Designing Ambient and Personalised Displays to Encourage Healthier Lifestyles

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Abstract. In recent years, the deteriorations of living habits like immobilization or unhealthy diet are becoming serious social problems in many developed countries. Even if we know the importance, it is difficult to change our undesirable habits and to maintain a desirable lifestyle. Previous studies have suggested that persuasive technology can play a significant role in persuading individuals for behavioural change. In the article, we discuss the design of persuasive ambient displays aimed at addressing this issue borrowing theories from behavioural psychology . In our design, aesthetic and empathetic expressions are used to represent the visualisation reflecting behavioural feedback of an individual. If an individual's behaviour is leaned towards healthier lifestyle, the display expression is designed to boost his/her positive emotion where as display expression is progressively shifted to increase negative emotion of the individual if he/she does not sustain the desirable behaviour. In this paper, we introduce design principles of our approach and present four case studies to show the applicability of our approach. We also discuss a number of issues uncovered during the design and evaluation of these case studies.

Keywords. Ambient Display, Persuasive Technology, Personalisation, Better Lifestyle.

1. Introduction

While the purpose of technology is to bring about positive change in the world, some problems cannot be fixed by simply applying a technological solution. Problems that arise from people's choices and lifestyles are often more effectively addressed by altering human behaviour than by attempting to develop a technological fix. In practice, desirable lifestyle patterns may be challenging for individuals to realize. In these cases, technology can be applied indirectly as a tool to motivate behavioural change.Persuasive media such as books and pamphlets have been used to change people's attitudes and behaviour since ancient times. Recent advances in persuasive technologies such as the Web and mobile phones have had a strong impact on our daily lives [7]. Several previous approaches [14,15] have tried to change an individual's daily behaviour to motivate him/her towards a better lifestyle.

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The objective of our work is to design solutions for an open-ended target group to bring about lifestyle changes in mundane daily activities. We felt that in this area ubiquitous computing technologies could provide new possibilities. Ubiquitous computing is already used in areas such as health, hygiene and food safety to directly address and fix people's problems. We focused on areas where improvement requires a change in voluntary human behaviour. A key promise of ubiquitous computing is that it allows us to design systems that are almost invisible to the user. The systems can obtain input from sensors and computers embedded in everyday objects, and provide calm output through ambient displays integrated with the environment. Considering the ubiquity of such peripheral displays in our environment we see an interesting opportunity to motivate behavioural change for healthier lifestyle by combining persuasive technologies with peripheral displays. To this end, in this article we present an approach grounded to the theory of behavioural psychology to design ambient displays aimed at motivating individual for a healthier lifestyle. We used some basic tenets from operant conditioning [6] as a basic principle for changing a user's habits. The most obvious issue is that the system should include a feedback loop between the user's behaviour and the expression shown on an ambient display.

Expression has a role not only as a representer of information but also as an external motivator for the user's future action. A picture is originally designed to be watched and to have something attractive, but it is also suitable for information visualization [10]. One of the important challenges in ubiquitous computing is how to represent large amounts of information in a calm and unobtrusive manner. Aesthetic expression of the information is also important in order to accept ubiquitous computing technologies in our daily lives. Our approach enhances traditional ambient displays to claim that an ambient display can be used to persuade to change a user's undesirable habits, and keep desirable habits.

In this paper, we discuss how aesthetic and empathetic expressions are effective in persuading a user to change his undesirable habits. In the next section we describe existing behaviour-shaping technologies, and discuss their benefits and limitations. We then present the design principles of our approach discussing the rationales behind our design decisions. Section 4 presents four behavioural-shaping application case studies with ambient display system designed following our principles: Persuasive Art, Virtual Aquarium, Mona Lisa Bookshelf, and EcoIsland. After that we discuss a range of issues uncovered during our research. Finally section 6 concludes the paper with avenues of our future work.

2. Related Work

Even though successful specialized computerized solutions for motivating change in behaviour have been demonstrated, their adoption in everyday life remains scarce. The researchers who created Squire's Quest found that it was challenging to find time for the gaming sessions that were intended to alter behaviour [2]. The sessions would also likely have to be repeated in order to maintain the effect. Effecting additional changes, such as improving dental hygiene in addition to teaching better nutritional choices, would require a separate set of sessions. The time requirement placed on the user limits the applicability of this type of serious games for effecting changes in people's lifestyles.

Furthermore, in some areas there may be psychological limits to the ability of education alone to effect behavioural change. Even when a person full-well knows that a par-

ticular behaviour is detrimental enough to her long-term well-being to offset any possible short-term benefits, she may still irrationally choose the short-term indulgence. Examples of such behaviour include smoking, over-eating, under-exercising and poor personal care. Future consequences, while widely known, are easily ignored in the present.

To combat these behaviour patterns, commercial software solutions are available that operate on a principle different from education: they turn long-term effects into short-term feedback. For example, so-called "Quit Meters" [25] provide smokers with constant feedback on how much money is wasted and how many minutes of life are lost. "Carb Counters"[24] for Palm handheld devices provide instant feedback on meal choices. Compared to games, quit meters and carb counters do not require setting aside time for game sessions, as their use is intended to happen during normal daily activities. But the feedback they provide lacks the engagement and fun that games strive for, lessening their emotional impact.

Quit meters, carb counters and many lifestyle-shaping games suffer from problems created by self-reporting. Besides being burdensome and time-consuming, reporting one's behaviour to a machine in order to obtain feedback is unreliable: people are known to submit false data, both intentionally and due to cognitive biases. This hampers the system's ability to effect real change. 'Ere Be Dragons' [5] is an example of a serious game that utilizes passive sensors to observe user behaviour. The game's purpose is to encourage the players to partake in a healthy level of physical exercise. Users roam in an outdoor space while the game collects data from heart-rate sensors and GPS devices and renders the game world on a PDA screen. The only self-reported bit of information is player age. As a tool for effecting lifestyle change in mundane daily activities, the concept behind 'Ere Be Dragons' nevertheless suffers from the same problem as Squire's Quest: it requires setting aside significant time and space for gaming sessions. Ubiquitous computing and ambient interaction solutions are intended to relax the time-space requirements of interacting with a computer system. Such systems are integrated into daily environments and seek to utilize peripheral perception capacity to deliver information in an unobtrusive way. An example of this idea is found in the Informative art project, where both the appearance and physical role of information displays is designed to resemble paintings hanging on the wall [12]. However, ambient displays are typically used to deliver outside information to the user, from weather conditions to unread emails. In our work, the goal is to motivate desirable lifestyle changes by making boring tasks fun rather than by just presenting information.

