Handbook of Research on Ambient Intelligence and Smart Environments:

Trends and Perspective

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Chapter 4
Embedding Context-Awareness into a Daily Object for Improved Information Awareness:
A Case Study Using a Mirror

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ABSTRACT

In this chapter, a case study on augmenting a daily object, mirror, for a contextual ambient display is presented. The mirror presents information relevant to a person who is standing and utilizing unshareable objects, e.g. a toothbrush, in front of it on the periphery of his/her field of vision. We investigated methods of interaction with the mirror by analyzing user preferences against contrastive functionalities. Experiments were conducted by a Wizard-of-Oz method and an in-situ experiment. The results showed that a short absence of the mirror function was not a big issue for the majority of participants once they were interested in presented information. The analysis also allowed us to specify requirements and further research questions in order to make an augmented mirror acceptable.

INTRODUCTION

One of the consequences of the convergence of pervasive technologies, including the miniaturization of computer-related technologies, the proliferation of wireless Internet, and advances in short-range radio connectivity, is the integration of processors and miniature sensors into everyday objects. Computing devices now pervade everyday life to the extent that users no longer think of them as separate entities. This development has revolutionized our

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perception of computing to the extent that we can now communicate directly with our belongings, including watches (Raghunath, 2000), umbrellas (Ambient Devices, 2004), clothes (Baurley, Brock, & Geelhoed, 2007), furniture (Kohtake et al., 2005) and shoes (Paradiso, Hsiao, & Benbasat, 2000). This allows us to acquire personalized information (meeting schedules, exercise logs) and use proactive information services (weather forecasting, stock prices, transportation news) in a timely fashion.

Major challenges in such technology-rich settings include perceiving information, facilitating sustained attention to information of interest, and maintaining awareness of changes in information in an unobtrusive way. Massive amounts of information have the potential to degrade daily living convenience or even create unsafe living conditions. Because of this, it is important to provide information in an appropriate way. This includes taking into consideration the proper media, timing, ease of understanding, location, identity, lifestyle, privacy concerns, and other factors where context-awareness plays a key role. A system that is aware of the context of a user's activities senses information related to a user (contextual information), after which it may (1) present information and services to a user, (2) automatically execute a service, or (3) tag context to information for later retrieval (Dey, 2000). Numerous studies have addressed the methods and effects of context-aware computing (Addlesee et al., 2001; Beigl, Gellersen, & Schmidt, 2001; Brumitt, Meyers, Krumm, Kern, & Shafer, 2000; Dey, 2000; Want, Hopper, Falcao, & Gibbons, 1992). We have been examining the information overload issues, and investigating sensing technologies, middlewares, and service models for many years (Fujinami & Nakajima, 2005; Kawsar, Fujinami, & Nakajima 2005; Fujinami & Nakajima, 2006; Kawsar, Nakajima, & Fujinami, 2008; Fujinami & Inagawa, 2009), where a daily object is used to obtain user contextual information and/or to present information or provide a service.

People normally use objects to perform specific tasks. For example, they use doors to enter or exit rooms. Sensing the usage state of an object by equipping it with a dedicated sensor (i.e., "door opened with inside doorknob"), allows a system to infer a user's current or upcoming action, such as "exiting the room". Possessing an understanding of a user's intention allows a system to take appropriate action that supports the task itself, or related tasks, without additional instructions from the user. The input to such a system is a user's normal activity. A human-computer interaction style that does not require an explicit user command is called implicit interaction (Schmidt, 2000) or background interaction (Hinckley et al., 2005). Furthermore, the sensing method is self-contained in an augmented object, and is thus lightweight, and no external infrastructure is required to determine a user's context. In contrast, other technologies that enable the same service, e.g., location tracking and video-based activity recognition (Harter, Hopper, Steggles, Ward, & Webster, 1999; Brumitt et al., 2000), require the addition of dedicated sensing devices to the environment.

We believe an augmented daily object not only has the potential to recognize the context of a user's activities, it can also assist by providing related information efficiently and effectively. In the case of the above-mentioned door, a display installed near the inside doorknob could be programmed to show the user a reminder to take mail to be posted. In this situation, a display would be situated at the periphery of the user's eyesight, thus allowing him or her to focus on the primary task at hand, which is exiting the room. The display only attracts primary attention when it is appropriate and necessary. Displays of this type are often referred to as peripheral (Matthews et al., 2004) or ambient displays (Wisneski et al., 1998). The challenge is to design the information display function in a way that avoids distracting or annoying the user. Accordingly, the usual manner of execution of a primary task should be respected while the context-enhanced value is being provided.

In this chapter, we present a case study on embedding context-aware features into a daily object, in this case a mirror, which has been augmented to support decision making at home, especially, in the morning. The design process, and evaluations on basic functions and interaction methods are then presented.

A MIRROR AS A PERIPHERAL INFORMATION DISPLAY

Humans have utilized mirrors since prehistoric times (Gregory, 1997). While normally used to examine the physical appearance of the person or object placed in front of it, a mirror can also be used to recognize and monitor objects and activities taking place in the background, such as people passing behind the user, or a boiling kettle. Additionally, people often spend a few moments in front of a mirror daily performing routine tasks such as drying hair, brushing teeth, etc., while thinking about topics relevant to their immediate concerns. These often include their schedule for the day, weather conditions at a travel destination, etc. This suggests that information could be conveyed by the surface of a mirror that incorporates a peripheral information display.

We propose a personalized peripheral information display called AwareMirror. AwareMirror is an augmented mirror that presents information relevant to the person in front of it, in anticipation of the fact that users may decide to modify their behavior once an unwanted/unknown situation is understood. This could be explained by a psychological notion called "objective self-awareness" (Duval, 1972), which is caused by the self-focusing stimulus induced by a mirror. Objective self-awareness is a state in which a person's consciousness is directed inward and the person begins evaluating his or her current state of being against an internal standard of correctness. In this state, the user tries to either avoid self-focusing stimuli, or to reduce a sensed negative discrepancy through changes in attitude or action. In addition to this natural and prominent effect of a mirror, we believe that information presented on the mirror surface could enhance objective self-awareness. This conclusion came from an assertion made by Pinhanez et al. in the context of a frameless display, which states, "positioning information near an object causes immediate, strong associations between the two" (Pinhanez & Podlaseck, 2005). Although their frameless display projected digital information on or near a physical object, we believe we could extend this idea to include information superimposed on the surface of a mirror because both the information and the user's reflected image would coexist on the same surface. Furthermore, we believe such superimposed information could affect a user more effectively than presenting information using a computer display installed separately near a mirror.

