Digital-Physical Hybrid Design: Enhancing Real Worlds with Augmented Reality

Tatsuo Nakajima, Tetsuo Yamabe, Todorka Alexandrova, Mizuki Sakamoto

Waseda University
Department of Computer Science and Engineering
tatsuo@dcl.info.waseda.ac.jp

Abstract : *The paper discusses how we need to design our daily environments that various computing facilities are embodied. These computer-enhanced environments become more and more virtual, and may lose the reality. Therefore, it is important to take into account how to recover the reality of the virtualized real world. If not, a user may not be able to find the right semantics of the environments, and lose how he or she behaves in the environments. We believe that the discussion is very important to discuss the design of future cyber-physical systems.*

I Introduction

Our daily world becomes more and more virtual through the computers embedded into our daily life [5]. The virtualized real world reflects various information on any intelligent artifacts, and Web and SNS allow us to cooperate together in a virtual way; we can even exchange digital items with real money. Technologies have become mature enough to realize the virtualized real world. Sensors retrieve various information about the real world, and ubiquitous displays and projectors make it possible to offer various useful information to users.

Computation becomes a primary method to realize intelligent artifacts. The virtualization of the real world through computational materials makes the distance between artifacts disappears, and the communication within a community becomes more asynchronous. In addition, information reflecting the current situation is embodied in intelligent artifacts. There are many advantages in using a virtualized real world. Virtualization makes our real world more flexible, and there is a possibility to incorporate more trading and gamification aspects, which will encourage user's motivation in his/her daily life.

However, how to ``successfully`` and "harmoniously" design the virtualized real world remains an important and challenging issue. In order to suggest some clues to this problem, in this paper, we describe four case studies and based on the experiences of them, we are able to discuss and consider some good design implications for the virtualized real world.

In this paper, we described three case studies to consider how to design virtualized real world. The discussions in the paper will be useful to discuss to design virtualized the real world.

II Three Case Studies

II-A Persuasive Ambient Mirror

Virtual Aquarium is an artifact called a persuasive ambient mirror [6] that has been developed and has the objective of improving users' dental hygiene by promoting correct toothbrushing habits. It is set up in the lavatory where it turns a mirror into a simulated aquarium as shown in Figure 1. 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, the fish become unhealthy and may even perish.

In this persuasive ambient mirror, we use a 3-axis accelerometer sensor that is attached to each toothbrush in a household. A user brushes his teeth in front of *Virtual Aquarium* using a brush with a sensor attached. Since toothbrushes are usually not shared and each sensor has a unique identification number, we are able to infer which user is using the persuasive ambient mirror at a given time. Toothbrushing patterns are recognized by analyzing the acceleration data. The toothbrush is able to observe how the user brushes his/her teeth passively. This is the only interaction needed to use this persuasive ambient mirror.

In this case, the ideal user's behavior model is defined as follows: 1) a user brushes his/her teeth at least twice a day; 2) one session involves at least three minutes of brushing; and 3) brushing involves patterns that ensure the teeth are properly cleaned. Each user's behavior is compared to the ideal one and translated into a feedback as described below. We believe that the existence of an aquarium in the lavatory is not disturbing and unnatural, but enriches and improves our daily life.

