Designing Smart Living Objects – Enhancing vs. Distracting Traditional Human-object Interaction

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Abstract. To realize Weiser's vision of ubiquitous computing, a popular approach has been to create so-called *smart living objects*, which are everyday objects in our living environment augmented with digital technology. In this paper, we survey different smart living objects and classify their design choices into different types of digital enhancement. These design choices are about choosing the relation between the object's digital enhancement and its traditional use – (1) whether the object's digital function *enhances* or *distracts* its original function, and (2) whether the object's digital interaction *matches* or *conflicts* with its original interaction. Finally, we formulate design heuristics that new digital enhancement should consider the object's traditional function and interaction method, and avoid conflict between the digital enhancement and the traditional use.

Keywords: smart object, smart living object, smart living space, human-computer interaction, context-aware computing, ubiquitous computing

1 Introduction

Recently, many researchers are working toward the vision of ubiquitous computing put forward by Weiser [1], with the goal of distributing computing into our everyday environments. A popular approach to realize this vision has been to create so-called *smart living objects*. They are traditional objects (which commonly exist in our living environment and whose functions and uses are familiar to us) augmented with a variety of digital technology to bring about novel functions, interaction, and user experience with computing. When Ubicomp researchers experiment with new smart living objects, they are often faced with a challenging design question as to how/what to digitally augment traditional objects in a way that the *enhanced functions* are *sensible* and the *enhanced interaction* is *natural* to human. Are there any general design heuristics for digital enhancement of smart living objects? What design heuristics have Ubicomp researchers tried in the past?

In this paper, we survey and analyze different smart living objects, and classify their design choices into different types of digital enhancement. Based on our observations, we identify two important design choices resolving the relation between the object's digital enhancement and its traditional use – (1) whether the object's digital function *enhances* or *distracts* its original function, and (2) whether the object's digital interaction *matches* or *conflicts* with its original interaction. Based on our own past experience in designing smart living objects and studies done by other researchers [17], we believe that these two design choices affect usability of smart living objects. After analyzing these design choices, we come up with the following design heuristics: *the digital enhancement should respect the object's traditional function and interaction, and avoid any conflicts between its digital and the traditional function and interaction.* In other words, the new digital capabilities should enhance or complement (and never reduce or distract) an object's original use. Our design heuristics are consistent with Nielsen's usability heuristics [2]. For example, one of his usability heuristics states "Match between the system and real world", which means that digital systems should follow conventions in real world and make information appear in a natural and logical order to human.

Below we define these two design choices that resolve the functional and the interaction relation between the object's digital enhancement and its traditional use.

- *Relation between digital and traditional functions*: Adding new digital features and functions is common to enrich user experience with everyday objects. We define three types of possible relation between digital and traditional functions: (1) *enhancement,* (2) *complement*, and (3) *unrelated*.
  - For the enhancement type, the new digital function does not only match with the object's original function, but also enhances its original function. An example is the Adidas bionic running shoes [12]. Its digital enhancement incorporates sensors to detect different walking/running surfaces, and then dynamically adjust shoes' cushions for better human comfort and performance. This digital function matches the shoes' traditional function to provide comfort and support for human feet.
  - For the complement type, the new digital function complements the object's original function, or offers a new possibility that extends its original function. An example is the Dietary-aware Dining Table in our previous work [8]. Its digital function incorporates weight and RFID sensors to track what and how much a table participant eats from the table. Then it provides awareness feedbacks about his/her dietary intakes. This digital function complements the dining table's traditional function in helping users with sensible eating.
  - For the unrelated type, the new digital function is unrelated to the object's original function. An example is the Internet Refrigerator from LG Electronics [7]. It embeds a computer with a LCD display mounted on the fridge door for Internet and multimedia access. Although its digital enhancement provides a rich set of features such as Internet browsing, a digital photo album, DVD playback, etc., these features have loose relationship to a fridge's traditional function of food preservation.
- *Relation between digital and traditional interaction*: To access the object's new digital function, an interaction method needs to be designed into the object's interface. We again define three types of possible relation between the object's

digital interaction and its traditional interaction: (1) *natural*, (2) *intuitive*, and (3) *unrelated*.

