressing the desired atmosphere. The rotation speed of the rotating disc can be changed by the user, similar to a potter's wheel, thereby manipulating the atmosphere's activity level. Four flags with two degrees of freedom (tilt and rotation) and a wooden and metal side can be used to 'sculpt' expressive patterns. When metal sides are dominantly visible, one could see a cooler atmosphere expressed, whereas the wooden sides relate to a warmer atmosphere.
A romantic atmosphere, which generally rates high on warmth and low on activity, could be expressed by a low rotation speed, combined with a smooth and closed flag pattern with the wooden sides dominantly visible. A happy, energetic atmosphere could typically be expressed by a high rotation speed, combined with upright flags that are directed outwards.
Pattern recognition is used to interpret the raw data generated by the Carrousel. The raw variables, including flag pitch and roll, and stage rotation, on itself give no indication of the expressive qualities of actions and their resulting flag patterns. Parameters describing these expressive qualities were derived from a user study by visual inspection of behavior on the prototype and subsequently approximated using geometric calculation. The resulting patterns were used to trigger the display of atmospheres generated via color light, music and wall art.

Using the tangible interface, the user can easily navigate through the atmosphere model in a continuous process, whereby the physical atmosphere gradually changes [13]. While the user can rapidly “sculpt” an atmosphere using the tangible interface, it can be difficult to navigate to an exact location in the atmosphere model, depending upon the amount of content in the model, and given that the model space is not physically visible. The user cannot personalize the atmosphere model using only the Carrousel, since there is no medium of communication to filter and position new content based upon user preferences.

Figure 7. With the Carrousel, a tangible interaction device, users can ‘sculpt’ atmospheres. The stage rotation speed and the orientation of the flags can be changed to express a desired atmosphere

3.6.2 Visual interface

The **visual interface** (Figure 8) is the only interface that allows the user to (visually) inspect the atmosphere model. In the case study, the visual interface was a PC-based application shown on a 20-inch touch screen. Users could navigate through the model without using a mouse or keyboard. The left side of the screen presents a visual overview of the model and a list of preset atmospheres. The right side of the screen shows a detailed overview for the model content: music, lights, and projection settings. Users can navigate by clicking objects in the visual overview, as well as by using the list of preset atmospheres and the playlist.