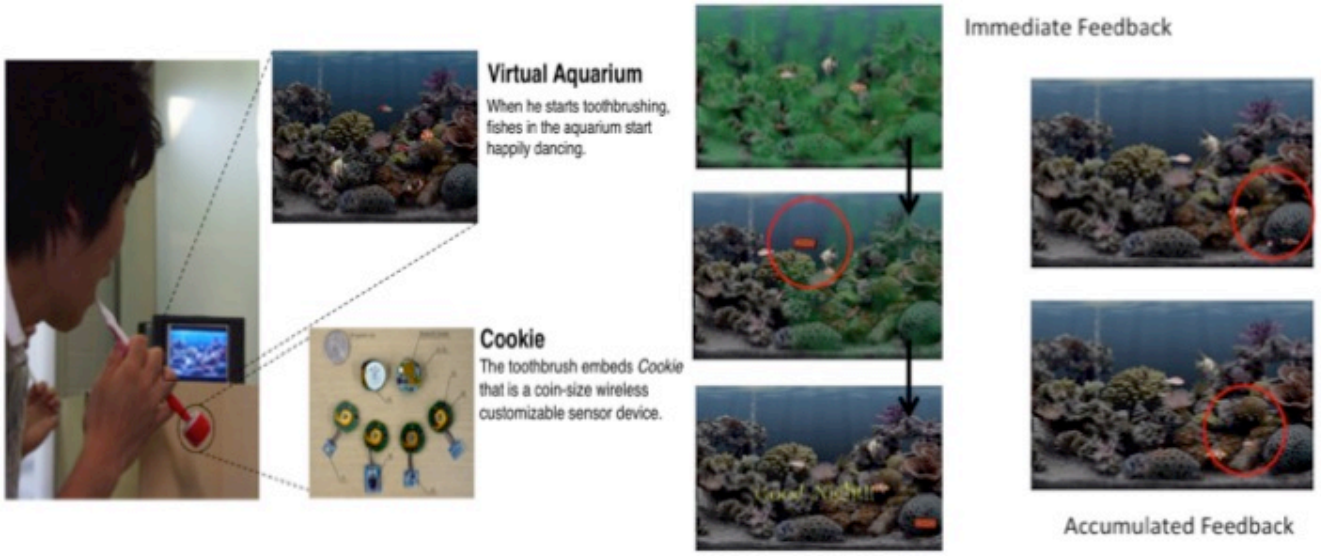

Figure 1: Virtual Aquarium System

As shown in Figure 1, when a user begins to brush his/her teeth, a scrub inside the aquarium starts cleaning the algae off the aquarium's 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 his/her teeth for a sufficient period of time, the scrub finishes cleaning and the fishes' dance becomes even more elegant. When the user finishes brushing, the fish end their dance and resume their normal activities. Both the activities 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. However, if a user does not brush his/her teeth sufficiently, the aquarium becomes dirty, and the fish in the aquarium become sick. The feedback information is returned immediately according to the movement of the user's toothbrush. We call this feedback *immediate feedback*.

The health of the fish is visibly affected by how clean the aquarium is. If the user neglects to brush his/her teeth properly, fish health worsens. In contrast, faithful brushing may result in the fish laying eggs as shown in the right pictures of Figure 1. At first, the eggs are not very likely to hatch. If the user continues to brush consistently for a number of days in a row, the incubation ratio increases. This way, the long-term feedback gives clues to the correct behavior and attempts to maintain motivation over a period of time. The long-term feedback is called *accumulated feedback*.

While designing the persuasive ambient mirror, we consider the association between a user's healthy lifestyle and the cleanness of the aquarium. Our design takes into account the fact that the user feels empathy for the virtual fish.

In our daily life, a mirror reflects our figure to show our appearance. The mirror allows us to know whether we are well or not, whether our makeup and clothes fit or not and so on, and has the power to make what is invisible from us visible. We believe that mirrors are adequate devices to reflect our current behavior that return immediate feedback on the current situation. *Virtual Aquarium* is a new type of mirror that reflects a user's current state, encourages him/her to change his/her behavior and motivates desirable lifestyle.

II-A Augmented Board Game

Go is a traditional board game for two players, where the goal is to occupy a larger portion on the board than the other player. Black and white stones are used to control the territory and a board with a grid of 19 x 19 lines is used as the game field. The rules of Go are relatively simple, but the underlying strategies are extremely complex and rich. As in chess and reversi, a numerous set of strategies have been invented to reduce the complexity, but studying them requires the player to actually understand the strategic concepts. Thus, it takes a long time for a beginner to play well with an experienced player and to feel pleasure during the play. *Augmented Go* supports several gaming modes to play a game. The basic idea is to offer useful information to beginners without extra interactions and intrusive devices as shown in Figure 2. Proactive feedback information is offered visually by superimposing guidance information onto the Go board by a projector. A web camera connected to a personal computer is used to detect the position of each Go stone. The OpenCV library is used for visual analysis and the core logic of the enhanced artifact generates information presented to the players according to the current game situation.