A similar mirror-based information system for supporting decision-making was proposed by Lashina (2004), using gestures and touch contact to manipulate presented information. Miragraphy, a mirror system developed by Hitachi Human-Interaction Laboratory, (Hitachi Human-Interaction Laboratory, 2006), provides involvement that is more active. Information and coordination options are displayed when the radio-frequency identification (RFID) tag of an individual piece of clothing is detected, after which clothing combinations that were previously captured by a video camera, are presented. To the best of our knowledge, a user must explicitly use the functions provided by these systems, which could be visualized as a gap between the user and the system. However, in our interaction method, the gap would be significantly smaller because AwareMirror is used as an extension of the normal activities that take place in front of a mirror. Philips Electronics N.V. released a commercial product, Mirror/TV, which consists of a versatile LCD display integrated into a mirror and which provides the core of an intelligent personal-care environment (Philips, 2007). Various ideas have been proposed for addition to the hardware platform, such as oral care coaching and mirror-integrated TV, "make-up" support. Although AwareMirror focuses on useful information for morning preparations, presenting information that could effectively increase health awareness or encourage improvements to bad habits might also be suitable for a mirror-based peripheral information display (Andrés del Valle & Opalach, 2005; Fujinami & Riekki, 2008).

In terms of information representation, peripheral displays are also used in workgroups during group awareness applications (Ferscha, Emsenhuber, & Schmitzberger, 2006), in physical space settings (Streitz, Rocker, Prante, Alphen, Stenzel, & Magerkurth, 2005), in enterprise applications for knowledge dissemination (McCarthy, Costa, Huang, & Tullio, 2001) or social applications like instant messaging (De Guzman, 2004), and disseminating information regarding family members (Mynatt, Rowan, Jacobs, & Craighill, 2001). The system developed by Rodenstein (1999) can also be categorized as an ambient display. These displays utilize transparency, which is the opposite feature of a mirror and the most significant characteristic of a window, to display information (such as short-term weather forecasts) concurrently with the image of an outdoor setting that would actually be visible if a window was installed at that location. Information visualization by artistic expressions such as Informative Art (Holmquist & Skog, 2003) and InfoCanvas (Stasko, Miller, Pousman, Plaue, & Ullah, 2004) can be considered "augmented paintings" that can be easily fitted into daily life. However, information presentation is the primary function of these systems, while AwareMirror has the specific restriction of maintaining a mirror's original function while offering additional value, i.e., personalized information.

A unique characteristic of AwareMirror is that it utilizes low-level sensing technologies and augments the function of a traditional mirror in a natural way. This is expected to eliminate feelings of obtrusiveness while minimizing the burden of information retrieval and comprehension. AwareMirror illustrates how computing capabilities can be incorporated into daily objects. In next section, the AwareMirror system design is explained.

DESIGNING AWAREMIRROR SYSTEM

Requirements

It is important to consider the usage context of a target object when proposing its augmentation. As the name implies, a daily object is one that has already been integrated into our daily lives, and large deviations involving such objects could cause users to reject the system. The system requirements we have specified, which are specific to a mirror and its installation location, are provided below (R1-R4):

- **R1:** Automatic start/finish presentation when certain conditions are satisfied
- **R2:** User identification that is implicit and natural, yet sensitive to feelings of privacy violation
- **R3:** Easy installation into daily living space
- **R4:** Information presentation without interfering with primary tasks and habitual activities

Information should appear and disappear automatically, so as to maintain the mirror's primary function and avoid turning it into a simple "display device" (R1). Accordingly, the system should identify the user without requiring any explicit action on his or her part. This calls for implicit interaction with the system. Additionally, this higher level of contextual information should be extracted without using privacy-intrusive sensing technologies (R2). While users naturally prefer to be presented with relevant contents at appropriate times, most would avoid using a vision-based service if it incorporated a visual imagery sensing technology because the video cameras used in such technologies cause feelings of privacy violation regardless of the actual data usage. This is because the area around a mirror is used for private activities, such as grooming and personal hygiene. Therefore, privacy requirements must be taken into consideration.

As for the third requirement (R3), easy installation is important because the system is intended for everyday use in locations where a large-scale installation would not be suitable. Finally, but also important, it is necessary to consider the characteristics of tasks or habitual activities conducted in front of a mirror when specifying the required information and display methods (R4). AwareMirror is a mirror, first of all, which means that users often perform their primary tasks, such as face washing, engaging in introspection while viewing themselves, or examining their faces, at times when they are not wearing their eyeglasses. In those situations, they might become aggravated if irrelevant information is displayed during the primary task. Furthermore, information displays should not disrupt the task at hand by taking excessive time to present information or by obscuring the user's mirror image with the superimposed information.

Design Principles and Approaches

The design principles necessary to fulfill the above requirements are (1) leveraging a usage state of an "unshared" object, (2) superimposing information with physical images, and (3) two-level information presentation. These are explained in subsequent subsections.

Utilization of an "Unshared" Object

Controlling the initiation and termination of presentation through the usage state of an "unshared" daily object satisfies the first two requirements (R1 and R2). Popular methods for identifying a person, or the timing at which to provide a service are as follows: (1) face recognition or gaze/head orientation detection by video imagery, (2) presenting an RFID tag that represents the user (or a target service), and (3) using biometric information such as finger/voiceprint. Biometric-based identification was not deemed appropriate, in this case, because a user would have to input a fingertip or speak into a sensor, which would violate the first requirement, "implicit and natural identification". The tag-based approach was rejected for the same reason. Video image captures were also deemed unsuitable due to the privacy violation concerned mentioned above. Since the popular methods were deemed unsuitable, we decided to introduce a fourth method. That is, monitoring the usage state of a daily object that is rarely shared with others, and which is normally used in conjunction with a mirror. Such daily objects include safety razors or electric shavers, toothbrushes, combs, etc. With these objects, the user is identified implicitly through its intended purpose once it is determined to be "in use" by an analyzing sensor, such as an accelerometer. In our study, we decided to use toothbrushes to detect users because they are gender neutral and are utilized by almost everyone. In later section, we will discuss a user survey regarding alternative identification methods such as image-based, tag-based, biometric-based, and sensor-augmented detection.

To present information effectively, a system of this nature also needs to ensure the toothbrush user is in front of a mirror. In our system, three types of information are integrated to detect a particular user's presence in front of the mirror. They are, (1) verifying a user's presence in front of the mirror with an infrared range finder (or a distance sensor), (2) proximity of the personal object (toothbrush) with the mirror, and (3) use of the personal object. When a person is detected in front of a mirror while a toothbrush is in use in the near vicinity of the same mirror, we assume that the person utilizing the toothbrush is identical to the person in front of a mirror. External information about the owner of the toothbrush enables identification of the person. Here, we also assume that a person in front of a mirror is looking into the mirror. Tracking a user's eyes might provide more precise detection points for timing purposes, but due to difficulties in installation and related costs, this feature is not feasible for most living environments. Furthermore, although significant effort has been applied to investigate practical tracking (Ohno & Mukawa, 2004), such sensing systems also require careful installation and calibration.