3. Design Principles for Ambient Displays

Traditionally, computational interfaces are confined to conventional displays. However with the emergence of pervasive technologies, displays of different size, shape and form factor are being embedded into our everyday lives. Most of these displays aim to be ambient and peripheral in nature (thus drawing minimal attention) yet delivering the intended information elegantly. These displays, so-called *Ambient Displays* due to their inherent characteristics of being operational in our periphery suit perfectly as the interfaces for persuasive applications aimed at improving our everyday lifestyles. In this section, we discuss different design cardinals to construct ambient displays. However, before moving to the design discussion, lets us take a closer look at the process of behavioural change,

the primary objective of designing these displays in the context of this work. A better understanding of this process will assist us in addressing the issues that are critical for the successful design of these displays.

Exploring the psychological research, we observe that one of the pioneer model that describes the mechanics of intentional behaviour change is the Transtheoretical Model of Change (TTM). Proposed by Prochaska et. al., this model suggests that individuals experience a cycle of stages before achieving the intentional behaviours [27]. In detail, The Transtheoretical Model construes change as a process involving progress through a series of five stages : precontemplation, contemplation, preparation, action and maintenance - until they relinquish the undesired behaviours.

1. The first stage, pre-contemplation, is where individuals are unaware and uninformed of their problems and have no intention to change the behaviour.
2. In the next stage, contemplation, they are aware of the problem but yet not committed to take action to alter the behaviours.
3. In the preparation stage, individuals form intention and actively plan to take action to address the problematic behaviours.
4. The fourth stage, action is where individuals willingly and actively taking actions to change their behaviours.
5. The last stage is maintenance where individuals try to sustain their actions to keep the new behaviours.

We argue that TTM provides a sound indication of the mechanics of intentional behaviour change. Many people remain in the first two stages of the TTM model regarding problematic lifestyle and possess mental barriers that prevent them from understanding the issue or seeing the benefits of behaviour change. Ambient display as a channel for raising peripheral awareness can address these pre-action stages. In addition, an feedback mechanism that can reflect the impact of later stages can significantly contribute in motivating individuals to sustain healthier lifestyle.

Motivating humans can be classified into two approaches. One is to make users aware of their current situation and the other is to enhance the user's willingness to change his habits. Motivating a change of habits can also be classified into two types. The positive expression style increases a user's positive emotion to motivate a change in the user's undesirable habits. The user feels happy when changing his/her undesirable habits even if the change is challenging and hard. Another type is the negative expression style. This promotes negative emotion to feel a sense of crisis that motivates to change the user's undesirable habits. For instance, if a user looks at himself in a mirror and finds that he is significantly overweight, this may motivate him to do more exercise.

Accordingly, our design principles are primarily driven by ambient display strategies and ambient feedback strategies.

3.1. Ambient Display Strategies

Pousman et. al defined Ambient Information System as the system that [26]

1. Displays information that is important but not critical.
2. Can move from the periphery to the focus of attention and back again.
3. Focuses on the tangible, representations in the environment.
4. Provides subtle changes to reflect updates in information and

5. Is asthetically pleasing.

We agree with their understanding, and consequently have adopted their guidelines in our display strategies which are described in the following:

Representation Fidelity: A major challenge in designing ambient displays is the representation fidelity taking into account how individuals perceive information, mange to sustain attentive to information of interest available in our periphery, and remain aware of changes of information in an unobtrusive way. Too much information potentially degrade conveniences of our daily living, and this inconvenience might lead an individual to ignore the information completely. Henceforth, significant research efforts focused on finding the proper balance between perceptual complexity and information overload, making sure information is provided in an appropriate way. Consulting the theory of semiotics, we can observe three alternatives for representation: Indexical - direct representation, Iconic - representation through related metaphor and Symbolic - abstract representation. Although, a range of previous studies (including ours as we will discuss later in the case study sections) have designed ambient displays with iconic or abstract images [29,28], we consider the ideal design would be a hybrid one, where abstract or iconic representation would be primary visual element that is augmented with minimal indexical representation when needed, reducing the fidelity of information so that it is easier to perceive. This indexical information is particularly important to ensure the intelligibility of the system.

History: It is also important that the representation portrays the temporal gradient of their action so that individuals can apprehend the progress of their behavioural change mechanics. This is a challenging aspect particularly considering the representation fidelity we have discussed earlier. Depending of the visualization technique it might be possible to reflect the progress but for a convincing understanding, abstract and/or iconic representation is not often adequate. However, designing visualization with Indexical representation can address this issue. In this case, indexical representation over a time period might not be the primary display content, but could be invoked through user interaction.

Intelligibility: One of the limitations of ambient visualisation is that individuals might not understand why the particular visualisation is displayed and how it reflects his/her action. Of course with careful design it is possible to formulate a direct connection between users physical actions and corresponding digital representation, but more than often users will feel confused as well as frustrated if the representation is not intelligible enough [32]. Addressing this issue at the representation level is very complicated, and it is often needed that the ambient display system provides visual clue and in some cases clear explanation to users describing the meaning of the representation.

Personalization: Related to the intelligibility of the visualisation, it is also important to place users at the central of the control of the ambient display system. This is particularly important to enable users to personalize their visualisation that reflects their personal likings, taste and values. Personalization is a matured concept that have widely used in different application domain to provide adaptive, custom tailored output. In an ambient display systems designed for behaviour-shaping applications, it is important that users can personalize the visual output, this could be as simple as changing the colour, brightness,

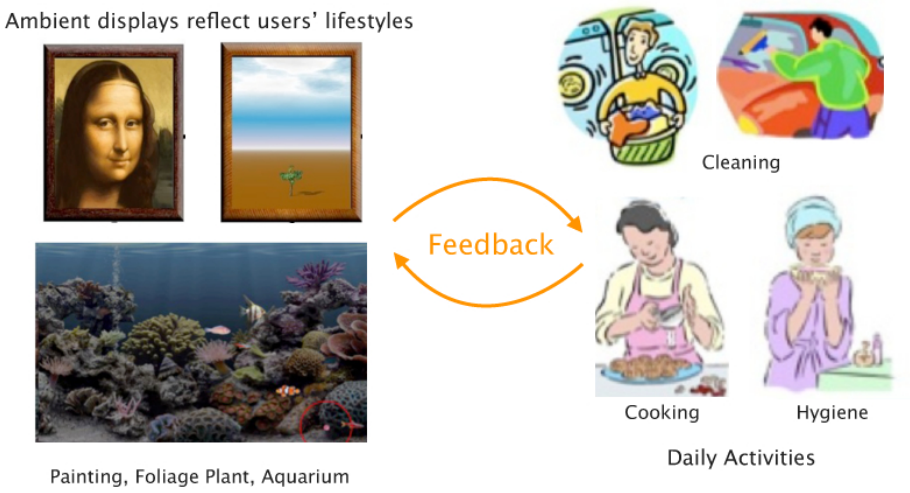

Figure 1. The ambient display system could be described as a kind of mirror, because it reflects something about the user. The display does not show the usual outward appearance, but reflects more personal facts that may otherwise go unnoticed.

transition effect etc., to more complex ones, e.g., modifying the underlying application policy, visualization technique, etc.