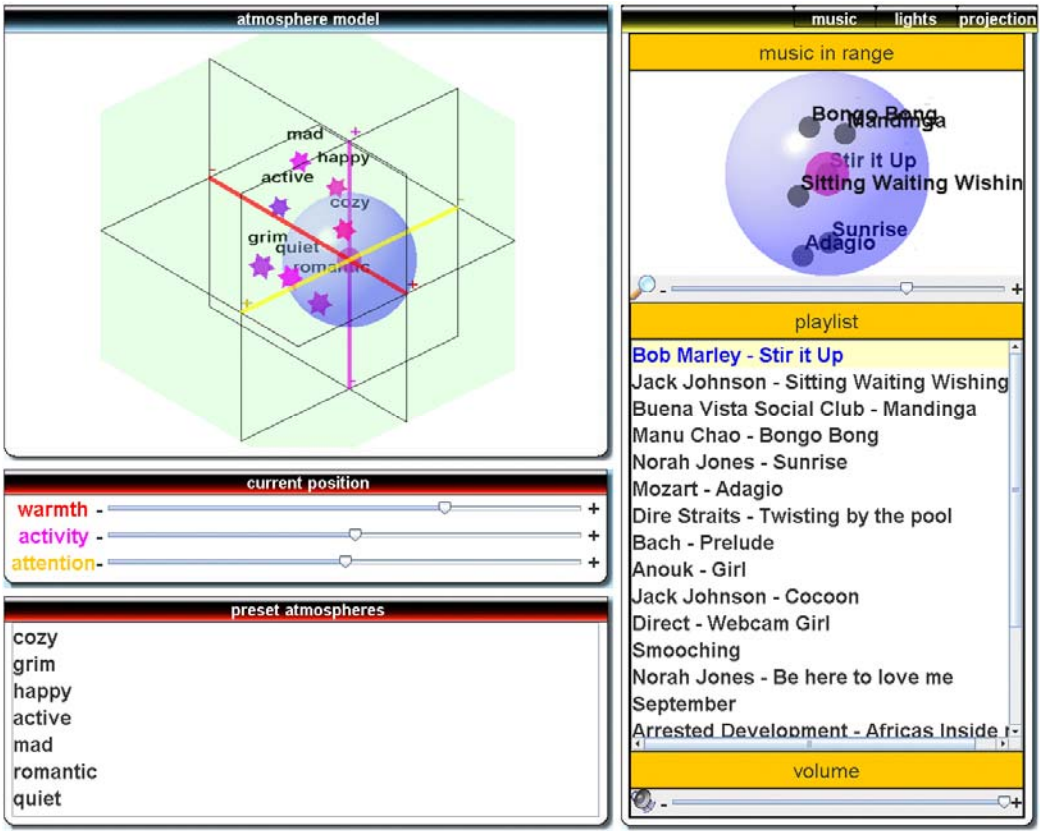

Figure 8. The visual interface provides a graphical overview of the objects, including complete atmospheres, and individual songs, video settings and light settings. The visual interface allows users to inspect and navigate through the atmosphere model. The top-left frame shows an overview of the model including the atmospheres. The current position in the model is visualized by the blue bubble. The sliders and the list of preset atmospheres can be used for navigating within the model. The frame on the right shows the model content: songs, light settings, and projections. The playlist can be used to activate specific content items

3.6.3 Speech interface

The **speech interface** enables the user to navigate through the atmosphere space, hand and eye free. Spoken navigational and manipulation commands are used to control the atmosphere model, which in turn triggers the output devices. The system includes a Things-To-Say (TTS) [3] module (Figure 9) that shows the user what can be said at any point, guiding the user through the speech dialog, based on a limited vocabulary. The user can navigate through the atmosphere space by stating “more” or “less” followed by an atmosphere-related term. For example, the user could say “more romantic.” The terms thus serve as anchor points in the model space. Although the speech interface might be improved by showing feedback on the current atmosphere as well as the atmosphere model, for the case study a speech-only interface was chosen for comparative reasons. Eventually, interfaces could be combined in order to create the optimal feedback.

Figure 9. The things-to-say list (TTS) guides the user through the speech dialog. According to the figure, the user can say "less cozy," "more active," etc.

4. Comparative user study

A user study was conducted to consider how the atmosphere models, the control system and the three alternative interfaces would be experienced. Participants were asked to repeatedly set the atmosphere using the tangible, speech, and touch screen interfaces alternatively. Because of the experience-oriented nature of the home environment, the interfaces were not only judged on *ergonomic quality* (EQ), but also on the dimensions of *hedonic quality* (HQ), *appeal* (A) and *trust* (T) [7]. These measures are explained below. Emphasis was placed on subjective measures, rather than objective human performance.

4.1 Method

4.1.1 Participants

Eighteen individuals (8 women, 10 men) aged between 24 and 33 (mean 26.8; SD 2.4) participated in the study. Eight were adult students and 10 were adult non-students from diverse backgrounds. Participants had no prior knowledge of the atmosphere control system or the interfaces.

4.1.2 Atmosphere model

The same atmosphere model was used for all participants; participants were told that they could personalize the model in the future, but the model was fixed for the experiment. Prior to the experiment, a ‘generic’ atmosphere model was created that fitted the individual experiences of the participants as much as possible; this was based on the model used in case study 1. In order to create a richer ‘atmosphere’ navigation landscape, the model was extended with additional songs. Twenty-five songs were rated by seven people, using the same measurement procedure as described in the case study. In order to create unified groups, five songs that deviated from the group means by more than 0.7 were omitted.

4.1.3 Measurements

A questionnaire was used to measure the perceived quality of the interfaces; the questionnaire consisted of 30 bipolar verbal scale anchors along the dimensions of *ergonomic quality* (e.g., simplicity, controllability), *hedonic quality* (e.g., novelty, originality), *appeal* (e.g., pleasure, desirability), and *trust* (e.g., system integrity). The 23 scales for EQ, HQ and A were adopted from Hassenzahl [7] and translated into Dutch. The eight scales for Trust were adopted from Jian [8]. The approach of comparing interface concepts based on these dimensions has previously been applied to compare a tangible music interface to the iPod [2].