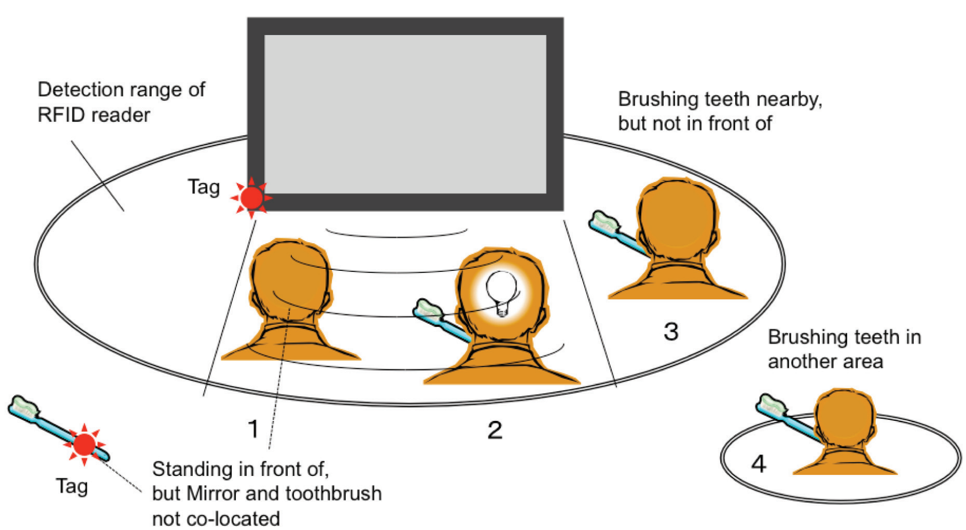
Figure 1 shows the four possible situations in which the AwareMirror system detects users. As shown in the figure, information is only provided to the user in Case 2, which satisfies the three above-mentioned conditions. Case 1 is not appropriate for presenting information because the user in front of the mirror is not using a toothbrush, while in Cases 3 and 4, the subject is using the toothbrush but is not in front of the mirror. Note that in Case 3, information for the person using the toothbrush near the mirror would be visible to any other person coming in front of the mirror later because the final condition (existence of a person in front of the mirror) would be satisfied. However, we consider this is a "rare case" since people tend to avoid close proximity with others during hygiene-related activities.

Superimposing Information with Physical Image Using a Two-Way Mirror

We considered three setup methods for displaying information on a mirror, i.e., superimposing information using reflected imagery. They were: (1) simulating a mirror using a video camera and a computer screen, (2) reflecting information on the opposite side of a mirror (such as the wall behind the user), and (3) using a two-way mirror and projecting information onto it from behind. Figure 2 shows these setup methods, each of which has advantages and disadvantages.

The simulation-based approach reproduces the function of a mirror by using image-processing techniques (Figure 2-(a)). This allows flexible mixing of information with a person's image and processing of the captured image. Applications for such mirrors include a simulation that makes the user look younger or older to encourage healthy-living (Andrés del Valle & Opalach, 2005)

Figure 1. User identification using low-level contextual information



and a makeup support system with automatic zoom/pan, lighting simulation, and other features (Iwabuchi, Nakagawa, & Siio, 2009). However, when considering screen resolution and real-time image rendering, along with the need to make images of the observed world consistent with the viewer's position, it is difficult to make a "virtual" mirror that is realistic enough for actual use (François & Kang, 2003).

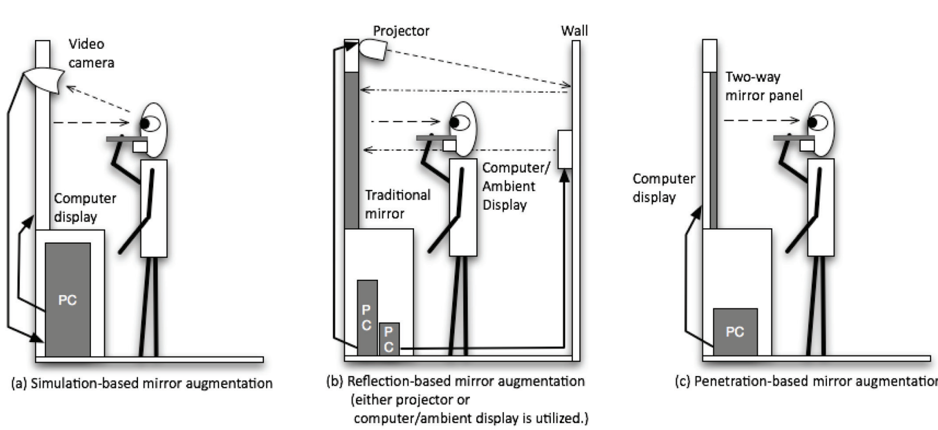
The reflection-based method does not require a special mirror (Figure 2-(b)). We developed this alternative version first using an array of LEDs that acts as indicators of two types of information attached to the front wall of an ordinary mirror. However, appropriate positioning of the display was required to prevent the LED display from being hidden by the user and persons crossing behind him or her. Furthermore, forcing the user to assume an unnatural position to see the content could induce the feeling of "being used by the system". Flexible projection systems like those proposed with steerable interfaces (Pingali et al., 2003) could allow the location of the presented information to be changed dynamically, but require a camera-based positioning system and extensive mechanical supports that are not suitable for daily living spaces.

The projection-based method requires a two-way mirror, with which the image and/or text displayed behind the mirror can be seen through the panel while physical objects in front of it are reflected as with an ordinary mirror (Figure 2-(c)). A two-way mirror is a translucent panel that reflects light from the brighter side when the light intensity difference between the two sides of the panel is significant. In other words, bright colors projected onto the panel from behind can be seen from the front, while a reflection of an object placed in front of the panel is seen in the areas that are dark behind the panel. Unlike the reflection-based method, we need not consider a person's position, even though a computer display needs to be installed behind the mirror panel. We adopted this approach to fulfill the third requirement (R3) and after considering recent advancements in thin, inexpensive computer display technologies.

Two-Level Information Presentation

If excessive or hard to understand information is presented, it could disturb a user and interfere with his or her primary task. Furthermore, it is important to ensure private information is safeguarded. Because of these factors, we decided to adopt a two-level information presentation

Figure 2. Three methods of superimposing information with physical images. Note that the size of the "PC" boxes indicate the amount of computational resources required for overall processing



system. At the first level, the AwareMirror system presents information in an abstract manner that the user can perceive in a glance. A second level, which provides information that is more detailed, is presented as text messages. In addition to the two presentation levels, AwareMirror has a default mode that does not display any information.