Emotional Engagement: The fact that the information is delivered in a non-disruptive way must not mean that it ends up being irrelevant to the user. To effect a change in behaviour in operant conditioning, we must be able to administer some sort of meaningful consequences to the user. We do not have means to effect changes in physical reality (such as threatening the user's family), so would it be possible to make the user care about changes in the internal state of a computer system? Computer games seem to be able to do this. Good games are able to provoke a range of emotional responses, from fun and satisfaction to guilt and discontent. By mimicking the techniques used in computer games, we should be able to build an emotionally engaging visual representation, allowing us to administer punishments and rewards without any physical resources. By "emotional engagement'" we do not necessarily mean strong and deep emotional responses, but the simple kicks that make many games interesting and addictive.

3.2. Ambient Feedback Strategy

Ambient feedback as shown in Fig. 1 is intended to be implemented using ubiquitous computing techniques, including sensors and ambient displays, but most implementation details are determined by the needs of a particular application and what behaviour it targets to satisfy the following principles below. To lend a solid framework for feedback design, we referred to elementary behavioural psychology. Behavioural psychology is a discipline dealing with the relationship between behaviour and consequences. It posits that

the form and frequency of behaviour can be affected by controlling the consequences. The principle to design the systems consists of the following three components.

Passive observation: One of the key factors limiting the applicability of the earlier solutions to our intended purpose is the various burdens they place on a user, either in the form of time use or effort. To avoid the burdens of self-reporting, the system should be able to passively observe the user's behaviour. To eliminate the need to set aside time or go to a special place, the system should be integrated with normal daily activities. Thus our first design principle is to use observations of the users' behaviour as the system's input, as opposed to using keystrokes or some other proxy behaviour. This also facilitates the delivery immediate feedback, a key factor in the effectiveness of operant conditioning.

Unobtrusive Feedback: To complete the integration of an ambient display into the user's daily living environment, we must also make sure that the notification mechanism of the feedback is appropriate. We refer to Mark Weiser's concept of calm technology: technology that is able to leverage our peripheral perception to deliver information, as opposed to constantly demanding direct attention [22]. Consulting the theory of attention management, we can categorise human attention into three types: inattention, focused attention and divided attention [30,31]. In inattention, objects might not be in our periphery but can still affect our behaviour (e.g., memory recall). In divided attention our attention is distributed over several objects whereas in focused attention, all our attention resources are dedicated on one stimulus. Considering the importance of information visualised in ambient displays we argue that feedback notifcation should operate in the degree of divided attention and should not consume entire attention space.

Focused Domain and Micro Activity: It is important the feedback is provided for a focused domain, and in principle for a micro activity. In some cases the activity might include multiple physical actions. If feedback is provided for multiple activities with an abstract representation it is often difficult to understand which activity is contributing to the visualisation and how. In addition, representing relationship effectively while ensuring the persuasive nature of the feedback is extremely difficult. As previous studies have discussed [33], it is very important to ensure that the feedback is provided for a focused domain so that representation is comprehensive to the users.

Feedback Logic The feedback logic determines the type of visualization that the system should be giving at any point in time. The decision is reached by comparing the userÕs pattern of behaviour, as reflected by the context information, with the desired "ideal" pattern. In principle, the closer the pattern is to the ideal, the more positive the feedback. The logic obviously depends on implementation and can be extremely complicated, in particular if it attempts to embrace a detailed psychological model. In operant conditioning, feedback content can be divided into reinforcement and punishment depending on whether behavior is encouraged or discouraged. Reinforcement and punishment are further divided into four types:

1. Positive reinforcement: encouraging a user's behaviour by providing a favourable stimulus in response to it.
2. Negative reinforcement: encouraging a user's behaviour by removing an averse stimulus in response to it.

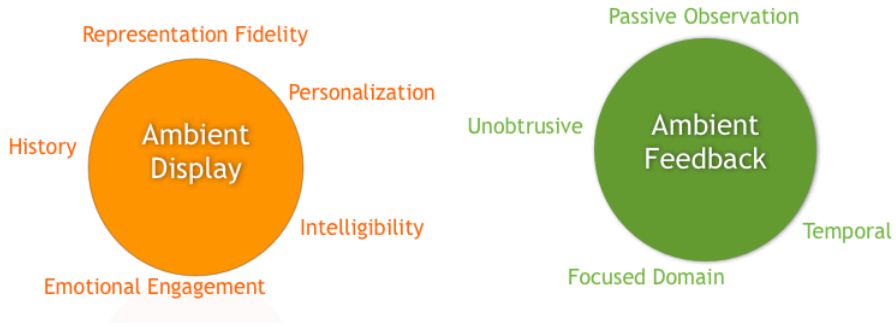

Figure 2. Design principles for Ambient and Personalised Displays.

3. Positive punishment: discouraging a user's behaviour by providing an averse stimulus in response to it.
4. Negative punishment: discouraging a user's behaviour by removing a favourable stimulus in response to it.

Another consideration in operant conditioning is scheduling: the temporal arrangement of stimuli in relation to behaviour. The feedback logic has to have a persistent state, so that it facilitates delayed, aggregated and scheduled feedback. In our design we have two types of feedback provision: "Immediate feedback" gives users an immediate clue on the desirability of their actions; "Accumulated feedback" may be used to reflect long-term consequences faster than the real long-term consequences of the behaviour would occur. It can also create an accumulated history for a behaviour that otherwise has little. For example, children (and adults, too) sometimes argue that cleaning one's room is futile, since it will be just as messy again the next week. This could be helped by keeping track of the number of times the room has been cleaned and presenting it in an engaging way. Instead of things seemingly returning to status quo, accumulated feedback shows that actions result in progress.