4.1.4 Procedure

The study was carried out in the living room laboratory at the Department of Industrial Design Engineering at Delft University of Technology. The three interfaces were evaluated across subjects in balanced order. For each interface, a video instruction was shown, demonstrating the functional use of the interface without further explanation. Participants were given five minutes to try out the interface. Following the trial period, subjects were instructed to: (1) “imagine you are in an active mood, set the atmosphere accordingly,” and (2) “imagine a friend drops by for a cup of coffee, set the atmosphere accordingly.” After finishing the assignments, the participants were asked to fill in the rating list, and proceed to the next interface. During the experiment, user feedback was logged. The evaluation of the user interfaces took approximately one hour per participant.

4.2 Results

To translate the 30 bipolar anchors into quality factors, a factor analysis using principal components and Varimax rotation was conducted on the questionnaire items for EQ, HQ, A and T (Table 4). The consistency of the EQ items was confirmed by the factor analysis; the analysis showed one factor with an Eigenvalue higher than 1. A factor analysis of the HQ items showed two factors with an Eigenvalue higher than 1. It would appear that the HQ items in the questionnaire captured two different concepts, so two factors, HQ1 and HQ2, were used to analyze the scores.
For both Appeal and Trust, factor analysis showed two factors with an Eigenvalue higher than one. However, in either case, the second factor did not contribute to the understanding of the scores. Therefore, only the first factor was used for Appeal and Trust.

Table 4. Overview of factors resulting from the factor analysis of the questionnaires

factor	interpretation
EQ	understandability, clarity and predictability
HQ1	exclusiveness
HQ2	interestingness and excitement
T	trust and support
A	pleasantness and desirability

The measures for each interface per factor are shown in Figures 10-12. The ratings for both EQ and T varied significantly across the interfaces (EQ: $\chi^2 = 28.8$, df=2, $p<.05$, T: $\chi^2 = 25.0$, df=2, $p<.05$). The Carrousel scored lower on ergonomics and trust, which corresponds to user feedback; when asked for general feedback on the interfaces, 7 out of 18 participants indicated they did not understand how to use the Carrousel, and 3 participants indicated they found it hard to predict the resulting atmospheres when using the Carrousel. Both the speech and the touch screen interface scored high on EQ and Trust.

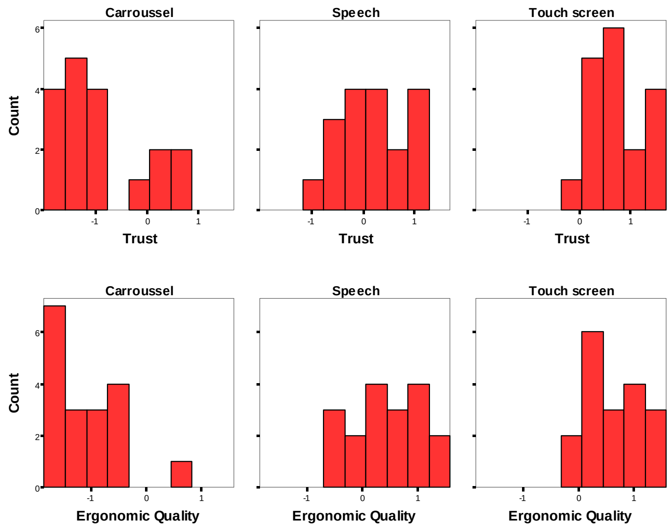

Figure 10. Histograms of trust and ergonomic quality for the three interfaces

The ratings for HQ1 varied significantly across the interfaces (χ^2 = 28.0, df=2, p<.05). The Carrousel was experienced as an exclusive interface, while the touch screen interface was experienced as a *familiar*, and therefore a more standard, interface. The ratings for HQ2 did not vary significantly across the interfaces.