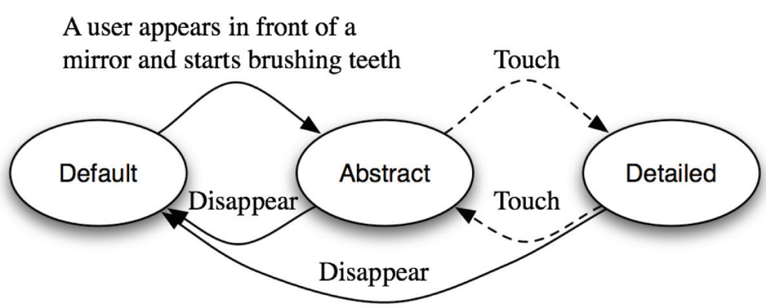
The transition between these three modes is illustrated in Figure 3, where the solid and dotted lines indicate automatic and manual transitions, respectively. When a user stands in front of an AwareMirror and the system detects a toothbrush in use, the system initiates the abstract mode. In this mode, AwareMirror assumes the role of a peripheral display and projects abstract information on the periphery of a user's field of view. Thus, in the abstract mode, AwareMirror can also be used as an ordinary mirror. Since some users do not wear their eyeglasses while brushing their teeth or washing their faces, and thus may not be able to read detailed information, abstract information is represented using familiar figures, colors or movements that can be readily understood, and which takes into account the characteristics of the location, i.e., in front of a mirror. However, we believe that it is useful for users to, at least, notice the availability of important information.

In the detailed mode, AwareMirror is explicitly used as a display rather than as a mirror. The system displays detailed information using text. However, presenting detailed information automatically runs the risk of violating our design philosophy, which is, keeping the original usage purpose of the mirror intact. Furthermore, if text messages are displayed suddenly, the detailed mode could also interrupt a user's primary task. To avoid this, AwareMirror requires the user to change modes manually. Only when the detailed mode is active does an AwareMirror become an information display instead of a mirror. We contend that this does not interrupt the user since the mode shift choice is voluntary.

Although the detailed mode has more information than the abstract mode, the AwareMirror system is not intended to provide a complete solution for our information acquisition requirements. In our daily lives, various types of media have already been developed to supply detailed information, such as TV/radio programs and the World Wide Web. We contend that presenting an excess amount of information would make the system excessively complex and thus unusable.

Once a user is identified and the information is presented, the information display remains visible even after the user finishes brushing his or her teeth. This is because while the toothbrush is used as a trigger to identify the user and start information presentation, the infrared sensor continues to detect the presence of the user even when he or she has stopped using the personal object. Both modes automatically return to the default mode when the infrared sensor no longer detects the

Figure 3. Transitions between default, abstract and detailed presentation modes: The solid and dashed lines indicate automatic and manual transitions, respectively



user. When describing the design heuristic of an ambient display, Mankoff et al. (2003) stated that a multi-level presentation approach should make it quick and easy for users to obtain information that is more detailed. The transition from abstract to detailed mode is achieved by an action with which a user can associate a separate action, in this case, "retrieving detailed information". Because of these features, the display allows easy access to information while minimizing interruptions to a user's primary task and while fitting naturally into daily living spaces.

PROTOTYPE IMPLEMENTATION

After presenting a usage scenario, the details of implementation, i.e., internal software components, augmentation of a mirror and a toothbrush, and presented contents, are explained.

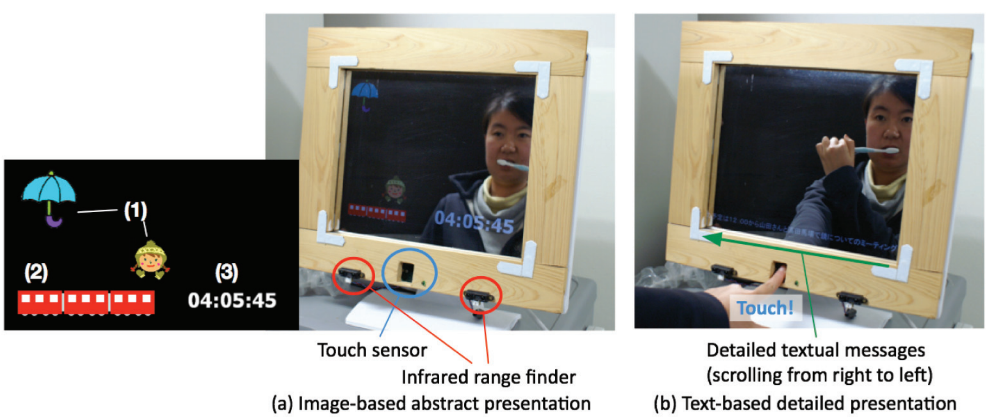
Using the AwareMirror System

Figure 4 demonstrates an AwareMirror usage scenario, where information related to the person in front of the mirror is displayed. In Figure 4-(a), a user is engaged in teeth brushing while perusing information displayed on the mirror at the periphery of his or her line of sight. This abstract representation of the implicit mode is initially displayed. In this case, which is based on the input schedule, it shows that (1) the weather forecast at the user's next destination is rainy (by displaying an image of an umbrella), (2) the maximum temperature at the destination is below 15 degrees Celsius (by displaying an image of a girl wearing gloves and a snow cap), (3) there are problems with rail transportation on the way to the appointment (by displaying a red train), and (4) the time remaining before the next scheduled appointment. Input scheduled appointment information is utilized as contextual information about future as well as present activities.

If the user wants to know more about the information presented in an abstract manner, he or she will suspend the current task (brushing teeth), and activate a touch sensor located the bottom of the mirror to further details (Figure 4-(b)). Then, the following text information scrolls from right to left repeatedly:

"The next appointment is [a meeting] with [Mr. Yama] to [discuss a mirror] at [12:00] at Tokyo station]. The weather (around Tokyo) is [rainy],

Figure 4. AwareMirror's (a) abstract and (b) detailed modes of presentation. Three types of information that support decision-making in front of a mirror are presented: (1) weather forecasting at a user's destination (state and maximum temperature), (2) state of the public transportation system to be taken, and (3) information about a user's next appointment (time to the event)



the maximum temperature is [10] degree's Celsius, and the probability of rainfall is [90]%. On your way to the next appointment, [the Central Line] is currently [not operating due to an accident]."