The system supports several gaming modes. As shown in Figure 2-(a), players can interact with the artifact by placing Go stones on a menu that is projected onto a board. We explain some of the modes and how players

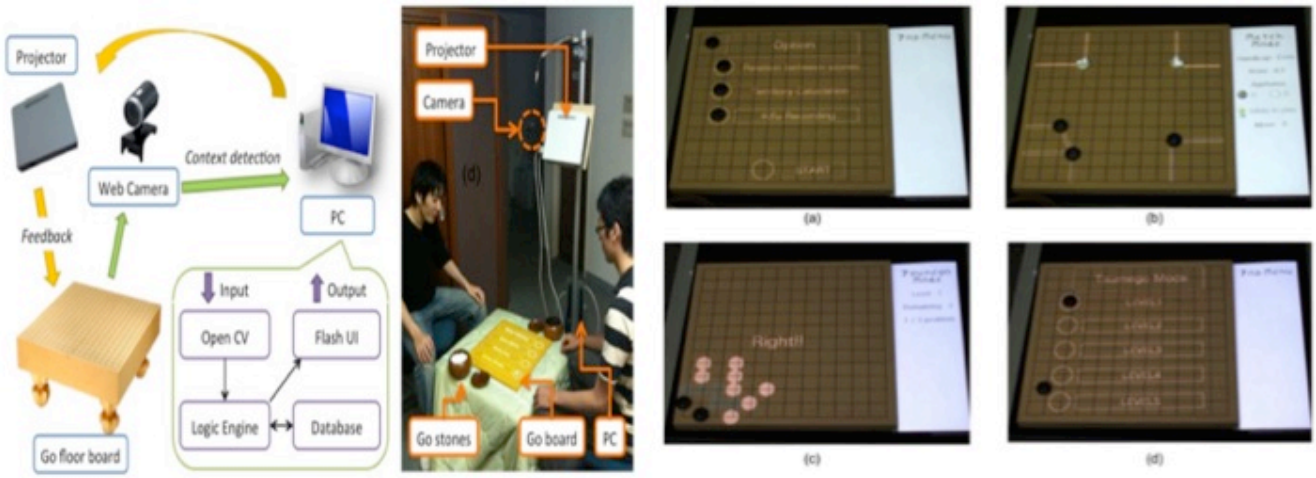

Figure 2: Augmented Go System

interact with *Augmented Go*.

Normal Play mode: The normal play mode is the basic form of the Go augmentation. In this mode, two players play Go as usual, but useful information is projected on the board to help beginners recognize the situation and make better decisions. The rules of Go are simple, but the vast number of possible moves in each turn makes it hard for beginners to make decisions. Moreover, on the large 19x19 board, beginners tend to concentrate on localized fighting in a narrow region and lose the big picture. It is difficult to recognize invaded areas, since an invasion process gradually progresses as new stones are put on the board. For choosing good offense and defense strategies, recognizing the links between the Go stones is important, but it requires some skills. Moreover, the normal play mode visualizes the strength of links between the Go stones. As shown in Figure 2-(b), same-colored stones are connected with lines. If a dangerous situation occurs somewhere on the board, a warning message appears for the players to avoid losing the area. The sequence of stone moves is also recorded into the database, which facilitates replaying the game for self-training. Replaying allows us to review and analyze the play by projecting the stones on the board later.

Tsumego mode: Tsumego is a type of exercise where the player is given a game board situation. The aim is to find the best sequence of stones' placement in a given board situation. In this mode, the positions of the stones are visualized on the board. Players can try different moves by placing stones on the board, with the results and comments explaining key important points displayed as visual feedback (Figure 2-(c)). The Tsumego mode prepares questions for a player with different skill levels, and the level of difficulty can be selected in the menu.(Figure 2-(d)).