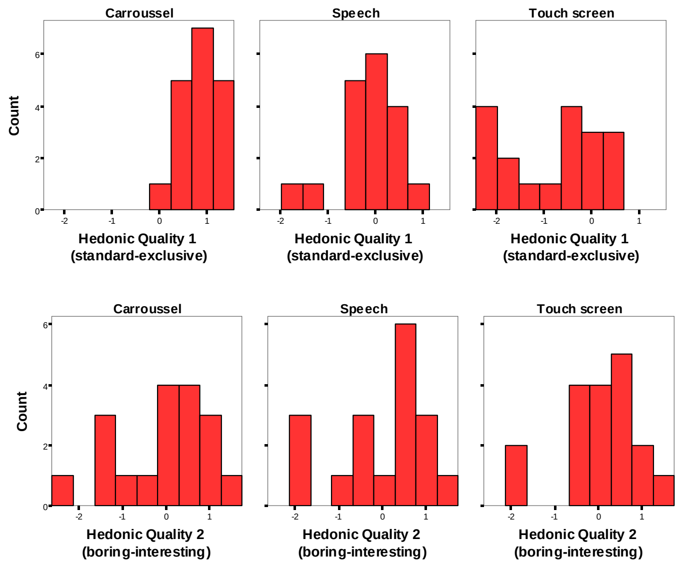

Figure 11. Histograms of the hedonic quality 1 (standard vs. exclusive) and hedonic quality 2 (boring vs. interesting) for the three interfaces

The ratings for Appeal varied significantly across the interfaces (χ^2 = 10.1, df=2, p<.05). Although the touch screen interface was perceived as being standard and familiar, participants valued its predictability and usability. The touch screen interface was rated high on appeal by all participants. The speech interface appealed to the majority of the participants; however, 5 out of 18 participants indicated they disliked this interaction concept. The results on the appeal measure for the Carrousel varied, ranging from very low to very positive.

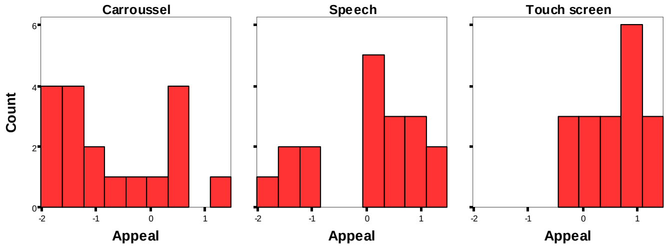

Figure 12. Histograms of the appeal of the three interfaces

4.2.1 User Comments

To summarize user comments, participants were generally uniform and moderate in terms of positive or negative feedback on the touch screen and the speech interface, whereas the **Carrousel** evoked a diversity of reactions. Some participants were plain negative ("*It is difficult to create a certain atmosphere,*" "*It irritates me,*" "*It is unpredictable*"), while others were positive ("*I like the physical control of the atmospheres*"). In general, test subjects appreciated the physical nature of tangible interaction and the feel of materials. Interacting with the expressive tangible product was a new experience for most participants and was experienced as engaging and pleasant. The **speech interface** ("*This one is real fun*") was appreciated for its possible use when doing other activities (setting the atmosphere when pouring coffee). The **touch screen** was valued for its understandability and predictability ("*I like this one, that's why it took me so long*"). Subjects noted that they were accustomed to the touch screen interaction, since they were used to using desktop computers.

4.3 Discussion

Participants were generally positive about controlling the atmosphere using the interfaces; however, subjects disagreed when assessing the interfaces in the study, providing varied ratings for appeal, ergonomics, hedonics, and trust. The results of the user study suggest that the choice of interface depends partly on the personal characteristics of the users. Given the observations and user feedback, the preferred interaction style might also depend on the task at hand and the context of use. These

findings are in line with the challenge of universal access in which designers have to cope with diversity in user characteristics, user tasks, and context of use [26].
Although the tangible interface scored lower on trust and appeal, observations suggest that this was partly due to the generic atmosphere model. Personalization of the atmosphere model would presumably increase the predictability of user actions with the Carrousel. The predictability of the Carrousel could also be improved by combining the visual interface (for model feedback) with the tangible interface (for navigation through the model).
The results of the user study indicate that the appeal of the user interfaces was not merely linked to their functionality and ergonomic qualities, but also to hedonic qualities. The three interfaces used in the study obviously differ in ergonomic and hedonic quality, and consequently they were perceived differently by the users. Users seemed to appreciate the 'exclusiveness' of the tangible interface, even though it was perhaps difficult to use from an ergonomic point of view. The speech and touch screen interfaces were perceived as being less exclusive, but they scored high on usability and trust.

