Pers Ubiquit Comput (2013) 17:1281–1293
DOI 10.1007/s00779-012-0635-x

ORIGINAL ARTICLE

Future home design: an emotional communication channel approach to smart space

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Received: 29 November 2011 / Accepted: 17 December 2012 / Published online: 7 February 2013

Abstract Smart spaces use human–computer interfaces (HCIs) to improve how humans experience their surroundings. However, HCIs are sometimes less user-friendly and intuitive than their traditional counterparts. Our research aims to use every-day objects to create communication channels between spaces and people, which can then strengthen interpersonal emotional relationships through a natural and unobtrusive interface. This study explores how using simpler instruments such as a whiskey glass, a table, and an MP3 player to interact with a dwelling improves user experience in a HCI-equipped smart space. We implemented a real smart space—the *Time Home Pub*, which not only adjusts the environmental atmosphere (such as background lighting, music, and photos) in response to human activities but also encourages a better connection between humans, their memories, and physical space. *Time Home Pub* was exhibited at the Taipei Fine Arts Museum in 2007 for the topic of Architecture of Tomorrow. Preliminary evaluations by visitors demonstrate the satisfactory feasibility of the system and how a smart space could change and improve human experiences through the use of new technology and architectural design elements.

Keywords Human–computer interface · Smart space · Ubiquitous computing

1 Introduction

1.1 From architecture to smart space

Prior to the twentieth century, designers focused mostly on architectural form and space layout. With the development of computational technology in the twentieth century, new media has played an important role in architectural design. In 1963, Sutherland [1] created the first computer graphics program, "Sketchpad," which revolutionized the way people manipulate the design process. The appearance of Computer-Aided Design/Computer-Aided Manufactured (CAD/CAM) technology has profoundly influenced architectural design [2–4] because digital construction is extremely different than traditional architecture. For example, the various kinds of CAD/CAM devices allow for computer-controlled cutting, routing, milling, and bending. These designs can then be automatically converted from digital models into full-size architectural components such as Frank Gehry's Guggenheim Museum in Bilbao.6 [5].

At the same time, computer technology has become ever present and widely integrated into our ambient environment, a phenomenon described by the term "ubiquitous computing" [6]. In order to create a new lifestyle for human beings, the new term "smart space" has emerged in space design. In 1980, the "*Smart House*" project proposed a home automation idea and applied a specific set of technology into a real house [7]. "*The Aware Home*"

Electronic supplementary material The online version of this article (doi:10.1007/s00779-012-0635-x) contains supplementary material, which is available to authorized users.

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project has built a living laboratory for research in ubiquitous computing for daily activities [8]. "*Augmented Reality Kitchen*" has applied augmented reality (AR) technology and user-centered interface to create a more efficient and safe kitchen to support the activities of a variety of people in diverse kitchen environments [9].

1.2 Smart space

Smart spaces aim to improve the interface between humans and physical space in order to provide a better life to the space's inhabitants. Some have suggested a smart space that responds to the dweller's needs and desires by adjusting lighting, temperature, and even ambient music, as described in the science fiction of the twentieth century [7]. However, in order to provide a safer, more comfortable, and more economical space, some researchers are incorporating new technology into interface design by using the smart space to bring computation into the real, physical world. Computers directly participate in activities that allow people to interact with computational systems the way they would with other people: via gesture, face detection, voice, movement, and context [10, 11].

Meanwhile, in order to allow for more natural interaction with smart spaces, some researchers have tried to explore a more intuitive and natural interaction between humans and space, such as brain–computer interface (BCI) [12, 13]. For example, "*The Smart Floor System*" was developed to identify users through the rhythm and pattern of the footsteps they take during their everyday routines [14]. For more intuitive control of lighting, air conditioning, and the environment, Huang [15] applied bio-signal interface to a smart space that could make people work more efficiently by adjusting background lighting through BCI. In order to enable people to work in an energized way, the environment can give appropriate feedback by monitoring their brainwaves. In parallel, the study of emotional communication between humans and machines has appeared in our lives with the development of technology [16]. One such emotional communication device, "*LumiTouch,*" can seamlessly transition between passive and active modes [17]. Since the increase technology is reducing communication between people, Kim et al. [18] developed four prototypes such as "*Home media pond*" to enhance the family communication by using digital technologies.

The new HCI technology has not been as easy to use as traditional interfaces, so some researchers have focused on the issue of human-friendly interfaces [19, 20]. Take gesture recognition, for example. In order for a signal to be successfully recognized, we may have to try different gestures to find the one that is easiest to detect. Thus, some researchers have used alternative technologies, to change the way people interact with objects in daily life [21]. People need not only a space that is more convenient and comfortable, but also an interesting and emotionally engaging one. Thus, Ishii and Ullmer [22] tried to explore Weiser's transparency in interfaces by developing a bottle filled with music: classical, jazz, and techno music. Physical manipulation by opening and closing is the primary mode of interaction. This provides a new way to interact with music without players or instruments. There are also many other interesting products that enable users to interact with their environments in novel ways. The project "*I/O brush*" explored the idea of "The World as your Palette" which developed drawing tools to allow people to create visual art with elements (specifically, the color, texture, and moving patterns) extracted directly from their personal objects and their immediate environment [23]. Schoch [24] used "pervasive computing" as the main concept to practice the idea of sustainable architecture in a real building. However, researchers have sometimes overused HCI devices and forgotten the essence of smart space—creating a safe, comfortable, and economical space for humans [15].

1.3 Interactive table

Recently, some researchers have tried not only to put HCI devices into a real space, but also to let people interact naturally with the space [15]. By analyzing how people interact with the space they live in through daily activities such as drinking a cup of coffee, watching TV, eating at the dining table, drawing, or writing at a desk, the designer tries to combine HCI technologies into objects which are related to the users' daily lives. The project of "digital architecture of tomorrow" used certain cognition-driven terms, such as 'smart' and 'intelligent', to describe the interactive and built-in programming nature of these everyday objects. They introduced a new architectural composite material, digital wallpaper, as a new design component [25]. Nakajima et al. [26] suggests that our daily lives will be more attractive when our surroundings become more intelligent. He thinks that when many services become embedded in our surroundings, we will begin to change the way we live. Alternatively, we may suggest that almost every daily event happens on tables, and that we perhaps could not live in a space without tables, including dining tables, meeting desks, and bar counters. Jorda et al. [27] designed an electro-acoustic music instrument called reacTable*, which supports a flexible number of users and allows simultaneously additive (users working on independent audio threads) as well as multiplicative (users sharing control of audio threads) behaviors.