The advantage of our approach is to allow players to receive information through the normal interaction with the Go board and the stones. By superimposing information onto the board, players can concentrate on the normal play or self-training without fragmenting their attention by taking an instructional book and etc. into their hands. This is important to make it possible for the players to allocate enough cognitive resources for understanding the current situations in the game.

II-C Augmented Trading Card Game

A trading card game is also commonly referred to as a collectible card game, a customizable card game, or CCG. For our purposes here, we will use trading card game (TCG) to refer to all the three varieties of games. In a nutshell, a TCG combines the collectability of trading cards with strategic game play. Typically a player purchases a starter set, containing a playable deck of cards and a manual that includes an explanation of the rules and the mechanics of the game in an introductory fashion. One of the biggest problems faced by any new TCG player is the need for an opponent to truly engage in the game play, as it is extremely unusual for any TCG to feature a solitaire mode. Players usually begin playing with a friend, at a particular location such as a hobby game store that offers organized gaming opportunities and includes a tutorial component, or via an online portal.

Computer-based TCG is also becoming popular, and in our project we make a comparison between the real TCG[1] and its virtual one running on Nintendo DS [7]. An important conclusion resulting from that comparison is that the computer-based TCG loses a lot of realities offered by the real TCG. For example, the sense of real cards is essential for many TCG players since making and completing collections of cards is a significant fount of pleasure for them. Also, the computer-based TCG implies some communication limitations, because it allows a

[1] In the paper, real TCG means that the TCG game performs the game using real trading cards on a real table, and two or four players play the game face-to-face.

player neither to have an eye-to-eye contact, nor to look at or chat with the opponent player.

As described above, although most of the current computer-based TCGs lose the realities of the real TCG, we claim that ubiquitous computing technologies may help to recover these lost realities and encourage and attract players to enjoy the computer-based TCG in a very similar way to the real TCG. Moreover, adding special effects and virtual forms to the computer-based game might increase the excitement of the game even more than the real one.

Figure 3 shows Augmented Trading Card Game (Augmented TCG) that is currently developed in our project. The system extends the trading card game running on Nintendo DS, where two players are usually located in different places while playing the game. In Augmented TCG, the opponent player is represented as a virtual character. The movement of the character is synchronized with the movement of the real opponent player by using MS Kinect, and the behavior of the character is determined by the information retrieved from a biosensor attached to the opponent player, i.e. the virtual character's behavior and emotions reflect the real player's behavior to some extent.

The trading card itself is also enhanced in the system. Cards presented on the display of the Nintendo DS are retrieved by Web cameras and projected on a real table. The projected cards can be enhanced by adding enjoyable battle effects or empathetic effects to the characters shown on the cards.

In the original computer-based game, a player usually cannot see the opponent player. The proposed Augmented TCG enables us to recover this lost reality by adding a virtual character whose movement and behavior are synchronized with the movement and behavior of the real opponent. In addition, the virtual trading cards carry some special effects that increase the sense and the excitement of the battle. Similarly, if the character drawn on a trading card shows some empathic expressions, a player feels more empathy on the character on the card, and feels