- For the natural type, the interaction to access the object's digital function is the same as its original interaction. Since a user is already familiar with the original interaction, accessing its digital function requires almost no new learning. An example is the I/O Brush from MIT Media Lab [3]. Its digital interaction method of using the I/O Brush to pick up digital paints from the physical environment is designed to be the same as using a traditional paintbrush to pick up color paints from a palette.
- For the intuitive type, although the digital interaction is not exactly the same as the object's original interaction, it is intuitive and has high relevance to its original interaction. An example is Topobo from MIT Media Lab [14]. Although assembling Topobo components is similar to assembling LEGO blocks, a child still needs to learn a new control interface to operate the motion record and playback buttons. This new control interface is intuitive because a child animates Topobo components in the same way as he/she animates LEGO blocks.
- For the unrelated type, the digital interaction bares no resemblance to the object's original interaction. An example is the Color Camera Wrist Watch [11] from Casio, which integrates a color camera into a wrist watch. Since camera features require operating a different set of buttons and interaction sequence than in the traditional clock features, a user needs to learn a new different picture-taking and picture-viewing interface.

Since an everyday object often has multiple functions and interaction methods, there exists *ambiguity* in determining the functional and interaction relation between digital and traditional. For example, a cup can serve multiple functions other than drinking, such as holding pens, social toasting in a party, etc. Furthermore, each function often comes with a different interaction method – if a cup is used as a pen holder, the interaction is dropping or grabbing a pen to/from the cup; whereas if the cup is used for toasting, the interaction is to raise the cup toward the person of honor. Therefore, the functional and interaction relation depends on how users perceive an object's traditional function and interaction. For example, an object's digital enhancement may be regarded as complementary or natural to a traditional function or interaction, but as unrelated to its other traditional functions and interaction. In this paper, we acknowledge this ambiguity and leave the decision of an object's possible functions and interaction to its designer and end-users. Since our classification method is about design choices, it is independent of different perception about an object's original function and interaction.

The remainder of this paper is organized as follows. Section 2 surveys different smart living objects and analyzes their design choices on the functional and interaction relation between the digital and traditional. Section 3 discusses these design choices, formulates our design heuristics on how to choose the functional and interaction relation, and provides rationale to support our design heuristics. Section 4 describes the related work. And Section 5 draws our conclusion.

2 Smart Living Objects

We survey 13 smart living objects from research works and commercial products. For each smart living object, we provide a general description of its digital enhancement, followed by its design choices on the functional and interaction relation between the digital and traditional. A smart object's functional (interaction) relation is determined by comparing its original function (interaction) and its digital function (interaction).

Project name: I/O Brush [3]
Affiliation: MIT Media Lab, 2005
Description: The I/O Brush augments a regular paint brush with a new digital capability to pick up color, texture, and movement from any surfaces in our physical environment. This is done by hiding a digital camera with a touch sensor and LEDs inside the I/O Brush.
Functional relation: enhancement. The I/O Brush's digital function matches exactly with the function of a traditional paintbrush, which is to paint pictures. Its functional enhancement comes from enabling a traditional paintbrush to pick up digital paints, which are any physical surfaces that can be captured by a hidden camera in the brush.
Interaction relation: natural. Using the I/O brush to pick up digital paints from physical surfaces is designed to be the same as using a traditional paintbrush to pick up color paints from a palette. In addition, the I/O brush stroke is also designed to be the same as a traditional paint brush stroke.