Additionally, the project iBar [28] created a specific bar counter that detects all objects touching the surface by using an intelligent tracking system. The input is used to let

the projected content interact dynamically with the movements on the counter. This system improves a consumer's experience of drinking or chatting around the bar counter. The bar counter showed the social relationships of people using the device which then facilitated social interactions between users. Furthermore, Patten et al. [29] created an audio electronic music controller on a tabletop tangible interface. This system is able to track the positions of objects on a tabletop surface and translate their motions into commands for a musical synthesizer. These kinds of HCI combination systems augment the function of tables and put more fun in life.

2 Problem and objective

Motion sensors, voice control, eye-tracking, and facial recognition devices were designed to improve the ease of using HCIs. Recently, in order to allow for more intuitive and natural interaction with space, Huang [15] has created a smart space that can respond to the user's mental state by adjusting the environment, through lighting, temperature, and music by monitoring the user's brainwaves. In addition, many researchers have tried to incorporate new technology into daily life. The introduction and rapid acceptance of digital cameras have fundamentally changed the way people take and share images [30]. Thus, the development of digital photo frames has transformed the traditional photo frame into a new style that enables users to change the photo display on a whim. Mynatt et al. [31] created a system of digital family portraits that was used to leverage existing emotional connections and the role those portraits already played in decorating a household space. Some researchers think that designing for digital photos to be dynamically distributed in the home environment allows for co-experience among family members, continuing their storytelling without the time delay of traditional, static photo displays [30]. Nevertheless, the limitation of the photo frame is that it only has one-way communication (display), with few connections to the environment.

As for the interactive table, iBar counter has created an innovative form of communication between people [31], but with only a single interaction between a glass and the interactive table, the system has difficulty recognizing individual users. The reacTable enables users to naturally control music by moving an object [24]. However, the controller is a specific pattern-attached object, and it would be better if that object could be a common one used in daily life. Most importantly, we can see that most systems only have a single interaction between the user and individual device. Furthermore, few of these projects focus on integrating the whole system into a space. Therefore, the goal of this research is to demonstrate a system prototype of smart space in a real living room that is able to solidify the links between people and between spaces by using HCI technologies.

In order to create a smart space which can provide adequate feedback and also strengthen the relationships between interacting people, we designed a futuristic space called the "*Time Home Pub.*" This smart space embeds different interactive devices, alternating between three modes (normal mode, bar mode, and music mode) to satisfy the emotional demands of the person staying in the smart space. Thus, an interactive table was used as the main component of the smart space. Three other devices in the space include a whiskey glass, a Liveframe (a digital photo frame which can be connected with interactive table and whiskey glass and will be described in Sect. 4.4.2), and an environmental atmosphere control. When a user moves the whiskey glass on the table, time-marks graphics that denote positional information of previous users at the table and the visual display on the table's surface will interact with the three other space components: visual interaction in the photo frame, acoustic interaction in the background music instrument, and animated interaction on the wall. Therefore, the interactions from the three components will, in turn, re-interact with the person's vision, emotion, and memory.

3 Methodology and steps

We implemented a future smart home that can naturally interact with the environment and apply HCI technology into a real space, as in previous research [9, 15, 26, 28–30, 32–35]. The difference between this work and previous research is that our system has specific emotional communication channels between both "human and human" and "human and space" interactions. It also shortens the distance and blurs the boundary between people and space. The methodological steps of this research are as follows:

3.1 Analysis of HCI in smart space

HCI technology is defined as "a post-desktop model of Human–Computer Interface" in which information processing has been thoroughly integrated into everyday objects and activities [6]. Home automation has increased, but no HCI system has been adopted in everyday life yet, even though the visions for it have been around for several years [36]. In addition, much of the smart home research has focused on novel technical artifacts, but has overlooked the issues surrounding social relationships in the home [37]. Therefore, how to appropriately arrange HCI into smart space has become more important than just adding a

novel or fancy interface into smart space. The challenges lie in identifying which daily objects to adapt and organizing a smart space around them. This research will also discuss the essential differences between traditional architecture and smart spaces that use HCI.

3.2 Scenario demonstration

In order to apply the *Time Home Pub* system into a real space, we created a scenario to demonstrate the system process (Fig. 1). The scenario is divided into three parts. First, by putting the whiskey glass on the interactive table, time-marks will emerge on the table. Second, moving the whiskey glass to a previous user's (e.g. Sasada's), time-mark will activate the Liveframe to show Sasada's photos. Third, moving the whiskey glass onto the music hot spot will initiate music to play.

3.3 System concept

To illustrate how the system works, we separate the system concept into three modes: normal mode, bar mode, and music mode. In this part, we explain the main concept of the system and how different modes can be represented in a cycle.

3.4 System framework

The system framework is composed of three main components: first, the interactive table and whiskey glass; second, the time-mark and Liveframe; third, the environmental atmosphere control and music hot spot.

Fig. 1 Interactive steps

4 Results

4.1 The analysis of HCI in smart space

First, this work explores a new vision of a smart space which not only improves comfort and convenience but also solidifies the relationships between family and friends by using HCI technologies. Thus, we consider HCI to be an important media which redefines traditional architecture into a new lifestyle space. We start from an architectural view to discuss what kind of architectural elements the space is composed of. How do we embed HCI into architectural elements to create a better smart space? This analysis of HCI in a smart space is separated into three parts:

First, the wall, ambient lighting, and music are the important elements composing the ambient atmosphere. By adding adjustable ambient atmosphere (HCI elements), the physical home environment (architecture) is able to transform itself into an adjustable scene (smart space) by accommodating users' behaviors. Second, since the table as an important medium in the space, it creates various interactions between people. This embedded interactive table (HCI element) transforms the space (architecture) into a memorized space (smart space) that is able to record human activities. Third, since photographs are important memory elements in our living spaces, they can create an emotional connection between people. Therefore, by adding Liveframe (HCI element), a daily object such as a photo frame (architecture) is transformed into a new style of digital photo frame (smart space) which is able to make connections between memory and emotion. Therefore, the systems of this research were separated into three parts, as indicated in Table 1.

4.1.1 Physical space enhancement (sofa, table, wall)

The design of HCI elements is combined into physical elements, such as sofas, tables, or lighting, and feedback is given according to human emotions. For example, by adding HCI sensor device (e.g. magnet switch sensor) to the table, it will become an interactive table that is able to track the glass's position and connect to the ambient atmosphere to adjust the space scene according to a user's activities.