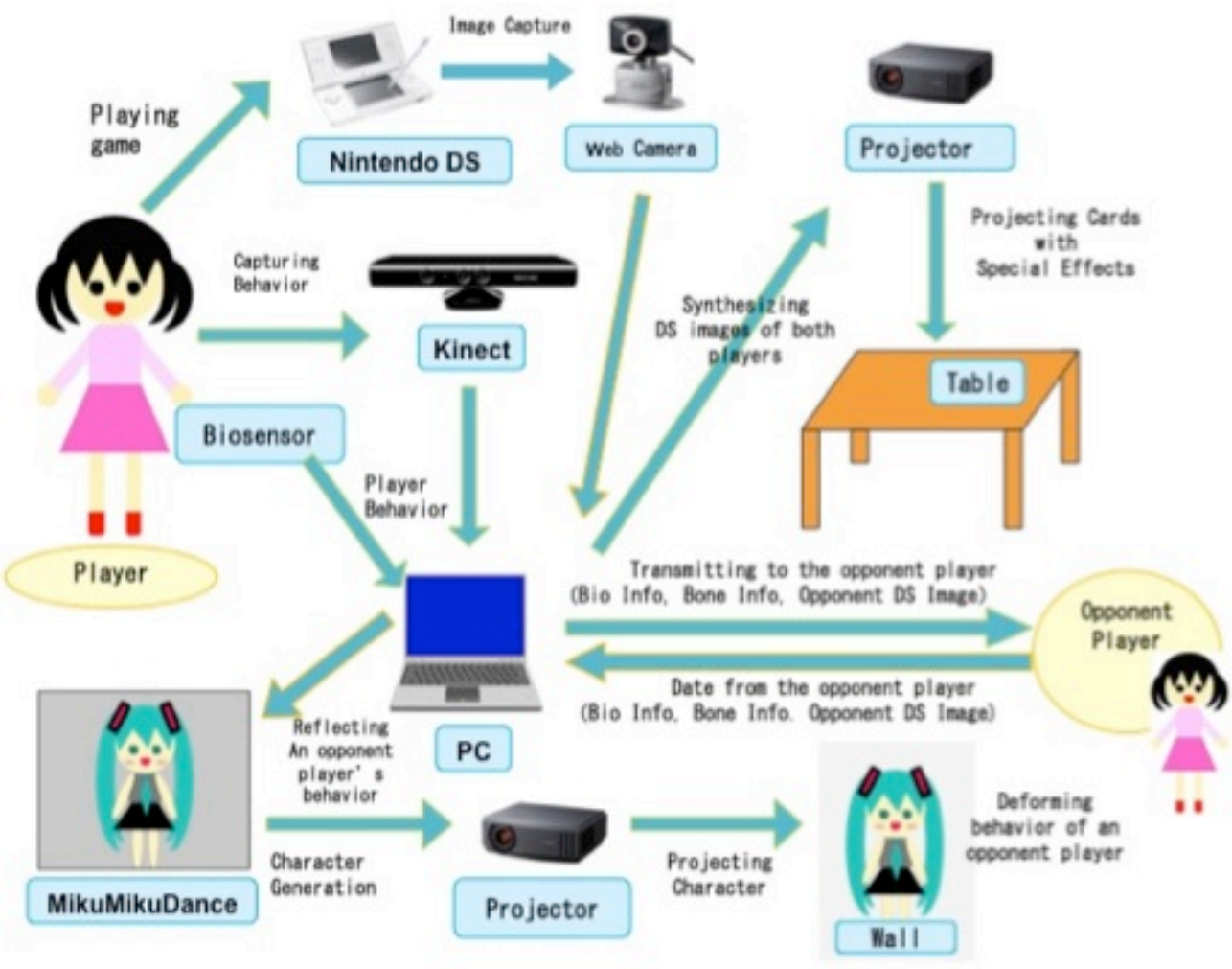

Figure 3: Augmented Trading Card Game

more enthusiastic and committed to the game. These special effects compensate the lost realities of the real trading cards. Also, virtually attached rarity to the virtual trading cards brings a feeling of reality and encourages a will to collect virtual trading cards.

III Design Implications

Baudrillard proposed that the consumption becomes more symbolized and additional values become more important than the products as materials [1]. For example, a brand offers significant additional values to fashion items, and a consumer feels the value on their virtual properties. On the other hand, adding values to virtual items makes a user to feel them to be materialized. This means that real products are becoming more virtual, and virtual products are becoming more real.