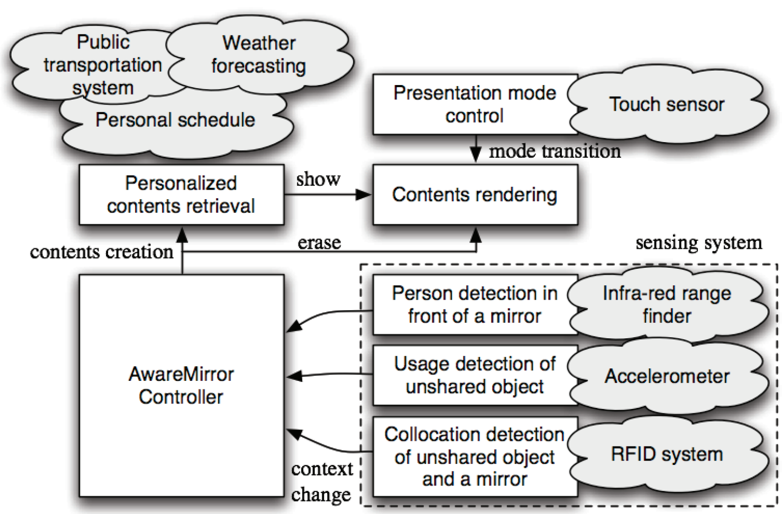
Note that the messages can be presented either in Japanese or in English, and the words in brackets are retrieved and set into template sentences from dedicated information sources described later. The information supports a person's ability to make decisions that are often made in front of a mirror in the morning. With it, users can be reminded to take an umbrella, locate a document necessary for a meeting, decide on an alternate route to a destination, or hurry to catch a train. Thus, AwareMirror provides a person with contextual information about present to future activities, first seamlessly (implicitly) and then explicitly, while preserving its traditional look and interaction mode of the mirror to the greatest extent possible.

System Components

As described in previous section, superimposing rendered information on the reflected physical image is achieved by attaching a two-way mirror to a computer display connected to a Windows-based PC that operates the functional components explained below. The relationship among the functional components (rectangle) and their implementation (clouds) is illustrated in Figure 5. The system consists of the sensing system, the AwareMirror Controller, personalized content retrieval as well as content rendering and presentation mode controlling components. The core function is the AwareMirror Controller, which accepts three source inputs from the sensing system to identify a person in front of the target mirror.

First, the existence of a possible user is detected by a change in the distance between the person and the mirror, which is determined by two infrared rangefinders. Such rangefinders can measure the distance to an object up to 80 cm from and within 5 degrees of the sensor. Accordingly, we situated two rangefinders side by side to extend the sensing area in a horizontal direction. The sensors are connected to the controlling PC with USB cables via Phidgets Interface Kit. As a second source input, a change in usage state of an accelerometer-augmented toothbrush is observed. The toothbrush is augmented with a Phidgets' 2-axes accelerometer connected to the

Figure 5. Functional components and AwareMirror implementation



same PC. Here, we defined the movement of a toothbrush with a certain variance in acceleration for a certain period of time as “brushing teeth”. To make the toothbrush a more reliable object for personal identification, the fact that the head of a toothbrush is actually inside the user’s mouth should be confirmed. However, after considering the difficulties involved in researching an ultra-small and safe chemical sensor to detect specific material in the mouth, we adopted a more approximate method for identifying teeth brushing. Since this component, the usage detector of an unshared object, hides the detail of sensing (such as chemical sensor and accelerometer), any unshared object that is augmented with a sensor could be easily incorporated into the system. Finally, when collocation of the mirror and the toothbrush is detected, a report is made to the controller component. In this situation, RFID tags are attached to both the mirror and a toothbrush, and an RFID tag reader is installed near the mirror. In our experimental environments, we utilized an active Spider III RFID system from RF Code Inc., which has a detection range about 3 m.

The AwareMirror Controller determines if the conditions for identifying a user are satisfied each time an event is updated. If they are satisfied, the component instructs the personalized content acquisition component to retrieve information about the owner of the toothbrush, after which, content is rendered in an abstract manner. If the person detection component reports that the person is no longer in front of the mirror, the AwareMirror Controller instructs the content rendering component to clear the presentation, which means AwareMirror reverts back to service as an ordinary mirror, which is the default mode. The presentation mode-controlling component uses a Phidgets-based touch sensor, to switch back and forth between the abstract and detailed information modes.

The abstraction, i.e. sensing, central controlling, contents acquisition, and presentation mode controlling components, make the AwareMirror system extensible with minimal alterations when a new sensor, information source, and/or presentation mode controller is needed. In actuality, different policies for the detailed mode rendering, as well as the controlling method of the presentation, were implemented and recorded for a later comparative study.

Contents

As shown in the usage scenario, we selected three types of information that can affect our behavior and support decision-making for display: (1) weather forecasts (forecast and temperature) at an intended destination, (2) the state of the user’s public transportation route, and (3) information on the user’s next appointment. All information types depend on the user’s personal schedule.

We then combined these content types to provide actual experiences during the in-situ experiments described in next section. In the prototype implementation phase, a user registers her schedule using an original Web-based scheduler in a structured manner. Once a user is identified, his or her next scheduled destination and the time of the appointment are extracted from the scheduler data. This data are then utilized as keys to obtain the weather forecasts. The system parses information from the weather portal service of Yahoo! Japan while the state of related public transportation systems is obtained by parsing actual railway company websites that report their operational states (mostly accidents).

The contents rendering component delivers the information using Adobe Flash Movie, which was selected because of its aesthetic features and ease of animation building. During the actual rendering, it was necessary to consider content colors because, due to the characteristics of a two-way mirror, dark colors are harder to see when projected through a translucent panel.

USER PREFERENCES FOR USER IDENTIFICATION METHOD

We then carried out a survey to determine the most preferable identification methods.

Profiles of Participants

The survey was conducted using questionnaires distributed among 50 people, 34 of which were members of the author's laboratory including one professor, four PhD students and 29 Masters Course and undergraduate students. Six of the 34 were female and approximately 10 were engaged in work on ubiquitous computing projects. The remaining 16 participants included five undergraduate students, five housewives, four company employees, and two artists ranging in age from 20 to 69.

Procedure

The four previously mentioned identification types were listed: (a) carrying an RFID tag that has a detection range of approximately 3 m (tag-based), (b) face recognition by video imagery (image-based), (c) usage state of a daily object that is rarely shared with others (augmented object-based), and (d) fingerprint or voice recognition (biometric-based). Since some participants were not familiar with these methods, we provided brief description of their general features, including principles, benefits and risks. Then, we asked them to compare the identification methods and assign a rank from 1 to 4, where 1 was the least preferred and 4 was the most preferred. Persons who choose (c) were also asked to identify which object would be most suitable for augmentation.