4.1.2 Records of human activities and events (moving the whiskey glass)

The interactive table records which of your friends have previously been to the space and presents time-marks with individualized styles. This means that the space can memorize events which have occurred in the room. This

Table 1 The media of HCI between architecture and smart space

Architecture space	HCI design	Smart space Life style
Physical home environment (sofa, table, wall)	Adjustable ambient atmosphere	Environment adjusted by human's emotion
		When the user puts the whiskey glass onto the table, and the space transforms into bar mode. The lighting becomes darker and patterns emerge on the wall
		If the user moves the whiskey glass onto the music hot spot, then environmental music gradually appears
A space for human activities and events (moving the whiskey glass)	Interactive table	Memorized space records human activities
		As time goes by, the time-marks, which are shown in different colors and patterns, stand for individual people and the frequency of visiting times are displayed on the table surface
Photo frame and whiskey glass	Liveframe	Tranquil communication between vision and mind
		Since the user moves the glass onto *Sasada's* time-mark, the Liveframe searches the database and shows *Sasada's* photos on the digital frame. This can trigger the user's memories through visual stimuli

adds some measure of artificial intelligence to the space, making it closer to human beings.

4.1.3 The connection between vision, feeling, and memories (Liveframe)

As indicated above, the interactive table can record which people have come to the space before. Liveframe is also connected with the interactive table. Through this system, time-marks trigger memories associated with photos (Fig. 2). This process is able to solidify the connection between vision, feeling, and memories.

4.2 System concept

In order to allow people to interact with a space more naturally, the space senses the changing events and activities by adjusting the background lighting pattern to provide a suitable ambience. The "*Time Home Pub*" we have created is able to adjust the environmental atmosphere naturally according to human activities. We used the whiskey glass as an atmospheric control switch and installed the control into a real living room. This system consists of three main devices: the interactive table, a whiskey glass, and Liveframe (see Fig. 3).

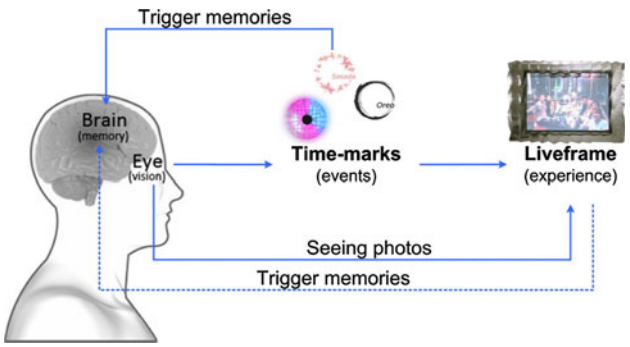


Fig. 2 Pictures and events trigger memories

In order to create a space that can adequately provide dwellers with feedback and satisfy their daily needs, we provide three modes in the system: normal mode, bar mode, and music mode (see Fig. 4). The modes are able to interchange according to human behaviors.

4.2.1 Normal mode

This mode presents a traditional and general living room with nothing different from an ordinary space. The photo frame serves as the traditional frame, which displays a static family photo (see Fig. 4-normal mode).

4.2.2 Bar mode

The environment changes to bar mode when the user puts the whiskey glass on the interactive table. The environmental wallpaper also changes to animated patterns at the same time, with the time-marks gradually emerging from the table. When the user moves the whiskey glass onto someone's time-mark, Liveframe is triggered and related photos are shown (see Fig. 4-bar mode).

4.2.3 Music mode

When the whiskey glass is moved onto a music mark on the table, music gradually begins to play. Furthermore, the pattern flow on the interactive table will follow the musical melody (see Fig. 4-music mode).

Fig. 3 System concept

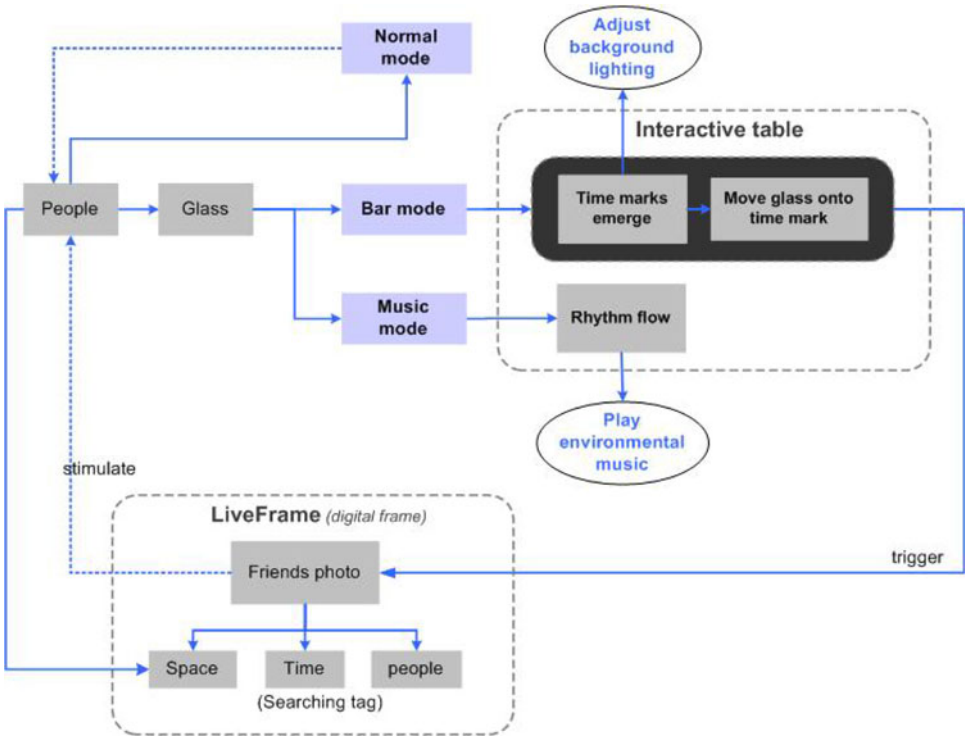


Fig. 4 Three modes

4.3 Scenario

Sean has just finished work and returns home at midnight. To take a break, he lies down on the sofa, takes out a bottle of Islay Island Whiskey, and puts a whiskey glass on the table. The space senses Sean's glass on the table and changes to bar mode. The environmental lighting slowly becomes darker, and the wallpaper switches to an animated pattern. A tracking mark is illuminated around the whiskey glass (Fig. 5b). Simultaneously, time-marks emerge on the table to stand for Sean's friends and family who visited the space in the past few years (Fig. 5c). Different patterns and opacities on the time-marks represent the time flow. The more time has passed since one of Sean's friends has been to the place, the dimmer the time-mark appears. While enjoying his single malt whiskey, Sean unexpectedly catches sight of Sasada's time-mark pulsing on the table (Fig. 5d). Sasada is one of his best Japanese friends, and he realizes that they have been apart for a long time. Therefore, Sean moves the glass onto Sasada's time-mark, and the Liveframe presents the photos in slides (Fig. 5e). Thus, the photos trigger recall of memories with Sasada. Sean then wants to listen to music, so he moves the whiskey glass onto the music hot spot. The place gradually becomes filled with Sean's favorite music. (Please see the scenario demonstration video—Online Resource 1 [39].