From the experiences with case studies, we extract six values to augment traditional artifacts to be used to design virtual forms. The first value is the physical value that offers the tangibility to artifacts. During the design of Augmented TCG, we compare the traditional trading card game and the game running on Nintendo DS [7], and many players prefer the feeing of the tangibility of the real trading cards while playing a game. We believe that the value increases the reality when some artifacts exist in the virtual world [3]. The second value is the empathetic value. The value is used in Augmented TCG, where a virtual character is used to increase the friendship with an opponent character when the player likes the character. The third value is the persuasive value that offers extrinsic motivation to a user. The transtheoretical model [8] defines five stages to change a user's behavior. The value is used in Virtual Aquarium, where a user continues to wash his/her teeth making fishes in the aquarium healthy. Then, in the later stage, the cleanness of an aquarium becomes a metaphor of the cleanness of the user's teeth, and the metaphor is useful that the user is aware of the importance of toothbrushing. The fourth value is the informative value. The value is effective to make a better decision. In Augmented Go, some information to help to choose the position of the next Go stone is projected on the real Go board. The next value is the economic value. The value is not directly used in the current case studies, but we discussed the importance of the value when designing the case studies. For example, a player likes to buy special effects in Augmented TCG. Finally, the last value is the ideological value. The value represents the metaphor that shows the dream or expectation of a user.

The above values are useful to identify what the main values of the traditional artifacts and how to add additional values to the artifacts for making them richer and more enjoyable. For example, in Augmented TCG, we found that the original game running on Nintendo DS have some problems. Especially, when a playing a game, a player cannot see an opponent player, so that the player tends to do an illegal play. For stopping the illegal play, it offers a virtual character as an opponent character by increasing the empathetic value. Also, special effects surrounding a player's trading cards are useful to motivate the player to win the game fairly.

During the discussion to develop the case studies, we consider the importance of the economic value. We consider to incorporate virtual items to be exchanged by users are promising to motivate a user to use the enhanced artifact [4]. For example, if a user develops a new way of the customization of an artifact, other users are interesting to use the customization even if they pay some money to buy the customization. We believe that this kind of the customization may offer the attractive business model to artifacts.

Aesthetics is an important concept to design the ideological value. Especially, in Japan, incorporating the ideological value in Japanese products is a promising way to sustain Japanese Economy [2]. Of course, Japanese traditional folkcraft represents the aesthetic value, and we need to investigate how to incorporate the aesthetic value into digitally enhanced artifacts in the next step in our research.

IV Conclusion

The paper shows three case studies that use augmented reality technologies to enhance daily artifacts. From the experiences with designing the case studies, we extract six values to identify to be helpful to design enhanced artifacts. We believe that the values are useful to design future digitally enhanced artifacts.

Our approach to use augmented reality technologies to existing artifacts makes it possible to gamify the use of the artifacts, and the use of the artifact is more enjoyable. The gamification [9] recently becomes popular to make daily activities and business activities more enjoyable. We hope that the proposed values are also useful to gamify these human activities.

References

[1] Jean Baudrillard, ``*Simulacra and Simulation*'', Univ of Michigan Pr, 1994.

[2] Kenya Hara, "*Japanese Design – Aesthetics makes the Future*", Iwanami Publisher, 2011.

[3] Ishii, H. and Ullmer, B, *"Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms",* In Proceedings of the CHI 97, (1997)

[4] Vili Lehdonvirta, "*Virtual Item Sales as a Revenue Model: Identifying Attributes that Drive Purchase Decisions*", Electronic Commerce Research, vol. 9, no. 1, 2009.

[5] Stefano Marzano , Emile Aarts , "*The New Everyday View on Ambient Intelligence* ", 010 Publisher, 2003.
[6] Tatsuo Nakajima, Vili Lehdonvirta, *"Designing Motivation in Persuasive Ambient Mirrors"*, Springer Personal and Ubiquitous Computing, 2012.
[7] Mizuki Sakamoto, Todorka Alexandrova , Tatsuo Nakajima, "*A Study on the Effects of a Computer-based Trading Card Game*", Under submission, (In Japanese), 2011.
[8] W. F. Velicer, J. O. Prochaska, J. L. Fava, G. J. Norman, C. A. Redding, "*Smoking cessation and stress management: applications of the transtheoretical Model of behavior change*", Homeostasis, 38 (1998).
[9] Gobe Zicbermann, Christopher Cunningham, "*Gamification by Design*", O'Reilly, 2011.