Results and Implications

Table 1 shows the median user preference score for each identification method. Note that the two central values are averaged if the number of the data is even. Larger values indicate that more participants preferred that method. The results indicate that a biometric-based method is the most preferred, while the imagery-based method is the least preferred. The biometric-based approach was preferred because the participants believe it would perform accurate identification and would not require them to manipulate anything. However, the method also requires explicit interaction with the system, such as putting a finger on a reader to identify a user. In contrast, as anticipated, the image-based method had the lowest preference total, because it engenders an obtrusive feeling of being observed, even though the respondents know that it requires no user input and that it can identify human activities, such as looking at a mirror. The natural characteristics of a washroom are considered likely to aggravate that sensitivity. As for the tag-based approach, participants liked the ability to control the timing of the information display, but they pointed out the possibilities to forgetting or misplacing the tag as a drawback of that approach.

They identified the merits of the augmented object-based approach as its implicit identification of the user through a daily object (such as a toothbrush) that is rarely shared with others. However, participants who specified a lower score emphasized the possibilities of intentional or unintentional use by other persons. We believe that utilizing the system in a reliable closed group, such as a family, would suppress the "misidentification" issue. Further, we believe that intentional misuse

Table 1. Participants' preferences for person identification method

Person identification method	Median of the preference score
Tag-based	2.5
Image-based	2
Augmented object-based	3
Biometric-based	4

rarely occurs and that potential feelings of privacy violation would be low if the object was used unintentionally.

Regarding daily objects that are seldom shared with others, toothbrushes were listed by most of the participants. Other objects include safety razors or electric shavers, towels, hairbrushes, and cosmetics. As described above, AwareMirror Controller separates the detection of an object from the underlying sensing technology. However, as some participants pointed out, a number of these personal objects, such as hairbrushes, might be habitually shared among family members. This indicates that the system needs to have a mechanism to gain a consensus on potential risks of sharing the object, which could be done when the object is associated with a person identifier for the first time.

COMPARATIVE STUDY ON INTERACTION METHODS WITH AWAREMIRROR

We conducted a comparative study with contrastive functions to confirm our augmentation rationale for a mirror, i.e. maintaining a mirror's primary function to the greatest extent possible while providing additional information.

Points of Comparison and Contrastive Functionalities

Contrastive functions were implemented, and tested along with the original ones. The points of the comparison are as follows:

C1: Automatic vs. manual activation of the first (abstract) scene
C2: Automatic vs. manual transition from abstract to detailed presentation
C3: Presence vs. absence of a mirror's primary function during the detailed presentation
C4: One-phase (textual message only) vs. two-phase information provision

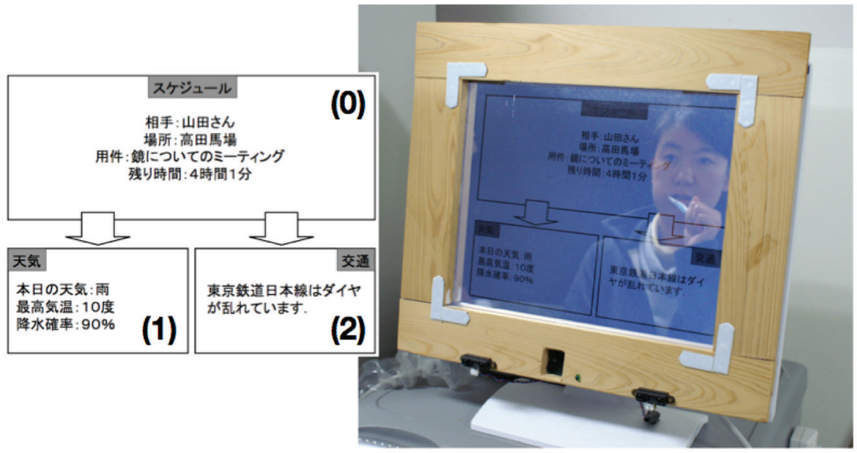
Regarding C1, to activate the first scenario, manual activation is realized by touching the same area as that used for mode transition, i.e. the touch sensor. This contrasts with the automatic activation that is invoked when the three conditions for user identification are satisfied. In the presentation mode transition (C2), the automatic transition presents the textual information 10 seconds later. In C3, a version that severely degrades the mirror function is achieved by displaying all messages simultaneously with black characters on a white background (Figure 6). This reduces the surface reflective characteristics of a two-way mirror. Therefore, the user's view is similar to that of a word processing or drawing application on a traditional computer screen, rather than that of a mirror. Finally, in C4, a two-phase information provision is compared to a textual message only function. Users indicate their preferences through voluntary utilization of these functions.

Methodology

The experiments were conducted using two approaches: a simulation-based experiment and an in-situ experiment. The former is often called the Wizard of Oz (WOz) approach (Kelley, 1984). An experimenter simulates the user identification process to obtain a comprehensive view from a relatively large number of participants at an early stage of prototype development. The simulation allows the elimination of the effect of the incomplete user identification component. In contrast, the in-situ experiment is intended to capture more detailed information through actual utilization of the system in a user's home, over a relatively long period of time. We adopted this approach to gain an understanding of the true utility and other qualitative values of our augmented system.

Fourteen participants were invited to the WOz-based experiment: 12 students who were

Figure 6. Contrastive rendering of the detailed presentation. Here, static text messages are displayed in black on a white background. (1) and (2) corresponds to the message in Figure 4 (b), while (0) indicates the details of a user's next appointment



not members of the author's laboratory (6 males and 6 females, in ages ranging from 18 to 29), one non-IT engineer (male, age 23), and one IT saleswoman (age 30). The simulation was conducted as follows. First, an experimenter provided a brief introduction of the system's functions. Next, participants were asked to imagine themselves standing in front of their washroom mirror in the morning. Then, each participant used the system by following instructions with the experimenter controlling situations where the participant experienced contrastive functions that were not fully operational. At the end of the experiment, the participants were asked to complete survey forms and were then interviewed regarding their answers.

Four people participated in the in-situ experiment. They included a family consisting of a 30-year-old female pianist, her 70-year-old artist father and her 63-year-old housewife mother, as well as an IT engineer (male, age 29) who was living alone. A working AwareMirror prototype was installed at both the family home and the single participant's home for 17 and 22 days, respectively. The prototypes were installed in the living room because of limited washroom space and because normal mirrors were already installed in both washrooms. During the experiment, the participants were asked to brush their teeth in front of AwareMirror, rather than in front of their washroom mirrors. They were further instructed to use all the system functions throughout the experimental period. The participants were also encouraged to change the properties for the different experimental conditions by themselves by means of a simple GUI and a user manual, in order to avoid intervention by the experimenter. Additionally, they were told to change the comparative functions immediately after the last utilization. This was done so that the subjects could focus on performing their primary task or using the function that was subject to evaluation. Thus, preparation for the experiment had to be completed beforehand. Finally, after the testing period, the participants' attitudes were evaluated using a questionnaire and through memos that they had written at various times during the experimental period.