4.4 Implementation

The *Time Home Pub* system consists of four main components, as shown in Fig. 6: the interactive table, a whiskey glass, Liveframe, and the environmental atmosphere control. The interactive table is composed of an array of LED chips and a magnetic switch array. The table is covered with white acrylic and is connected with the main server computer (PC 1). Once the interactive table detects a whiskey glass on the interactive table, the server (PC 1) connected with projector 01 displays the time-marks on the

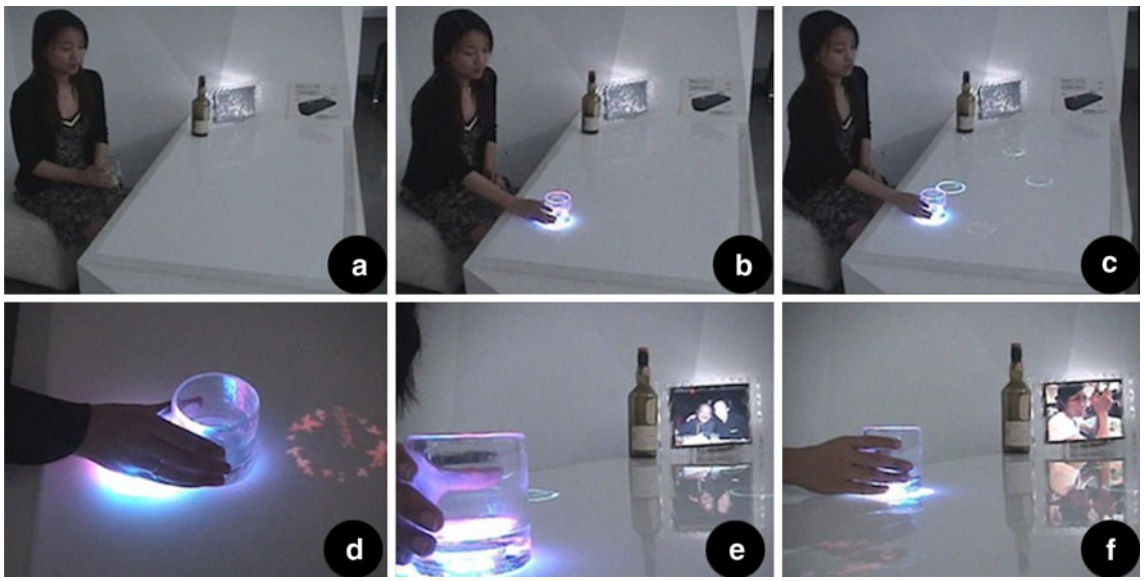
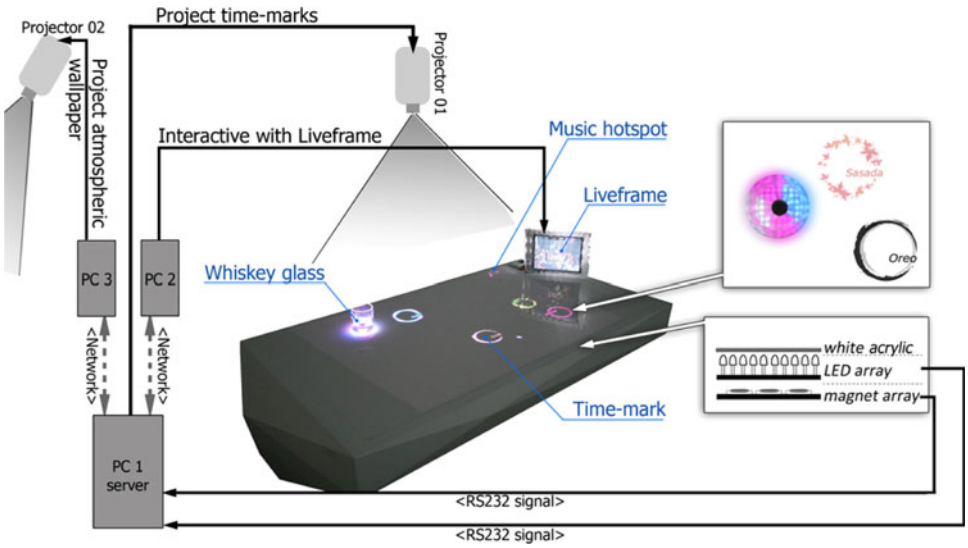


Fig. 5 Scenario demonstration: **a** normal mode; **b** the whiskey glass was put onto table, and the tracking mark lights up to follow the glass; **c** simultaneously, time-marks emerge; **d** user moves the whiskey glass onto "Sasada's" time-mark; **e** the Liveframe displays a slideshow of photos related to Sasada and the user; **f** the whiskey glass is moved onto "Mary's" time-mark, and the Liveframe shows related photos

Fig. 6 System framework



surface of the interactive table. At the same time, through the networking system, the server sends a signal to PC 3, another computer which is connected with projector 02, and displays different wallpaper on the wall. In addition, PC 1 also sends a signal to PC 2 to control the Liveframe. Basically, the interactive table is controlled by PC 1 and is the main control server of the *Time Home Pub* system.

4.4.1 Interactive table and whiskey glass

The interactive table is the main control center of the whole system and is connected with PC 1. The interactive table has two layers (see Fig. 8). The first layer is composed of an LED chip array and can show the glass tracking mark; the second layer is designed to recognize the position of the whiskey glass.