Project name: Pick-A-Drawer [4]
Affiliation: Georgia Institute of Technology, 2002
Description: The Pick-A-Drawer interconnects two remote drawers through the concept of a virtual shared drawer. The goal is for distant family members to connect and share parts of their physically disjoint living spaces. In a chest of drawers, one drawer contains a digital camera to capture images of the drawer's content, which is then transmitted and shown on a LCD display of its remote drawer pair.
Functional relation: enhancement. A traditional drawer serves the function as space for family members to store and share living things, e.g. schoolwork, treasures, etc. The Pick-A-Drawer enhances this sharing function by breaking its physical boundary and by enabling remote family members to enjoy this space sharing experience.
Interaction relation: natural. The Pick-A-Drawer retains the same interaction as a traditional drawer – pulling out a drawer, seeing contents inside, putting objects in it, and pushing to close. From children to grandparents can use its digital function naturally and experience this warm feeling of sharing interesting living things.

Project name: Lover's Cups [5]
Affiliation: MIT Media Lab, 2006
Description: The Lover's Cups are based on the idea of sharing feelings of drinking between two people located in distance places. Two cups are connected to each other wirelessly and embedded with sip, liquid, and pizeo sensors to detect drinking actions. LED illumination is used to show the drinking status of the other Lover's cup. For example, when two lovers are drinking at the same time, both Lover's Cups glow.

Functional relation: enhancement. In a social setting, traditional cups are not only used for drinking but also for toasting to reinforce social ties between people. The Lover's Cups enhance a traditional cup's social function by enabling far-away people to engage in this social experience of sharing a drink together at the same time.
Interaction relation: natural. The Lover's Cups do not change the cups' traditional drinking interaction, which is to pick up and drink with them.

Project name: Nutrition-Aware Kitchen [6]
Affiliation: National Taiwan University, 2007
Description: It provides digital awareness of nutrition facts in food ingredients that go into a meal preparation. To recognize cooking activities and food ingredients used, weighing sensors are embedded underneath the kitchen surfaces. The goal is to promote healthy cooking to family cooks. They can cook naturally while receiving nutritional information during the cooking process.
Functional relation: complement. A kitchen's traditional function is meal preparation. This digital nutritional awareness complements a kitchen's traditional function through a passive, ambient display to bring nutritional awareness of food ingredients to family cooks.
Interaction relation: natural. It is natural because nutritional monitoring and awareness display are recognized by sensors without any explicit human input. A family cook simply cooks naturally in the kitchen while he/she can choose to read or ignore the nutritional information.

Project name: Internet Fridge [7]
Affiliation: LG, 2002
Description: LG's Internet fridge embeds a computer with a LCD display mounted on the fridge door for Internet and multimedia access. Through the LCD display, it offers a rich set of digital features and interaction such as Internet browsing, a digital photo album, DVD playback, etc. This smart fridge can also be used as a server for remote controlling other home appliances, such as a microwave, a washing machine, and an air conditioner.
Functional relation: unrelated. A fridge's traditional function is to store and preserve the freshness of foods. However, the Internet browsing, multimedia access, and appliance remote control features have little relationship to a fridge's traditional function.
Interaction relation: unrelated. The digital interaction for Internet browsing, multimedia access, and appliance remote control differs from a fridge's traditional interaction of storing and retrieving foods.

Project name: Diet-aware Dining Table [8]
Affiliation: National Taiwan University, 2006
Description: It augments a traditional dining table by embedding weighing and RFID sensors to recognize what and how much a table participant eats from the table. Then it provides awareness feedbacks to the users about their dietary consumption. The goal is to help users with sensible eating.
Functional relation: complement. The dietary tracking and awareness function complements a dining table's traditional function by not only presenting available foods on a tabletop surface but also bringing awareness of actual amount of food intake.

Interaction relation: natural. It is natural because nutritional monitoring and awareness feedback are automated without any explicit human input – a user simply eats naturally from the table while he/she can choose to read or ignore his/her dietary information.