Figure 2 highlights the different cardinals of our design principles distributed across ambient display and feedback strategies. These design principles provide basic directives for designing ambient displays for behaviour-shaping applications. However, more situated strategy can be adopted in the design depending on the application context and the target activities.

4. Four Case Studies

In this section, we discuss four case studies where combinations of the design principles introduced in the previous section have been applied.

4.1. Persuasive Art

Decorating walls with pictures is common at home. Pictures are a very important way to increase aesthetic feeling in our daily lives. Persuasive Art uses a painting to motivate

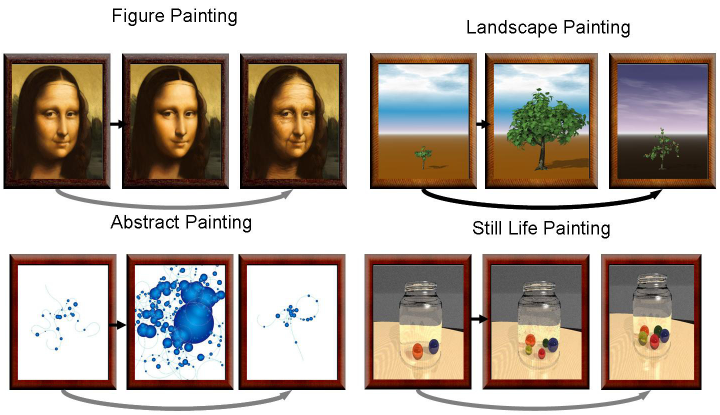

Figure 3. Four alternative Virtual Paintings for Persuasive Art

a user to walk at least 8000 steps every day to keep his/her fit. The number of steps are monitored automatically and stored into a computer. The painting shows the feedback of the current status of the user's exercise to motivate him to maintain desirable habits. Persuasive Art currently offers the following four paintings as shown in Fig. 3. The landscape painting includes a tree that grows and withers, The figure painting is Mona Lisa, the abstract painting has objects that change in size, and the still life picture contains changing number of orbs.

When using the landscape painting, the tree's growth is varied according to the user's behaviour. When the user maintains desirable habits by walking daily 8000 step or more, the tree will grow, but if he/she does walk enough, then the tree gradually dies. So, the basic metaphor here is that the increase of healthy activities makes the tree more healthy, but the neglect of the exercise lets the tree die. The other paintings are of similar strategy, i.e., Mona Lisa looks older, object size shrinks, and orb number reduces, all to reflect unhealthy behaviour.

This visualization tries to reduce the information fidelity by adopting a symbolic (abstract) representation, provides history through gradual transition, tends to be emotionally engaging and provides personalization features through multiple paintings. In addition, the metaphors used for the paintings are self explanatory thus exhibiting a minimum level of intelligibility.

The feedback strategy here is temporally accumulative, unobtrusive in the sense that the paintings do not provide too much information consequently draw less attention, and reflect one micro activity, i.e., number of walking steps which is observed passively through an on-body pedometer.

4.2. Virtual Aquarium

Virtual Aquarium shown in Fig. 4 has the objective of improving users' dental hygiene by promoting correct toothbrushing practices. The system is set up in the lavatory where it turns a mirror into a simulated aquarium. Fish living in the aquarium are affected by the users' toothbrushing activity. If users brush their teeth properly, the fish prosper and procreate. If not, they are weakened and may even perish.

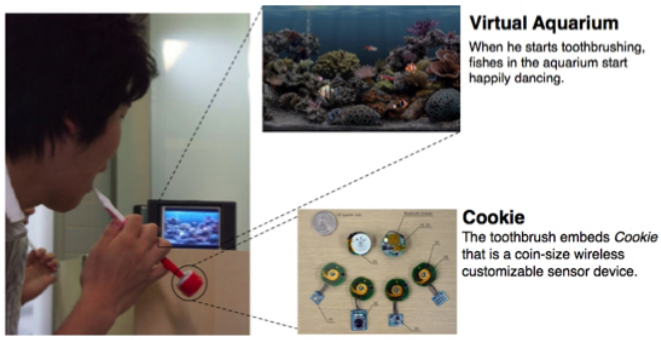

Figure 4. A user toothbrushing in front of a Virtual Aquarium. The toothbrush carries a wireless sensor device that tracks the users' activity.

Figure 5. Screen Images of Virtual Aquarium

In this system, we used a 3-axis accelerometer that is attached to each toothbrush in a household. Since toothbrushes are usually not shared and each accelerometer has a unique identification number, we are able to infer which user is using the system at a given time. Toothbrushing patterns are recognised by analysing the acceleration data. Fig. 4 shows a user brushing his teeth in front of the Virtual Aquarium using a sensor augmented toothbrush. The toothbrush is able to observe how a user brushes his/her teeth passively without requesting extra actions.

The objective of Virtual Aquarium is to promote good toothbrushing practices. In this application, the ideal behaviour was defined as follows: 1) users should brush their teeth at least twice per day; 2) one session should involve at least three minutes of brushing; and 3) brushing should involve patterns that ensure the teeth are properly cleaned. User behaviour is compared to this ideal and translated to feedback as described below.

When a user begins to brush her teeth, a scrub inside the aquarium starts cleaning algae off the aquarium wall. At the same time, a set of fish associated with the user starts moving in the aquarium in a playful manner. When the user has brushed for a sufficient time, the scrub finishes cleaning and the fishes' dance turns to a more elegant pattern. When the user finishes brushing, the fish end their dance and resume their normal activities. Both the activity of the fish and the movement of the scrub are designed in such a way as to give the user hints regarding the correct method of toothbrushing. The left picture in Fig. 5 shows a scene from the aquarium during brushing. However, if a user does not brush his/her teeth sufficiently, the aquarium becomes dirty, and the fishes in the aquarium become sick.

Figure 6. Mona Lisa Bookshelf prototype installation.

Figure 7. Two example outputs of the Mona Lisa Bookshelf. The image on the left shows that some books are tilted and in the wrong order. Some books are also missing. The image on the right side indicates that none of books have been picked up for a long time.

The fish's health is visibly affected by how clean the aquarium is. If a user neglects to brush her teeth, some fish fall ill and may even die. In contrast, faithful brushing may result in the fish laying eggs (The right picture in Fig. 5). At first, the eggs are not very likely to hatch. If the user continues to brush consistently for a number of days in row, the incubation ratio increases. This way, the accumulated feedback gives clues to the correct behaviour and attempts to maintain motivation over a period of time.