The first layer: LED chip array

In order to show the tracking mark for the whiskey glass, we put the LED chip array (Fig. 7c) on the first layer. To be more colorful, this interactive table is composed of three different colors of LED chips: pink, blue, and white. A total of 8192 LED chips (64 × 128) were planted on the second layer and divided into 32 units. Each unit consists of 16 × 16 LED chips. Each row has 8 units and is manipulated by a controller board (Fig. 7a) to which PC 1 can send signals. To enable the interactive table to render a

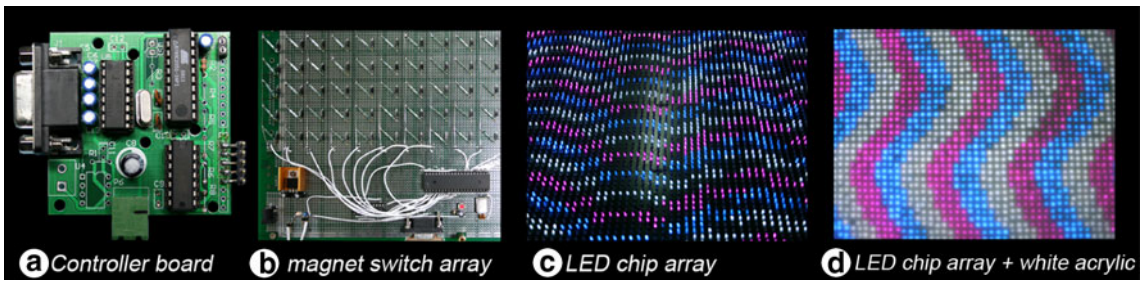


Fig. 7 Interactive table components

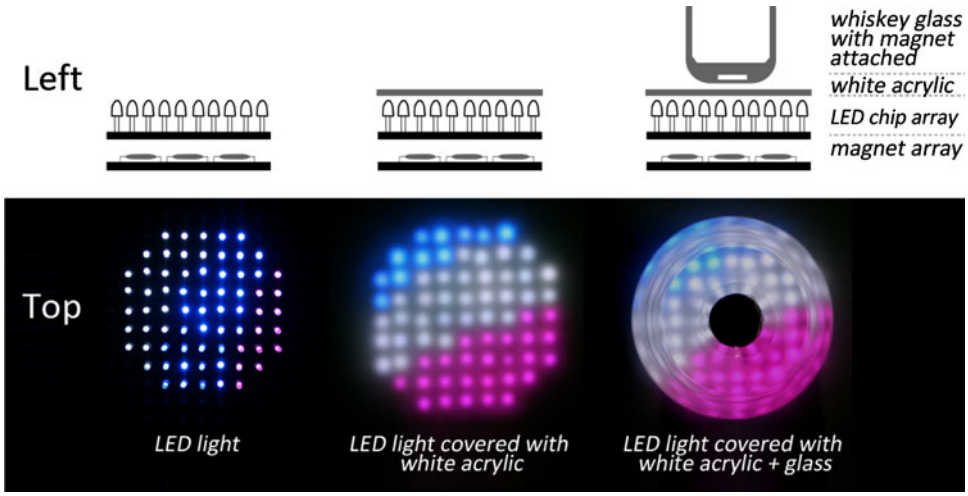


Fig. 8 Section of interactive table

tracking mark from the back of the surface, we put a sheet of white, three-millimeter-thick rectangular acrylic above the LED chip array. This kind of acrylic is translucent and shows a diffuse glow on the surface of the interactive table (Fig. 7d) only when LED chips are very close to it (see middle of Fig. 8).

The second layer: magnet switch array

The magnet switch array is put in the second layer, under the LED chip array, to detect whether the whiskey glass is on the interactive table and assess its position. This magnet switch array (Fig. 7b) can recognize the position of the whiskey glass by sensing the strong magnet at the bottom of the glass. When the whiskey glass is moved, the magnet will switch on each of the magnet switch arrays, sending a signal to PC 1 through the RS232 serial interface to give the position of the whiskey glass. Eventually, PC 1 sends a signal to the controller board (Fig. 7a), which will switch on the LED for the glass tracking mark (see Fig. 8 right). The glass tracking mark thus follows the whiskey glass.

4.4.2 Time-mark and Liveframe

Time-marks (see Figs. 3, 6) represent people and are recorded when they come to the place by specific RFID tag. For example, when a user comes to the space, the interactive table records the event by randomly stamping a time-mark on the table with an individual pattern. These time-mark patterns are projected through projector 01, which is controlled by the server. As time passes, the user's time-mark becomes fainter if he/she does not come back, which means that the user and the guest may be out of touch for a long time. Therefore, through the changes in the time-mark, one may be reminded to keep in touch with friends and family.

Liveframe is a digital frame, connected with PC 2, that can display photo slideshows or present static photos (see Fig. 6). The functions of the Liveframe include a photo browser (Fig. 9 left-b), drawing program (Fig. 9 right), and webcam. In the normal mode, users can browse photos by touching the screen directly. They can also draw or sketch on the Liveframe with their fingers (see Fig. 9 right). However, when the environment is changed to the bar mode, the Liveframe is controlled by the user's behavior. For instance, if the user moves the whiskey glass to each of the time-marks, he may be thinking of someone, so the person's photos are displayed in the Liveframe. PC 1 (server) senses the position of the whiskey glass and sends a signal to control PC 2 and trigger the Liveframe to display relevant photos. Although the user cannot meet his friends or family members immediately, he can reminisce about them through the photos on the Liveframe.

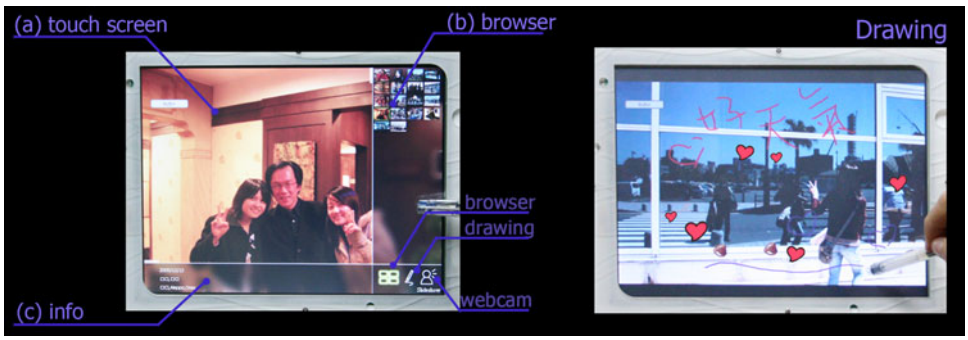


Fig. 9 Liveframe (*left* Liveframe diagram; *right* drawing demonstration)