Results and Implications

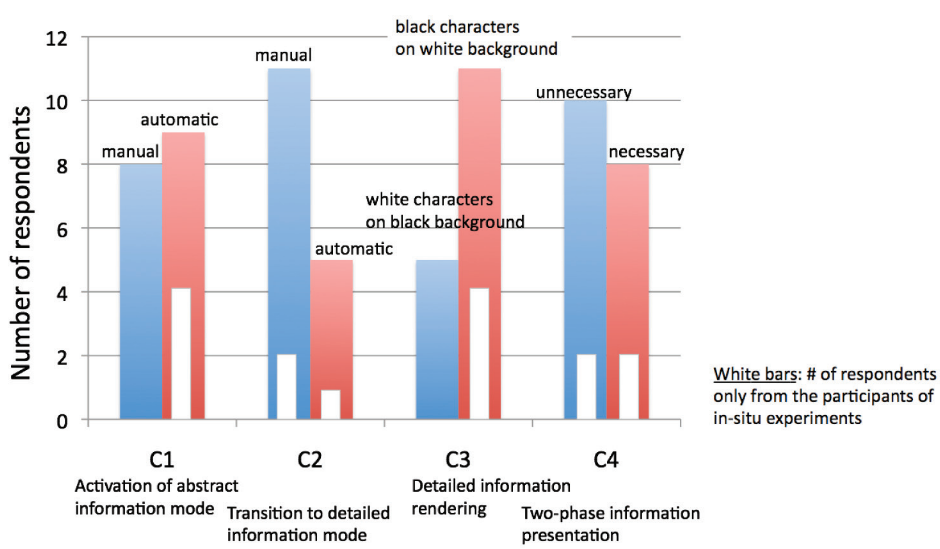
The results of both experiments are summarized in Figure 7. These results suggest that there was not a one-sided preference in the functionalities. For practical use, a preference management function needs to be integrated into the system. This is a very common approach in current software systems. For example, one can change the time a laptop PC will enter its sleep mode when it is not in use. In the remainder of this section, we show the preferences for each point of comparison (C1-C4), and explore both potential needs and issues.

Activation of Abstract Presentation Mode (C1)

Seven Participants (59.2%) preferred automatic activation that does not require any explicit invocation. The participants who supported automatic activation said that even simply touching the sensor was messy during a busy morning, and was easy to forget sometimes. Interestingly, all four participants from the in-situ experiments preferred this version. In contrast, the participants who preferred manual activation pointed out that they did not always need decision-making information. This normally arose from situations where they had no specific plans that required the decision-making information provided by AwareMirror. In such situations, the presented information became obtrusive even if it was restricted to image-based abstract information. Therefore, we believe that the system should filter out irrelevant information for users based on their preference, or, more intelligently, by analyzing the contents of information in terms of relevance and usefulness. For instance, it should be possible to set the system so that only a serious accident on a planned railway would be shown. These facts suggest that preserving a mirror's original function is of primary importance, at least initially.

The other interesting reason for not supporting automatic activation is that unreliable behavior of the system caused participants to reject proactive information provision. This situation arose due to a sensing subsystem failure. One participant complained that he had been surprised by the sudden activation of the abstract presentation mode at midnight, since he had not been brushing teeth, but simply looking at his face in the mirror at that time. Because he knew that the utilization of a

Figure 7. Summary of experimental results. Each bar indicates the number of the respondents who preferred a particular contrastive function for both WOz-style and in-situ experiments. The white bar shows the results of the in-situ experiment only



toothbrush was a condition of activation, he did not expect AwareMirror to display information at the time. This made him feel as if he was being monitored. Implicit interaction, an interaction paradigm that AwareMirror is employed, depends on various sensors and context recognition systems, which cannot always prevent misdetection of a user's context. We believe it would be more problematic if the system were activated improperly than would be the case if it did not activate when proper conditions were satisfied because users might experience anxiety about privacy violations. Also, it is more likely to be perceived by a user as a failure of a system than the case of "no-activation" since "no-activation" provides a user with a chance to initiate manually and thus might appease her frustration.

Transition to Detailed Presentation Mode (C2)

Eleven participants (68.8%) supported manual transition. The major reason for this preference was the feeling of being in control of the system. This requires active involvement with an (augmented) mirror that does not exist in relationships with normal mirrors. These participants indicated that they did not want to wait for the automatic transition (10 seconds) when there was something they wanted to know quickly, or that they did not want to see detailed information. Such user preferences were the reason for our two-level design philosophy.

In contrast, the participants who liked the automatic transition gave several reasons for not preferring the manual transition, i.e. not wanting to touch anything with wet hands or the feeling it was bothersome to change the mode by hand. We believe these were not affirmative preferences for automatic transition. Instead, they indicate the need for a new manual control method that takes into consideration the constraints of a washroom. Note that the system should be controlled in a robust manner with less burdensome controls than the present touch control, since some participant considered even such simple operation to be messy.

Detailed Information Rendering (C3)

The version displaying static textual messages in black characters on a white background (Figure 6) was preferred by 11 participants (68.8%) because they thought the information could be accessed easily. While some participants pointed out the loss of a mirror's reflective function during the full screen presentation, they also indicated that it did not matter to them since the time needed to check the detailed information was short due to its "at a glance" nature.

In contrast, the scrolling text version (Figure 4-(b)) requires a user to follow the message to the end, which means the user must pay attention for a longer period of time. Such users had to follow the scrolling text until the desired information appeared. This could take up to approximately 40 seconds. This suggests that the full screen version contributes to reducing the interruption into the primary task. This is important because, in the case of a manual transition from the abstract presentation mode, a user would become impatient if the system does not immediately supply the requested detailed information.

On the other hand, the participants who had negative impressions of the full screen version noted the superior clarity of the rendered information of the scrolling text version, i.e. black background version, compared to the white background version. This was because of the low contrast of the characters against the white background, which resulted from the characteristics of the two-way mirror used in our experiment. Generally, a two-way mirror does not transmit light completely, which made the text hard to read for some people. However, this situation would be improved if a high quality two-way mirror such as the one used in Philips Mirror TV (which "transfers close to 100 percent of the light through the reflective surface") was adopted.

Another participant preferred the scrolling text version because she wanted to see her face during the entire time she brushed her teeth. The scrolling text version presents information on the bottom of the display using white characters on a black background to maximize the reflective area. It seems the highest priority for this participant was to maintain mirror's original function. This emphasizes the need for a preference management facility that respects the user's relationship with the mirror.

Two-Phase Information Presentation (C4)

Ten participants (55.6%) considered the two-phase information presentation unnecessary. The major reasons were that either (1) they thought the information could sufficiently be represented by images, or (2), they felt that the presented images were of limited value. Four participants thought that only the first scene was needed. However, we believe it would be very difficult to render detailed information, such as the time, location and estimated recovery time for a train accident, with images alone. Accordingly, even the participants who considered the two-phase presentation to be useless might eventually be convinced of its necessity.