Project name: The History Tablecloth [9]
Affiliation: Goldsmiths College, U. of East Anglia, and Lancaster U., 2006
Description: It augments a traditional tablecloth by recording and displaying how long an object has been left on a table. Its goals are to bring awareness about the flow of things over a surface at home, and to provide an aesthetical looking home décor with rich information for people to interpret.
Functional relation: enhancement. One of tablecloth's traditional functions is decoration. This digital function enhances this decorative function by dynamically changing the artistic patterns on the tablecloth according to how long things have been left on it.
Interaction relation: natural. It is natural because users can simply put things on the tablecloth as on any traditional tablecloth.

Project name: Digital Family Portrait [10]
Affiliation: Georgia Institute of Technology, 2001
Description: It augments a traditional family portrait by providing qualitative visualizations of a family elder's daily life using iconic imagery on the picture frame. The displayed information includes the elder's health, environment, social interaction level, activity level, etc., over the past few weeks. The goal of this digital awareness is to communicate the elder's well-being and to bring peace of mind to his/her concerned family members.
Functional relation: complement. A family portrait's traditional function is to bring back the memory of a loved family member, and also to serve as a reminder to care for him/her. The digital awareness provides additional, complementary information to the caregivers about recent health condition of the elder.
Interaction relation: natural. It is natural because a caregiver simply needs to glance at the iconic frame to interpret the elder's health condition.

Project name: Color Wrist Camera Watch [11]
Affiliation: Casio, 2006
Description: It integrates a color camera into a traditional digital watch. It combines two unrelated features, showing time and taking picture, into a watch-sized device.
Functional relation: unrelated. A watch's traditional function is to track and show the time of day. The new digital camera functions, such as taking and browsing pictures, have little relationship to a watch's traditional function.
Interaction relation: unrelated. Since camera features require operating a different set of buttons and interaction sequence than in the traditional clock features, a user needs to learn a new different picture-taking and picture-viewing interface.

Project name: Bionic Running Shoes: Adidas_1 [12]
Affiliation: Adidas Group, 2006

Description: Adidas_1 incorporates sensors and a microprocessor to detect different walking and running surfaces, and then dynamically adapts shoes' cushions for better human comfort and performance. The goals are to provide users with better running experience and to protect their feet when striking ground.
Functional relation: enhancement. The shoes' traditional function is to provide comfort, support, and protection for human feet while running or walking. Adidas_1 improves this traditional function through intelligent adaptation to different physical walking or running environment.
Interaction relation: natural. It is natural because intelligent adaptation to the environment is automated. Users simply wear the Adidas_1 shoes, and they can run and walk naturally in the environment as any other traditional shoes.

Project name: ComSlipper [13]
Affiliation: Carnegie Mellon University, 2006
Description: ComSlipper augments traditional slippers, enabling two people in an intimate relationship to communicate and maintain their emotional connection over long distance. To express emotions such as anxiety, happiness, and sadness, users perform different tactile manipulations on the slippers (e.g. press, tap at a specific rhythm, touch the sensor at the side of slippers, etc.) which ComSlipper recognizes. The remote slipper pair then displays these emotions through changing LED signals, warmth, or vibration.
Functional relation: complement. Slippers' traditional function does not only protect our feet, but also brings an intimate feeling of comfort and warmth [13]. Thus, ComSlipper complements this traditional function by communicating intimate messages between two people.
Interaction relation: unrelated. The interaction of ComSlipper is unrelated to its traditional interaction, which is to simply wear them. That is, users need to learn different tactile manipulations of slippers and mapping to different emotions, which may not be natural or intuitive for most people. In addition, users need to learn how to interpret messages through LED lights, warmth, or vibration.