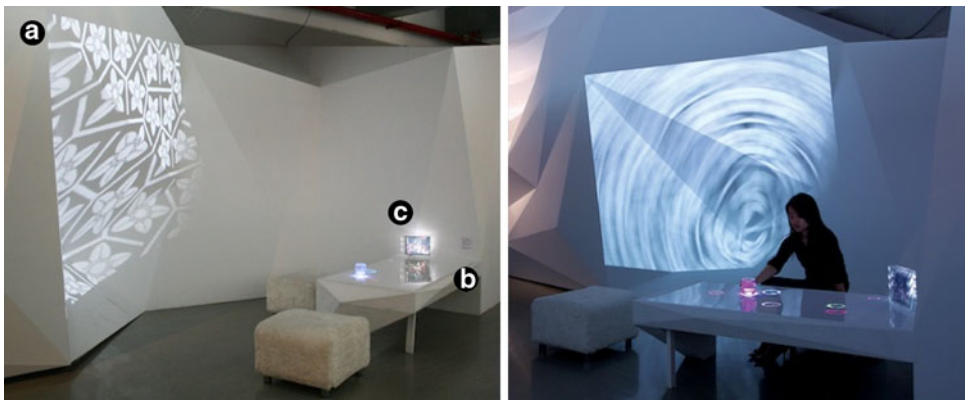


Fig. 10 Environmental atmosphere of bar mode. *Left* **a** animated wallpaper; **b** interactive table; **c** Liveframe; *right* system demonstration

4.4.3 *Environmental atmosphere control and music hot spot*

PC 3 cooperates with the environmental control, which includes lighting adjustment, wallpaper, and ambient music. In the normal mode, the environment is in its general state. When the user puts the whiskey glass on the interactive table, the environmental atmosphere will change into the bar mode. When the interactive table receives the commands, it sends a signal to PC 1, which then notifies PC 3 to change the environmental atmosphere. Simultaneously, the animated wallpaper (see Fig. 10a) will be projected onto the wall by PC 3 (see Fig. 4-bar mode). As the user drags the whiskey glass to the music hot spot, the music mode is switched on, and the space is filled with the user's favorite music. At the same time, the rhythm of the music is displayed on the interactive table (Fig. 4-music mode).

5 Evaluation

Time Home Pub is the practical realization of an imagined future smart home. As to the user's experience, this HCI embedded smart home enables people to experience the space which provides a natural connection between users, events, and time through daily use instruments. *Time Home Pub* is a preliminary prototype for future homes. And empirical evaluations will be based on visitors' opinions during the exhibition—*Architecture of Tomorrow* (see Fig. 11a). Also, the observations and interviews of visitors can efficiently evaluate the system concept, and test if this system adapts to real life.

5.1 User experience evaluation

In this section, two methods were used for the research: First, we collected observations about user experiences by noting their non-verbal expressions since some experiences are difficult to articulate. Second, we analyzed visitors' feedback and questions during the exhibition. Both methods can be analyzed from the user experiences of visitors' point of view, for example: How well did visitors become accustomed to this new environment? Furthermore, what did they think about the smart home? Was it fun? Non-intuitive? Or did they find it difficult to control?

5.2 Test scenario

The users' experiences of these features were evaluated with the following predefined scenario as was mentioned in the part 4.3.

- The user is asked to sit on the sofa.
- The user puts the whiskey glass onto the tea table, and simultaneously the time-marks emerge, which causes

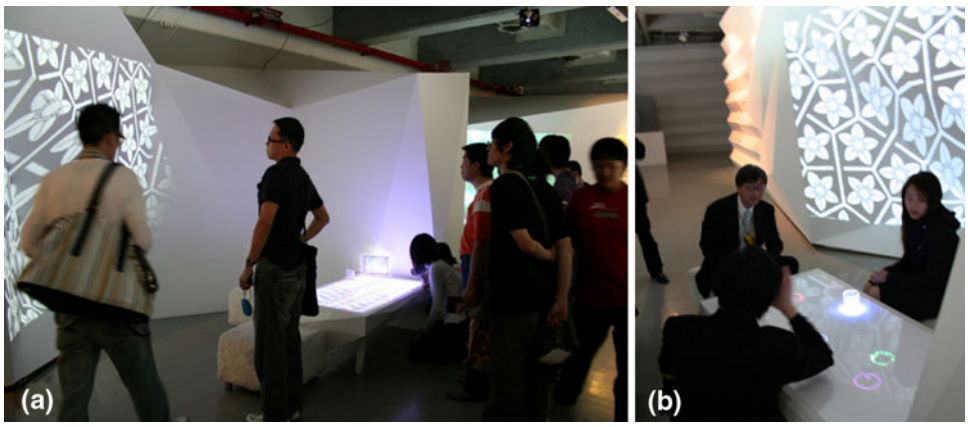


Fig. 11 **a** Visitors are experiencing bar mode and music mode by moving a whiskey glass on the table; **b** Japanese architect '*Toyo Ito*' visiting the exhibition. He highly complimented the future home concept!

the user to remember the friends and family that have previously used the table.

- The user then moves the glass onto each of the time-marks that represent his/her close friends or families. Liveframe then shows related photos in slides to trigger user's memories.
- Then the user moves the whiskey glass onto the music hot spot.

This scenario was created to test the whole system of *Time Home Pub*. It also allows us to evaluate user experience in the smart home. Although the user experience of *Time Home Pub* is slightly different compared to a traditional home, through the test scenario, we can observe if visitors adapt to a new environment without practice, and also if this smart home has a better communication channel than conventional home design.

5.3 Test methods and analysis

5.3.1 Test methods

Since *Time Home Pub* is a preliminary prototype, and this project was invited for exhibition in the Taipei Fine Arts Museum, the evaluation is based on the interviews and observations made during its 2 months of exhibition in 2007. The space of exhibition was a living room-like smart home. It had an open space and only two opposing walls, so visitors could enter the exhibition from different directions. There was a small instruction booklet of "*Time Home Pub*" attached on the side of a wall. However, sometimes visitors were not aware of the instructions and tried their own ways to experience the smart home. Thus, the analysis of the evaluation is divided into two parts (see Table 2): First, the visitors who followed the instructions to test the environment and second, the visitors who manipulated the environment without the aide of instructions. After experiencing the smart house, visitors were asked to talk about their opinions or pose questions about the system.

5.3.2 Analysis

For analysis, the interviews of visitors about their experiences can be separated into three kinds of issues (see Table 1):

5.3.2.1 Vision Most visitors were interested in this future home design. Through this test process, they could imagine future life and felt it inspired about their current lives. For example, some visitors expressed, "*I won't feel lonely when I drink whiskey. My home can be changed into a bar. It is so cool!*"; some visitors may ask "*Will* Time Home Pub *come true in the future? Or is it already a commercial product? Can I apply it to my home? How much does it cost?*" Compared to the visitors who did not read the instructions, visitors who did easily adapted to the scenario and asked further questions about feasibility. Therefore, the above questions implied that they really appreciated this project and also demonstrated that this project would work well if integrated into their daily lives.