This aquarium visualization also tries to reduce the information fidelity by using symbolic (abstract) representation, provides history through gradual transition of the aquarium conditions, tends to be emotionally engaging and playful. In addition, the metaphors used for the aquarium is easy to co-relate with the activity in context, so we consider the application to be intelligible.

The feedback focuses on micro activity, i.e., toothbrushing and is both temporally immediate and accumulative. We also found the feedback to be unobtrusive in the sense that tooth brushing can easily be performed while looking at the aquarium as the feedback is immediate, individuals can actually use the aquarium as a mirror. Finally, the activity is tracked completely passively without any intervention from the user.

4.3. Mona Lisa Bookshelf

Resources shared by a number of people, such as a public toilet or a bookshelf in a research lab, tend to deteriorate quickly in a process called the tragedy of the commons. This happens because each individual derives a personal benefit from using the resource, while any costs are shared between all the users, leading to reckless use. Garret Hardin, the ecologist who popularized the concept, noted that this belongs to the category of problems that cannot be solved by technology alone, requiring instead a change in human

behavior [11]. Mona Lisa Bookshelf, is aimed at keeping a bookshelf organized. It tries to encourage users to keep books in order and to return missing books, but also to take books out every now and then for reading. Each book in the shelf is linked with a piece of a digital image of the Mona Lisa. Like a picture puzzle, the image changes according to how the books are positioned. A high-quality flat display placed near the bookshelf shows the image to the users.

The tracking of a user's behavior is based on optically detecting books in the shelf. In the prototype system, visual tags are attached to the spines of the books to facilitate their detection and identification. Visual tags are also attached to the corners of the shelf to determine its dimensions (Fig. 6(Left)). The detection system (Fig. 6(Middle)) comprises the following hardware: a digital video camera (iSight by Apple), a high-resolution digital camera (D50 by Nikon) and two infrared distance detectors (GP2D12 by SHARP). The distance sensors and the digital video camera are used to detect whether a user is manipulating books in the shelf. OpenCV, a real-time computer vision software library, is used to analyze the video signal. As soon as a user is seen leaving the shelf, the high-resolution still camera takes a picture of it and all the books contained within it. Images captured by the still camera are analyzed by the VisualCodes [20] software library, which recognizes the visual tags attached to the books. The system is shown installed in Fig. 6(Right). Each visual code yields data regarding its position, alignment and identity. This is then translated into context information that describes the bookshelf's width and height, which books are currently contained in shelf, and how they are aligned and ordered. This information is then passed to the feedback logic component. The above approach is able to observe how a user uses her bookshelf passively without requesting extra actions to play the game.

In this system, the feedback logic aims to encourage the following ideal behavior: 1) books should be arranged correctly and aligned neatly; and 2) at least one of the books should be read at least once per week. The correct arrangement of the books is pre-programmed, and could be e.g. alphabetical. User behavior is compared to this ideal, and translated to feedback as described below.

Mona Lisa Bookshelf also offers two expression styles to return feedback to a user to encourage cleaning his/her bookshelf or reading books in the following ways. When a book is removed from the shelf, the corresponding piece of the Mona Lisa image also disappears. If books are lying on their face or otherwise misaligned, the pieces of the image also become misaligned, distorting the picture. When the books are arranged neatly, Mona Lisa smiles contently. The assumption is that users are aware of how da Vinci's Mona Lisa is supposed to look like, and as when completing a picture puzzle, inherently prefer the correct solution to a distorted image. The feedback thus provides clues and motivation for keeping the bookshelf organized. The left picture in Fig. 7 shows and example of a distorted image. Also, if none of the books are removed from the shelf for over a week, Mona Lisa starts getting visibly older. The right picture shows and example of an aged portrait. As soon as one of the books is removed from the shelf, she regains her youth.

The Mona Lisa painting reduces the information fidelity by using symbolic (abstract) representation, provides history through gradual transition, aesthetically pleasing, emotionally engaging and playful. In addition, the metaphors used for the painting is easy to co-relate with the activity in context, i.e., organising the bookshelf , so we consider the application to be intelligible.

The feedback strategy used in this application is accumulative. The activity is tracked completely passively without any intervention from the user, thus letting users to focus primarily on the activity at hand. This contributes to the unobtrusiveness of the feedback. Finally, the feedback reflects the behaviour of one singular activity, i.e., organising the book shelf.

4.4. EcoIsland

Global warming caused by greenhouse gases released into the atmosphere through the actions of man is believed to be a major threat to the earth's ecology [13]. Efforts to reduce greenhouse gas emissions come in two forms: technological solutions and changes in human behavior. Technological solutions broadly include improving energy efficiency and developing cleaner energy sources. Dramatic changes in human behavior may also be necessary if catastrophic climate change is to be avoided.

Public and private efforts to change individual behavior towards more environmentally friendly practices usually rely on education, but there are psychological limits to the ability of education alone to effect behavioural change. Even when a person full-well knows that a particular behavior is detrimental enough to their long-term well-being to offset any possible short-term benefits, their may still irrationally choose the short-term indulgence. Future consequences, while widely known, are easily ignored in the present.

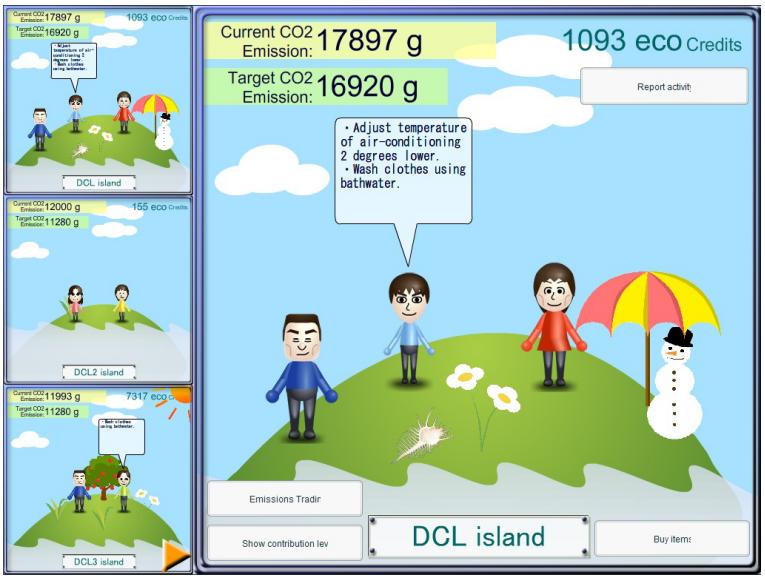

Figure 8. Some Screenshots of EcoIsland

EcoIsland is a game-like application intended to be used as a background activity by an ecologically minded family in the course of their normal daily activities. A display installed in the kitchen or another prominent place in the household presents a virtual island. Each family member is represented on the island by an avatar (Fig. 8). The family sets a target CO_2 emission level (e.g. national average minus 20%) and the system tracks their approximate current emissions using sensors and self-reported data. If the emissions

exceed the target level, the water around the island begins to rise, eventually sweeping away the avatars' possessions and resulting in a game over.