5. Personalization of the atmosphere model

In the current study, a generic model incorporating 'average' atmosphere content was used to avoid a tedious set-up procedure when first using the system. Although a generic model can serve as a starting point, atmosphere models need to be personalized to manage the different experience of atmospheres found between subjects. Second, laboratory studies with a basic prototype home atmosphere controller have shown that attachment to the system can be increased by allowing people to add personal content [11]. Possible approaches to personalization include content adaptation and remodeling.

Personalization through content adaptation

Content items can be inserted or removed (e.g., *add "disco atmosphere"*), while leaving the model dimensions (warmth, activity and attention) intact. In addition, existing items can be repositioned to reflect personal interpretations of atmospheres. Positioning of the items is critical if the three dimensional navigational structure is to be maintained. When items are in a position that does not reflect the personal experience, the system may behave in a confusing and incoherent manner. Model consistency has to be safeguarded whenever the model is updated.

Personalization through remodeling

Instead of the dimensions warmth, activity and attention, which were developed in the current study on the basis first of mood boards and later actual projections coupled with semantic scaling, new dimensions could be added to an atmosphere model. For example, users could create an atmosphere model for specific events, such as a birthday party. Although remodeling enables a vast range of new atmosphere combinations, one should be careful not to overwhelm users with too many models. Future studies will measure the effect of remodeling the space and the use of multiple models on model consistency and perceived transparency. Still, the beauty of the single-model solution with its fixed dimensions might be its simplicity.

6. Reflections on design and approach

Even though many test subjects indicated that they disliked technology in their homes in general, they felt positive about the atmosphere controller. The prototype evoked reactions of astonishment and surprise, and the default atmospheres inspired the participants to create their own, personal atmospheres [11]. Before a semantic model-based atmosphere controller can be deployed in the home, field studies need to examine the degree to which the atmosphere controller will be accepted as part of everyday life.

In terms of design approach, building the atmosphere control system on the basis of a model of experience provided a degree of flexibility in the design of diverse user interfaces to the model, which in turn provided a broad range of interaction possibilities. At an early stage of the process, the perception of atmospheres was captured in the atmosphere model. The model allowed new interface concepts to be rapidly developed, making it easy to study different styles of interaction and expression, and in particular individual preferences of modalities for user-system communication. User involvement early in the design process and the embedding of user experiences proved valuable contributions to the final product concept.

The prototype home atmosphere control system demonstrates the use of a model based on how humans perceive atmospheres. Instead of adding a new button for every feature, the atmosphere model permits atmospheres to be created and changed at the level of experience. The design approach described in this article can also be applied to other areas where human perception of phenomena is central: i.e., where phenomena can be measured using semantic scaling. For example, the design approach could make a visit to a museum “experience driven.” Imagine an electronic personal museum guide on a mobile computer that by default starts with the masterpieces from the golden age. Without users being aware of it, the electronic guide could use a pre-defined semantic space of all art pieces in the museum. Instead of organizing art pieces by describing the features (the painter, the time period, topics, etc.) [6], a semantic model would be organized based on how people experience the paintings. Individual visitors could then personalize the route through the museum by giving feedback on paintings and on the guided tour in natural terms (for example, “less abstract pieces,” or “paintings that are more romantic”). Furthermore, by incorporating feedback from previous museum visits, combined with an element of surprise, the museum guide could eventually turn into a genuine personal guide.

The case study demonstrated how a complex control problem can be approached by focusing on desired user experience, rather than designing interaction at the level of functions and features. The experience model-based design approach may be especially beneficial when designing complex systems which have to accommodate a wide range of users and user preferences.