5.3.2.2 Function In terms of functionality, some visitors embraced the idea of *Time Home Pub* quickly and found it easy to work with. Visitors also thought this smart home created a new vision of the future home, not only providing an emotional channel for space, but also enhancing the functions of elements. For example (Fig. 11b), Toyo Ito said: "*Oh! That's such a great design if I can drink with my old friend virtually…*" On the other hand, with the development of computational technology, people are more and more used to or even rely on constant digital information and technologies. Pertaining to this, some visitors asked questions such as, "*Can this system be applied to multi-users?*" or "*Why are there only three modes? Can I set other modes?*" In the future, our system can be modified through new generations of technology. In addition, some visitors asked: "*Could the equipment, whiskey glass, be substituted with normal mugs or specific glass is required to interact with the space?*" This project uses

Table 2 Study of *Time Home Pub* user experience during 2 months of exhibition in Taipei Fine Arts Museum

Visitors' experiences	Observation		Interviews by visitors	
Reading instructions	The illuminating tracking mark is following the whiskey glass when moving the glass; can I change tracking mark patterns or colors?	+ positive opinion	*Will Time Home Pub come true in the future?*	Vision
	Whiskey glass can be connected with the ambient environment, but this whiskey glass seems a little different from general glass		*Time Home Pub explored a new vision of future home that lets us imagine the future*	
	The ambient music was changed with moving the glass		*I will not feel lonely when I want a cup of drink even in my own place. My home can be changed into a bar, so cool!!*	
	The animated wallpaper and music suddenly disappear when I pick up the glass		*Is it already a commercial product? Can I apply it to my home? How much does it cost?*	
	It would be great if I could have this interactive table in my store. It must be something to attract many guests!!		*Can this smart home be available for multi-users?*	Functions
			What if I don't want the ambient change when I put the glass on the table?	
			Can I manually set different modes?	
			Toyo Ito: *Oh! That's such a great design if I can drink with my old friend virtually…*	
			Should I use specific whiskey glass or table?	
Without reading instructions	The whiskey glass seems to control the environment lighting and music…	− fair	*The whiskey glass seems to control the environment lighting and music…*	Vision
	The photos of Liveframe seem to be changed by moving the glass, but they don't exactly know the relationship between the table and photo frame.		*WOW!! The future living room lets us interact with our daily objects…see the animated wallpaper…*	
	Don't know how to make it work?	− negative	*Why does the glass control the ambient display and space music?* (It's not reasonable…)	Function issue
	The interactive table seems interesting, it displayed some patterns on the top of the table		*Does the rhythm flow of the interactive follow the music's tempo?*	
	Liveframe looks so pretty. It displayed someone's photos in slides	+ positive opinion	*Using two projectors in a room is wasting resources of a living environment. Do you think Time Home Pub cares about environmental protection?*	Others
	A beautiful animated lighting table with bar music…		*Price issues*	

custom-made glasses to interact with the space. However, the glasses could be substituted with the alternative technology such as pattern recognition [38] to recognize the different users and a variety of glasses.

5.3.2.3 Others Environmental protection issues were also raised by some visitors. The smart home may seem energy consuming since three computers and two projectors were used; however, this system is a preliminary prototype and can be improved by substitute technology. Some visitors were, furthermore, concerned about the cost of the construction and equipment of such a space. Nevertheless, these issues could be resolved after *Time Home Pub* becomes a popular commercial product.

In observations and interviews (see Table 1), the users generally provided more positive opinions than negative ones. Moreover, most visitors embraced experiencing *Time Home Pub*, especially the connection between time-marks (history), friends (human), and old photos (memories), which has never been realized in traditional architecture. Also visitors thought that it would be great if the space could create a better communication channel between space and user. These results demonstrate how space can serve as an important emotional communication interface to strengthen the relationship between dwellers.

6 Concluding remarks

With the emergence of computer technology, architecture design has been advanced to the next generation. This involves not only changes in building appearance but also new technology in the form of HCI software embedded into space design. Since people prefer to live different lifestyles, the design of a smart space has attracted great attention. Most new interfaces between human and space are difficult to use and need to be improved in order to enhance the experience of the dwellers. Further, some projects focus on creating a novel or complicated interface between user and devices but ignore the relationship between humans and the living environment. For examples, iBar counter has created an innovative form of

communication between people [31], but this system has difficulty recognizing different users. It can only have a single interaction between the glass and interactive table. The reacTable enables users to naturally control music by moving an object [24]. However, the controller is a specific pattern-attached object, and it could be improved if objects were devices used in daily life. Therefore, smart spaces not only provide more a natural communication between users and space, but their design must also take user-friendliness into consideration.

Thus, in order to make a space more "intelligent" and sense human touch, we implemented a new vision of smart space–*Time Home Pub*—which enables communication between physical environment, dwellers, and dwellers' memories. Preliminary evaluations by visitors during the exhibition demonstrate the satisfactory feasibility of the system and how space can be used as an important emotional communication interface to strengthen the relationships between people.

Although the installation of the system is difficult and complex (three computers, two projectors, and an interactive table are required), the research makes HCI devices "more human" and breaks the unfriendly boundary between human and space. Also, it visualizes the feedback of sensation, which helps to reduce loneliness and feelings of isolation. In the future, by adding more modes (such as game mode, dinner mode, and meeting mode) to adapt to different human activities, the system will become more variable and flexible, and spaces will become friendlier and more suitable to live in.

Acknowledgments The author would like to express her sincere gratitude to Professor Yu-Tung Liu for his comprehensive help and guidance. And thanks Professor June-Hao Hou who helped me a lot in National Chiao Tung University and all Aleppo*ZONE* team members who have been involved in the exhibition—*Architecture of Tomorrow*.