On their mobile phones, the participants have a list of actions that they may take to reduce the emissions: turning down the air conditioning by one degree, taking the train instead of the car, et cetera. Upon completing an action, a participant reports using the phone, and the water level reacts accordingly. Reported activities are also shown in speech bubbles above the corresponding avatars. A lack of activity causes the avatars to suggest actions. Participants can also see neighbouring islands and their activities in the display, and can list buy and sell offers for emission rights on a marketplace. Trading is conducted using a virtual currency obtained from a regular allowance. The credits are also used to buy improvements and decorations to the island, so successful sellers can afford to decorate their island more, while heavy emitters have to spend their allowance on emission rights.

The general approach from ambient lifestyle feedback systems is to provide a feedback loop for user behavior. The virtual island shown in the display acts as a metaphor and makes the participants conscious of the ecological consequences of their choices and activities. We also tap into social psychology, attempting to exploit *social facilitation* and *conforming behavior* to encourage the desired behavior. Social facilitation is the phenomenon where a person performs better at a task when someone else, e.g. a colleague or a supervisor, is watching [23]. Conforming behavior is the desire not to act against group consensus [1]. EcoIsland's design facilitates these by involving the whole family, and by presenting the participants' activity reports in the speech bubbles and providing contribution charts and activity histories. On the other hand, the fact that the game is played by a family unit instead of an individual means that participants can also agree to assign tasks to certain members.

Lastly, there is the trading system, which is based on the same principle as industry level emissions trading systems: reductions should be carried out in places where it is easiest to do so. A family that finds it easy to make significant reductions can sell emission rights to households that find it difficult due to e.g. location or job. This should make it possible to attain the same amount of total reductions with a lower total cost (measured in disutility), promoting use of the system.

The visualization used in this application is a combination of Iconic and Indexical, whereas the virtual island metaphorically represents our planet and the labelling within the visualization shows the actual data of the application. The visualization is aesthetically pleasing, emotionally engaging and playful as we have found from our studies. It also reflects the temporal gradient of the activity through progressive transition. In addition, the metaphors used is easy to co-relate with the activity in context, i.e., reducing carbon emission , so we consider the application to be intelligible.

The feedback strategy used in this application is accumulative. In this application the activity is tracked in both passively and through active participation of the users. This participation obviously reduces the degree of unobtrusiveness, however, as we discussed in the design section, tapping into Transtheoretical Model of Change (TTM) [27] we argue that this active participation in fact complements the later stages - preparation and action.

5. Some Experiences with Case Studies

Through the development of these ambient displays, over the years we have gained deeper insights on several issues that are significant for the design of future ambient displays aiming at persuasive applications. Drawing on our experiences in this section we discuss some of these issues which we consider could instigate further work in the field.

5.1. Sensing and Lightweight Interaction

Virtual Aquarium uses a 3D accelerometer to recognise the movement of the user's toothbrush to observe the userÕs behavior without his explicit interaction. Our experiences show that recognizing the user's behavior with sensors has its limitations in reliability. In Virtual Aquarium and Mona Lisa Bookshelf, we chose to analyze a very simple context that can be implemented in a reliable way. It is very difficult to analyze the user's behavior correctly without heavy-weighted algorithms. Thus, EcoIsland uses a self-reporting method to input what kind of actions the user takes in order to avoid complex behavior analysis.

EcoIsland encourages the user to input his actions to reduce CO_2 emission since he is recognized as an eco-conscious person. However, we believe that lightweight interaction techniques such as using gestures is important in order to compensate implicit interaction for realizing passive observation. The user will be able to input his current action with a minimum cognitive effort. Lightweight interaction can also be used to correct mistakes of behavior analysis. Gesture analysis is easier to compare than general behavior analysis. The combination of explicit interaction with gesture analysis and implicit interaction with sensor data analysis is a very interesting topic and has a critical role in our future researches.

One of the problems in the current case studies is that a user may cheat the analysis of the sensors consciously. For example, in Virtual Aquarium, some users imitated the movement of their toothbrushes in order to make the fishes dancing. There are two approaches to solve this problem. The first approach is to prohibit cheating by increasing the accuracy of the movement analysis. The second approach is to encourage the user not to cheat to use sensors. We are very interested in adopting the second approach in our future case studies. This approach requires the user to think about the merit behind the desirable lifestyle. How technologies can be used to encourage a user to think more deeply is a very challenging issue.

5.2. End User Involvement

As we have shown in all these case studies, one important element of designing ambient display systems is the instrumentation of everyday objects, e.g., toothbrush, bookshelf etc. This puts forth a range of unprecedented opportunities for end-users to manage, co-ordinate, and control these smart artefacts to realize unique, personalized and coordinated behaviour within and across devices that were not anticipated by the designers. For instance, an individual might be interested in using Persuasive Art for reflecting toothbrushing behaviour rather than Virtual Aquarium, or composing both. Another end-user might compose a small electrical appliance, e.g., an iron, a kettle, etc. with the Mona Lisa painting (e.g., increase in the energy consumption is reflects by ageing Mona

Lisa) to understand and compare its energy consumption to make informed decisions. Such possibilities of software driven personalized behaviour generation with ambient displays signify the transformation of our physical world into a programmable information space and can effectively increase the impact of these displays in changing problematic behaviour. While the technological building blocks for realizing programmable physical space is converging [35], there is a clear need to shift the focus onto end-users. It is essential to empower end-users with an appropriate capacity to program this interactive physical space and enable them to unleash computing enabled creativity capitalizing the possibilities offered by pervasive computing, and ideally this should be done in a Do-It-Yourself (DIY) fashion [34]. For the success of ambient display systems in motivating individual's behavioural change it is very crucial to involve end-users in display and feedback generation process as it is the people who occupy those environments and have the best knowledge about how their physical and computational environments should respond to their activities.