The people who participated to the in-situ experiment turned to the textual presentation mode when they actually wanted to know further details. Two of them changed their behavior twice based on information contained in the text displayed (once because of low temperatures and once because of an accident on public transportation). Such decision making support during an ordinary task is what AwareMirror was designed to achieve. However, the small number of supported events (twice) does not mean that the system did not support the users' decision-making process. We believe the small number came from the fact that we utilized real information sources rather than simulated ones. Additionally, the other two participants (the older parents) seldom rode trains or had appointments.

Other Implications

One participant looked forward to seeing the novel changes in the images. She was pleased with the fact that could find something different, rather than with the information itself. This aspect, pleasurability, has been ignored in favor of traditional "efficiency and productivity-focused" computing paradigms for work environments. However, pleasurability is gradually gathering attention as an important aspect for objects designed for daily use (Jordan 2002; Norman, 2003; Pousman et al., 2008). We believe that this additional value makes augmented objects more acceptable and may allow them to be more commercially successful. Therefore, other elements of acceptable "change" that increase a user's engagement with the system need to be investigated. The design space for such elements includes (1) level of expectation in the change itself, i.e. regular vs. irregular change, (2) level of anticipation in the content of changes, (3) level of ambiguity in the representation of changes, and (4) the relationship between the system and a user. A study on a "relational agent" (Bickmore & Picard, 2005) could contribute to fourth element investigations. Bickmore and Picard designed a relational agent as a computational entity that aims at establishing and maintaining long-term social-emotional relationships with users. A relational agent could be equipped with strategies that are often utilized in face-to-face communication, such as social dialogue, empathy dialogue, and humor. In our context, we believe a relational agent would actually be able to attract users to the augmented mirrors in anticipation of pleasurable or amusing experiences. This might also to make him or her more forgiving of unreliable behavior and help to maintain/regain the credibility of the system.

CONCLUSION

In this chapter, an augmented mirror, AwareMirror, was presented. AwareMirror is a mirror that not only reflects the appearance of a person who is standing in front of it, it also supports morning decision-making by providing information in context with the user's present or future actions. Three types of information were selected for inclusion based on the analysis of the cognitive tasks users perform when using a mirror, especially in the morning: (1) weather forecasts at an intended destination, (2) state of the user's public transportation system, and (3) information on the user's next appointment. The information reflects an individual schedule, which requires the system's ability to identify the user of the mirror without disturbing his or her primary task and without causing him or her to feel monitored. Based on these requirements, a combination of (1) a user's presence in front of the mirror, (2) coexistence of an unshared object (e.g., toothbrush) with the mirror, and (3) utilization of an unshared object in front of a mirror using noninvasive sensors was adopted. Hence, AwareMirror system embodies context-awareness both in sensing and in presenting contextual information. We designed user interaction with AwareMirror with the aim of balancing passive utilization of the normal mirror function with active involvement with its augmented functions. Two-level information presentation, the core of the balancing technique, was realized by an implicit activation with abstract representation (triggered by the implicit user identification) and explicit transition to detailed textual presentation (triggered by user input).

To confirm our augmentation rationale for a mirror, we fabricated a prototype system and carried out a survey for investigating preferable identification methods, and a comparative study with contrastive functions. The lessons learned as a result of the experiments are as follows:

- **L1:** Minimum information should be presented in a meaningful fashion.
- **L2:** The environmental constraints of the location where the system is installed should be taken into account when determining sensing and presenting modalities.
- **L3:** A mirror's reflective nature can become secondary once a user becomes interested in the presented information, and the system should be easy to use and useful in order for its eye-disruption characteristics to be accepted.
- **L4:** Improper detection of an activating event can make a user feel monitored.
- **L5:** Appealing element offers pleasurable experiences.

We need to evaluate the impact of context-aware objects on our daily lives over long periods of time. Various forms of informative media, such as TV and radio programs, are used on a daily basis and the relationship between these media and their users can be considered "steady." During the in-situ experiment, two of the four participants already received daily weather forecasting information prior to using AwareMirror. Thus, it would be interesting to investigate whether long-term use of peripheral displays would have an effect on their habits of utilizing those existing media. Further studies on peripheral display systems are required to investigate changes in (1) peripheral comprehension, (2) their life styles after utilizing the system for a long period of time, and (3) impression of the users on the systems when appealing/affective elements are properly adopted under imperfect context recognition conditions.

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KEY TERMS AND DEFINITIONS

Context Awareness: A system property that defines the capability of a system to handle context information of a user, a device, and/or a surrounding environment. Examples of context are the location and current activity of a person; remaining battery time of a mobile phone; the ambient light level of a room, etc. A context-aware system should support a user's decision making by extracting relevant and necessary information from complex and huge amount of data, should perform automated tasks on behalf of a user, and should make a user feel inconvenient and uncomfortable without it.

Implicit Interaction: A style of human-computer interaction that does not require explicit commands from a user, i.e., a system can take appropriate actions to support a user's primary task or related tasks autonomously. The input to such a system is usually the activity context of a user, and thus it is very natural to a user. In the implicit interaction paradigm, it is essential to consider the unobtrusiveness of the context acquisition as well as service provision mechanisms.

Augmented Daily Objects: A daily object that is augmented with a computational capability to obtain user context and/or present contextual information to a user. People normally use objects to perform specific tasks. For example, they use doors to enter or exit rooms. Sensing the usage state(s) of an object by equipping it with one or multiple dedicated sensors allows a system to infer a user's current or upcoming action. An augmented daily object is considered as the key element in an implicit interaction.

Peripheral/Ambient Display: A display situated at the periphery of human attention with abstract and aesthetic expressions. The display only attracts attention of a person when it is appropriate and necessary, which allows him or her to focus on the primary task at hand. The primary challenge is to design the display in a way that conveys important and just-in-time information without distracting and annoying the user.

Two-Way Mirror: A translucent panel that reflects light from the brighter side when the light intensity difference between the two sides of the panel is significant. In other words, bright colors projected onto the panel from behind can be seen from the front, while a reflection of an object placed in front of the panel is seen in the areas that are dark behind the panel.

Wizard of Oz Experiment: A simulation-based user experiment. A subject interacts with a system that he or she believes to be autonomous, while an unseen experimenter actually operates or partially operates the system. The functionality that an experimenter performs might be implemented later, yet the complete implementation is considered irrelevant to the goal of the study.

Personalization: In Human Computer Interaction, personalization is used to denote the system feature that enables a user to customize the behavior of a system in his/her own personalized way. It involves using technology to accommodate difference between individuals and to represent their uniqueness.