References

1. Sutherland I (1963) Sketchpad-A man-machine graphical communication system. Ph. D. Thesis. Massachusetts Institute of Technology, Cambridge
2. Liu YT (1996) Understanding of architecture in the computer era. Hu's, Taipei
3. Cache B (2002) Gottfried semper: stereotomy, biology and geometry. Archit Des 72:28–33
4. Liu YT, Lim CK (2006) New tectonics: a preliminary framework involving classic and digital thinking. Des Stud 27(3):267–307. doi:10.1016/j.destud.2005.11.008
5. Mitchell WJ (1998) Antitectonics: the poetics of virtuality. In: Beckmann J (ed) The virtual dimension: architecture, representation and crash culture. Princeton Architectural Press, New York, pp 205–217
6. Weiser M, Brown JS (1996) The coming age of calm technology. http://www.ubiq.com/hypertext/weiser/acmfuture2endnote.htm. Revised version of: Weiser & Brown. "Designing Calm Technology", PowerGrid Journal, v 1.01, http://powergrid.electriciti.com/1.01 (July 1996)
7. Gross MD (1998) Smart house and home automation technologies. In: van Vliet W (ed) Encyclopedia of housing. Sage, New York
8. Kidd CD, Orr R Abowd, GD, Atkeson CG, Essa IA, MacIntyre B, Mynatt E, Starner TE, Newstetter W (2002) The aware home: a living laboratory for ubiquitous computing research. In: Proceedings of the 18th national conference on artificial intelligence, pp 668–669
9. Bonanni L, Lee CH, Selker T (2005) Counter intelligence: augmented reality kitchen. CHI'05 extended abstracts on human factors in computing systems, pp 1228–1231
10. Coen M (1998) Design principles for intelligent environments. 15th National conference on artificial intelligence. AAAI Press, pp 547–554
11. Yang MH, Ahuja N (2001) Face detection and gesture recognition for human-computer interaction. Springer, Berlin. ISBN 9780792374091
12. Wolpaw J, Birbaumer N, McFarland D (2002) Brain-computer interfaces for communication and control. Clin Neurophysiol 113(2002):767–791
13. Negueruela C, Broschart M, Menon C et al (2010) Brain–computer interfaces for space applications. Pers Ubiquit Comput 15(5):527–537. doi:10.1007/s00779-010-0322-8
14. Orr RJ, Abowd GD (2000) The smart floor: a mechanism for natural user identification and tracking. In: Proceedings of the 2000 conference on human factors in computing systems (CHI 2000), The Hague, Netherlands, April 1–6, 2000
15. Huang YC (2006) A space make you lively: a brain-computer interface approach to smart space. In: Proceedings of the 11th international conference on computer aided architectural design research in Asia (CAADRIA 2006). Kumamoto, Japan, pp 303–312
16. Wickens CD, Holland JG (1994) Engineering psychology and human performance, 2nd edn. Prentice Hall, Upper Saddle River
17. Chang A, Resner B, Koerner B, Wang X, Ishii H. (2001) LumiTouch: an emotional communication device. CHI "01: CHI"01 extended abstracts on human factors in computing systems. ACM Request Permissions. doi:10.1145/634067.634252
18. Kim SH, Chung A, Ok JH, Myung IS, Kang H, Woo JK, Kim M (2004) Communication enhancer? Appliances for better communication in a family. Pers Ubiquit Comput 8(3–4):221–226. doi:10.1007/s00779-004-0281-z
19. Do JH, Jang H, Jung SH, Jung J, Bien Z (2005) Soft remote control system in the intelligent sweet home. In: Intelligent robots and systems, 2005 (IROS 2005). 2005 IEEE/RSJ international conference on, pp 3984–3989. Presented at the intelligent robots and systems, 2005 (IROS 2005). 2005 IEEE/RSJ international conference on. doi:10.1109/IROS.2005.1545302
20. Yang S, Do J, Jang H (2007) Human-friendly HCI method for the control of home appliance. Human interface and the management, Part I, HCII 2007. LNCS, vol 4557, pp 218–226
21. Huang YC (2011) How human-computer interface redefines original lifestyle in architecture. J Adv Mater Res 250–253: 1088–1097. doi:10.4028/www.scientific.net/AMR.250-253.1088
22. Ishii H, Ullmer B (1997) Tangible bits: towards seamless interfaces between people, bits and atoms. In: Proceedings of conference on human factors in computing systems CHI '97. ACM Press, pp 234–241
23. Ryokai K, Marti S, Ishii H (2005) Designing the world as your palette. In: Extended abstracts of conference on human factors in computing systems (CHI 2005)
24. Jorda S, Kaltenbrunner M, Geiger G, Bencina R (2005) reacTable. In: Proceeding of the international computer music conference (ICMC2005), Barcelona (Spain)

25. Schoch O (2006) Applying digital smart technologies for a sustainable architecture. In the Proceedings of the 11th international conference on computer aided architectural design research in Asia (CAADRIA 2006). Kumamoto, Japan, pp 261–268
26. Ataman O (2005) Smart architecture: integration of digital and building technologies. In: Proceedings of the 2005 annual conference of the association for computer aided design in architecture, ISavannah (Georgia) 13–16 October 2005, pp 259
27. Nakajima T, Fujinami K, Tokunaga E (2005) Building intelligent environments using smart daily objects and personal devices. In: CIT '06: Proceedings of the sixth IEEE international conference on computer and information technology (CIT'06)
28. iBar (2005) Intelligent surface system, mindstorm, http://www.i-bar.ch/en/info/, Accessed June 2007
29. Patten J, Recht B, Ishii H (2006) Interaction Techniques for Musical Performance with Tabletop Tangible Interfaces. Advances in Computer Entertainment 2006, June 14-16, Hollywood, California
30. Kim J, Zimmerman J (2006) Cherish: Smart digital photo frames for sharing social narratives at home. In: Proceeding of CHI2006, Montréal, Québec, Canada, pp 953–958
31. Mynatt EZ, Rowan J, Jacobs A, Craighill S (2001) Digital family portraits: supporting peace of mind for extended family members. Proc CHI 3(1):333–340
32. Ishii H (1997) tangible bits: tangible bits: towards seamless interfaces between people, bits and atoms. CHI 97 * 22–27 March 1997
33. Ishii H (2004) Bottles: a transparent interface as a tribute to Mark Weiser. IEICE Trans Inform Syst E87-D(6):1299–1311
34. Kobayashi K, Hirano M, Narita A, Ishii H (2003) A tangible interface for IP network simulation, CHI 2003, April 5–10, 2003, Ft. Lauderdale, Florida, USA
35. Chiu ML, Chiang B, Lee GC, Tseng H (2006) House sense: designing smart houses with intelligent interface design. In: Proceedings of the 11th international conference on computer aided architectural design research in Asia (CAADRIA 2006). Kumamoto, Japan, pp 313–323
36. Björkskog C (2007) Human computer interaction in smart homes. Retrieved August 1st, 2007, from http://www.hiit.fi/~oulasvir/58307110/smarthomes.pdf
37. Davidoff S, Lee MK, Zimmerman J, Dey AK (2006) Socially-aware requirements for a smart home. In Proceedings of the international symposium on intelligent environments, pp 45–48
38. Fukunaga K (1990) Introduction to Statistical Pattern Recognition, 2nd edn. Academic Press, Boston. ISBN 0-12-269851-7
39. Time Home Pub Scenario (2007) http://www.youtube.com/watch?v=Ntjzt_xM9bo&list=UUj1UxOtFGNbH865wq01y7gA&index=2&feature=plcp