5.3. Persuasive Expression

The user study on Persuasive Art shows that users preferred the tree and the Mona Lisa over the abstract and the still life. The reason given was that more figurative paintings were considered to be more "intuitive". While any visual representation can be used to relay information, shapes that come with pre-attached meanings (e.g. "a tree withering is a negative thing") are more capable of evoking emotional engagement. It is therefore important to remember this third design principle when choosing a presentation metaphor. Tan and Cheok [21] showed that a real creature is found to arouse more empathy than a virtual creature. However, especially in Japan, people feel empathy also to virtual creatures. Fujinami [9] presented that Japanese users feel empathy for even virtual creatures represented as abstract symbols. We sometimes assign different meanings to a real creature and a virtual creature because we know the differences between them. We need to investigate the effect of virtual creatures as a persuasive expressions in future case studies.

In the future, it is necessary to consider how the feedback information appeals users without the explanation about the interpretation of the expressions because ambient lifestyle feedback information will appear anywhere to visualize a variety of aspects of our lifestyle. The metaphor visualizing a user's lifestyle helps him to notice the feedback information. The concept of affordance could be a guideline in designing linkages between activities and feedback. Product semantics [17] may be one suitable theory to help how feedback expression affords the meaning of the expression. A user sometimes mistakes to make the meaning of an expression, and this is one of the serious problem to rely on affordance. The user tends to define the non intentional meaning of an expression [3]. For example, an ugly picture may be used to discourage to keep the current undesirable habits, but the picture may encourage to keep the current undesirable habits for some avant-garde people. This is highly depending on the cultures and personalities of the users. It is not easy for a designer to assign a single meaning to a specific expression by all people. We believe that the expression of showing some virtual creatures is more acceptable to most of the people. Of course, each person may love different creatures. Empathetic feeling is a key to design successful ambient lifestyle feedback systems.

There are some very close systems to ambient lifestyle feedback systems. Playful toothbrush [4] shows a virtual teeth representing the current status of the user's tooth-

brushing. It explicitly shows the goals of the user's behavior. The user continues to use and enjoy the systems until he achieves the goal. However, motivating a user based on a long-term goal is important to maintain desirable lifestyle. The advanced motivation theories [19] help us to develop more effective case studies. It is useful to distinguish a short-term goal and a long-term goal to encourage the change away from undesirable habits and to keep desirable habits. In our case studies, Virtual Aquarium sets a short-term goal to complete sufficient toothbrushing in every night. On the other hand, EcoIsland sets a long-term goal to reduce CO_2 emission. Showing the explicit goal is effective to keep desirable habits until achieving the goal. The goal setting should be carefully designed so as not to stop desirable habits before achieving the goal. The combination of a short-term and a long-term goal is a very effective way to motivate a better lifestyle. Also, it is important to consider how to represent a goal in the expression. In Persuasive Art, the growth of the tree can be reinitialized every week to start a new goal, but it may reduce the sense of achievement in long-term. The relationship between the expression and goal setting should be investigated more in the near future.

5.4. Feedback Control and Emotion

In operant conditioning, feedback content can be divided into reinforcement and punishment depending on whether some behavior is encouraged or discouraged. Reinforcement and punishment are further divided into four types [6]: Positive Reinforcement, Negative Reinforcement, Positive Punishment, and Negative Punishment. Our case studies use the combination of the above four types of feedback. One of our finding is that the balance between positive reinforcement and positive punishment is very important in changing a user's behavior permanently. The user may be bored if the expression offers only positive reinforcement. On the other hand, the user may give up his hope to change undesirable habits when only positive punishment is offered. An appropriate balance is important in order to change the user's behavior permanently.

Jordan classified pleasure into four types: physio-pleasure, psycho-pleasure, socio-pleasure, ideo-pleasure [16]. This classification is a useful tool to design a reinforcement and a punishment. Physical comfort and discomfort are used as reinforcement and punishment to change the user's behavior. For example, a chair may change our comfortability by moving the backrest or arms. In the near future, we are interested in using physio-pleasure to design smart objects that change their shape according to the user's current behavior. In most of our case studies, the user's behavior is changed due to positive and negative emotion caused by the expression representing the user's current behavior. Dancing fishes make the user exited and increase his positive emotion, but when Mona Lisa is getting old, the negative emotion is increased and he feels anxious. Emotion is a very powerful tool to change a user's behavior [8] and we will try to develop a systematic way to use positive and negative emotions. We are going to enhance the use of social aspects into the feedback expression. If all people know the rules, the expression displayed in a public space would put interesting pressure on the user who is the target of the information. In EcoIsland, we have tried to use socio-pleasure as the feedback of the user's activities to reduce CO_2 emission. Social effects are an interesting tool in designing the feedback and need to be investigated more in the near future. Ideo-pleasure is interesting to be used to change the user's attitude in future case studies. The user's long-term good attitude will permanently change his undesirable habits and maintain his

desirable habits. Ideo-Pleasure makes it possible motivate the user by himself. He has a belief called self-efficacy that he will be able to achieve his goal. Contemporary arts make us to think deeply about our future like sustainability and peace in the world. We like to consider how to use the expression of contemporary arts to persuade the user to change his attitude in future case studies.

6. Conclusions and Future Directions

In our daily lives, most of our behavior do not return adequate feedbacks. If computer technologies help to return adequate feedbacks to the user, they make him aware of his current lifestyle and he can change undesirable habits and maintain desirable habits easily. In the paper, we introduced a brief overview of ambient lifestyle feedback systems and four case studies. Each case study gave us various insights and we showed several findings with the case studies.

Economic benefit is a strong incentive to motivate the user to change his behavior. We have introduced the "Eco credit" concept in EcoIsland. The user will be encouraged if he has an incentive to get a return for his effort or contribution to reduce CO_2 emission. The user's activities are monitored by the system and paid to users in order to stimulate their desirable actions. In EcoIsland, a user can use the credit to purchase decorating items or to trade eco-unconscious activities. Thus, the user will be both a consumer and a producer. We believe that we can accelerate the money circulation by adding economical concepts in ambient lifestyle feedback systems.