7. Future work

A multimodal interface approach may help compensate for some of the limitations found for each interface type. Participants of prototype tests disagreed in their choice of preferred input device: some favored the tangible interface, while others preferred the visual or speech interface. The choice of interface might not only depend on the person, but also on the task at hand. For some tasks, it might even be preferable to use a combination of input devices, instead of a single device [9, 17]. The concrete interaction of the speech interface could be combined with the expressive power of the tangible device when navigating through the atmosphere model. When adding content to the atmosphere model, the speech interface could be used in combination with the visual interface, enabling concrete control and visual feedback. Based on the findings of the user studies, the existing interface concepts could be improved and combined to create a multimodal interface solution combining the best qualities of the tested interfaces.

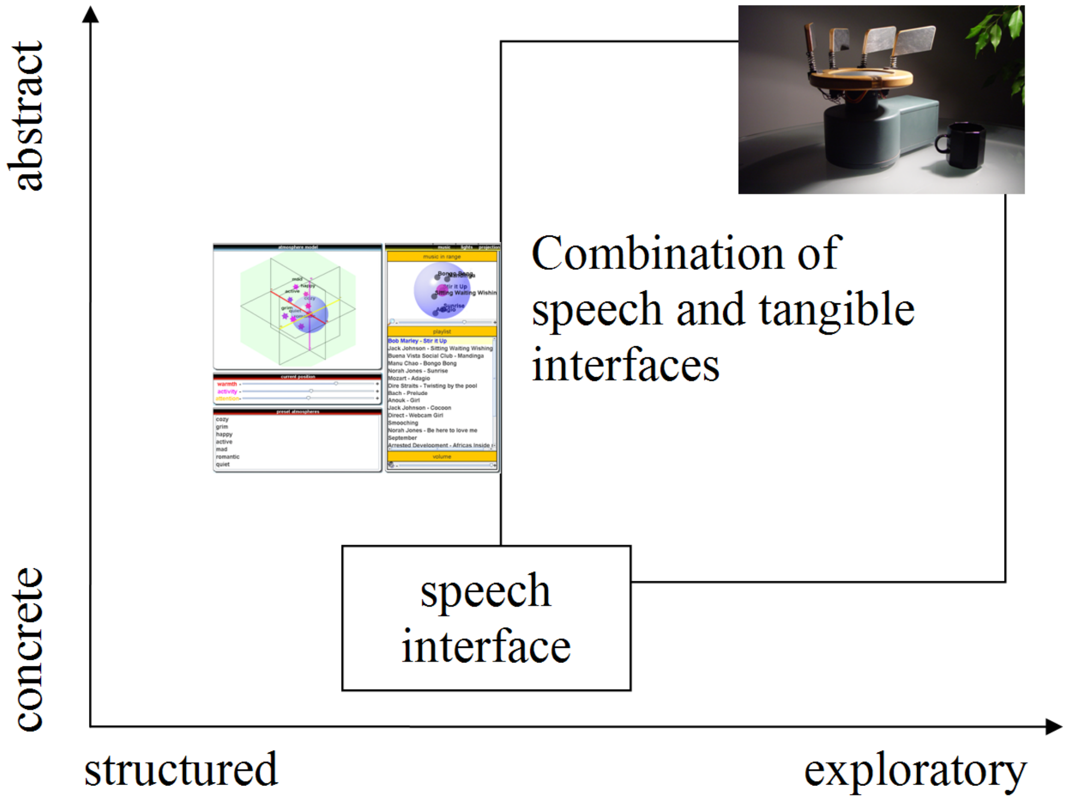

Figure 13. Interaction can be supported along a continuum from concrete to abstract control and from structured to exploratory navigation

Exploring experiences

A home control system could support users when exploring new experiences. In the domain of music, commercial applications such as MoodLogic, Pandora, and LivePlasma[1] offer collaborative filtering mechanisms that can be used to create personal music playlists using a database with feedback from a community of users. These applications introduce users to music that they might not have heard before. New studies are foreseen in which users will explore new home atmospheres using collaborative filtering mechanisms linked to the atmosphere model.

Acknowledgements

The work presented in this article was partially funded by the Dutch Ministry of Economic Affairs. The authors wish to thank the anonymous reviewers and H. de

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[1] Examples of commercial applications for collaborative filtering for music can be found at: http://www.moodlogic.com, http://www.pandora.com, and www.liveplasma.com.

Ridder for their valuable comments, and the ID-StudioLab for their support during the course of design and research.

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