There are many places to encourage a user to change his/her behavior to motivate a better lifestyle. In our case studies, Persuasive Art and Virtual Aquarium assume that the systems are installed in the user's house. In the near future, our daily life was become more nomadic and we often stay in hotels for personal or business reasons. In this case, we cannot see the status of the tree or the dancing the fishes. Some participants in the user study in Virtual Aquarium told that they wanted to take care of the fishes even when they were not stay at home. Thus, we believe that the feedback should be reflected in many places such as hotels and public spaces. One of the problem to realize the goal is that the user needs to find which digital expression reflects the feedback of his behavior. However, if we can use a public display to show the feedback of the user's behavior, it makes it possible to use social factors as positive reinforcement and punishment. Ambient lifestyle feedback systems may be installed everywhere to enhance a variety of our daily activities in future, but we also need to consider whether this is our dream or just a nightmare. Is this really a better lifestyle for the future ? Also, using ambient lifestyle feedback systems everywhere may take control of our attitude, which may cause serious ethical problems. The user should have a right to control which behaviors are reflected in expressions. We also need to discuss who chooses expressions to reflect the user's behavior. Does the system choose expressions automatically ? Can the user choose expressions manually ? It is important to consider how to reflect the user's behavior when trying to change multiple behaviours at the same time.

References

[1] S.E. Asch, "Opinions and social pressure". *Scientific American*, pp. 31-35. 1955

[2] T.Baranowski, J. Baranowski, K.W. Cullen, T.Marsh, N.Islam, I.Zakeri, L.H.Morreale, and C.deMoor, "Squire's Quest! dietary outcome evaluation of a multimedia game", American Journal of Preventive Medicine, 24(1), 2003.

[3] U. Brandes, M. Erlhoff, "Non Intentional Design", daad, 2006.

[4] Y. Chang, J. Lo, C. Huang, N. Hsu, H. Chu, H. Wang, P. Chi, Y. Hsieh, "Playful toothbrush: UbiComp technology for teaching tooth brushing to kindergarten children",*In Proceedings of ACM CHI '08*, 2008.

[5] S.B.Davis, M.Moar, R.Jacobs, M.Watkins, C.Riddoch, and K.Cooke, "Ere be Dragons: Heart and Health", In Proceedings of PerGames 2006, 2006.

[6] M.P. Domjan, "The Principles of learning and behavior", Wadsworth, 5th edition, 2002.

[7] B.J. Fogg, "Persuasive technology: using to change what we think and do", Morgan Kaufmann, 2002.

[8] B.L. Fredrikson, "The Value of Positive Emotions: The emerging science of positive psychology is coming to understand why it's good to feel good", *American Scientist*, Vol.91, July-August, 2003.

[9] K. Fujinami and J. Riekki; ÒA Case Study on an Ambient Display as a Persuasive Medium for Exercise AwarenessÓ, *In Proceedings of the 3rd International Conference on Persuasive Technology*, 2008.

[10] L.Hallnas, J.Redstrom, ÒSlow technology - designing for reflection", *Personal and Ubiqutious Computing*, Vol.5, No.3, Springer, 2001.

[11] Garrett Hardin, "The tragedy of the commons", *Science*, 162:1243–1248, 1968.

[12] L.E.Holmquist and T.Skog, "Informative art: information visualization in everyday environments", *In Proceedings of GRAPHITE '03*, 2003.

[13] IPCC. *IPCC Fourth Assessment Report: Climate Change 2007*, http://www.ipcc.ch/

[14] S.S. Intille, J.Nawyn, and K.Larson, "Embedding behavior modification strategies into a consumer electronics device", *In Proceedings of Ubicomp '06*, 2006.

[15] N.Jafarinaimi, J.Forlizzi, A.Hurst, and J.Zimmerman, "Breakway: An ambient display designed to change human behavior", *In Proceedings of ACM CHI '05*, 2005.

[16] P.W. Jordan, "Designing pleasurable products: An introduction to the new human factors", Routledge, 2002.

[17] K.Krippendorff, "The semantic turn: an new foundation for design", CRC Press, 2005.

[18] T. Nakajima T., V. Lehdonvirta, E. Tokunaga, H. Kimura. "Reflecting Human Behavior to Motivate Desirable Lifestyle", *In Proceedings of ACM Designing Interactive Systems '08*, 2008.

[19] Johnmarshall Reeve, "Understanding Motivation and Emotion", Fourth Edition, Wiley, 2005.

[20] M.Rohs, "Visual code widgets for marker-based interaction", *In Proceedings of ICDCS Workshops: IWSAWC '05*, 2005.

[21] R.K.C. Tan and A.D. Cheok, "Empathetic Living Media", *In Proceedings of ACM Designing Interactive Systems '08*, 2008.

[22] M.Weiser and J.S.Brown, "Designing calm technology", December 21, 1995 [online, February 27, 2007], http://www.ubiq.com/hypertext/weiser/calmtech/calmtech.htm.

[23] Zajonc, R. B. Social facilitation. *Science*, pp. 149, 269-274. 1965

[24] List of diet and nutrition software for Palm [online, February 27, 2007], http://www.handango.com/SoftwareCatalog.jsp?siteId=1&platformId=1&N=96804+95712.

[25] List of quit smoking meters [online, February 27, 2007], http://www.ciggyfree.com/ODAT/index.php?option=com_content&task=view&id=205&Itemid=25.

[26] Z. Pousman, and J. Stasko. A taxonomy of ambient information systems: four patterns of design. *In Proc. of AVI 2006*, 2006.

[27] J. Prochaska and W. Velicer. The Transtheoretical Model of health behavior change. *Am. J. of Health Promotion*, 12(1):38Ð48, 1997.

[28] K. Kappel and T. Grechenig. Show-me: water consumption at a glance to promote water conservation in the shower. *In Proc. Persuasive Technology 2009* (2009), 1Ð6.

[29] J. Froehlich et al. UbiGreen: investigating a mobile tool for tracking and supporting green transportation habits. *In Proc. of CHI 2009* (2009), 1043Ð1052.

[30] A. Mack. ÒPerceptual organization and attention.*Cognitive Psychology.* 24:475-501. 1992.

[31] A. Treisman. Distributed attention. .*In Attention: Selection Awareness and Control* pp. 5-35. 1993.

[32] B. Y. Lim, A. K. Dey, D. Avrahami. Why and why not explanations improve the intelligibility of context-aware intelligent systems. *27th international conference on Human factors in computing systems (CHI*, 2009.

[33] A. Woodruff, J. Hasbrouck, and S. Augustin. A bright green perspective on sustainable choices. *CHI 2008* (2008), 313-322.

[34] F. Kawsar, K. Fujinami, T. Nakajima. Deploy Spontaneously: Supporting End-Users in Building and Enhancing a Smart Home; *The 10th International Conference on Ubiquitous Computing (Ubicomp 2008)*, pages 282-291

[35] F. Kawsar, K. Fujinami, T. Nakajima. A Document Centric Approach for Supporting Incremental Deployment of Pervasive Applications; *The 5th Annual International Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services (MobiQuitous 2008)*.