Project name: Topobo [14]
Affiliation: MIT Media Lab, 2004
Description: Topobo is a LEGO-like constructive assembly toy enhanced with so-called kinetic memory, or the ability to record and playback physical motion. After a child manipulates toys with a certain motion, Topobo can record and replay this motion again.
Functional relation: enhancement. One of the traditional functions of a constructive assembly toy, such as LEGO, is to stimulate a child's creativity through playing and making. This digital animation function brings out a child's creativity while enhancing the toy's enjoyment.
Interaction relation: intuitive. Although assembling Topobo components is similar to assembling LEGO blocks, a child still needs to learn a new control interface to operate the motion record and playback buttons. This new control interface is intuitive because a child animates Topobo components in the same way as he/she animates LEGO blocks (e.g., compose blocks into a vehicle and make it move), except that Topobo motion can repeat itself.

Project name: Shopping Buddy [15]
Affiliation: IBM for Retail, 2004
Description: It augments a traditional supermarket shopping cart with a RFID reader to scan all RFID-tagged items placed into the cart. Through a LCD display mounted on it, a consumer can see pricing information on each item, as well as calculating the total amount in the cart. It helps budget-conscious consumers with sensible shopping.
Functional relation: complement. A shopping cart's traditional function is to hold to-buy items for users. This new digital function complements a shopping cart's traditional function by helping users shop appropriate amount of items according to his/her planned budget.
Interaction relation: intuitive. It is intuitive because after a user places items into the smart shopping cart, they will see price information on the LCD monitor. This is similar to the experience on the point-of-sale machine.

3 Discussion

The design choices made by the surveyed smart living objects are categorized in a classification matrix shown in Table 1. Most smart living objects fall into the lower left four cells. Their design choices are in agreement with our design heuristics that functional relation between the digital and the traditional should be enhancement or complementary, and the interaction relation should be natural or intuitive.

Table 1. Classification matrix

		Functional Relation		
		Enhancement	*Complement*	*Unrelated*
Interaction relation	*Unrelated*		- ComSlipper	- Internet Fridge - Color Camera Wrist Watch
	Intuitive	- Topobo	- Shopping Buddy	
	Natural	- I/O Brush - Adidas_1 - Pick-A-Drawer - History Tablecloth - Lover's Cups	- Diet-aware Dining Table - Nutrition-Aware Kitchen - Digital Family Portrait	

We would like to further give rationale to support our design heuristics. Note that these design heuristics should be considered as good general design practice applicable to many of smart living objects, but not universal design principles for all of them. The rationale can be explained from *functional sensibility* and *ease of interaction*. Functional sensibility means how well users perceive the value of a new digital function added to these everyday objects – are they acceptable, sensible, and fitting? Ease of interaction means the amount of user efforts to learn to interact with the digital functions. Since many everyday objects have been in existence for years, their practical and sensible functions and usability have been proven with extensive testing and refinement. Applying digital technology to radically alter these functions or interaction styles without considering these objects' traditional functions and interactions, is likely to run a risk of defying their well-established convention, which may lead to potential confusion and poor acceptance. Adapting our design heuristics in everyday living objects harmonizes the relation between their digital enhancements and traditional uses, making them simple, intuitive, and natural.

4 Related Works

Several studies have addressed related issues on smart living objects. Bohn *et al.* [16] classified the social, economic, and ethical implications about developing smart every objects. Kranz *et al.* [19] focused on implementation issues related to prototyping smart objects, covering the hardware, software, and device aspects. Bouchard *et al.* [17] identified both conceptual and practical issues related to augmentation of everyday items, e.g., physical embodiment vs. external augmentation. Our paper shares their viewpoint that the distribution of computing power into our physical environment is through "enriching ordinary, commonly used objects with extraordinary capabilities". Rogers [18] criticized the current Ubicomp work in ambient and ubiquitous intelligence, and pointed out the difficulties in building calm computing systems with them. Rocker *et al.* [20] employed a scenario-driven approach and adopted quantitative and qualitative methods to elicit user requirements for intelligent home environments. Rather than discussing and listing social or general issues of smart objects, we propose design heuristics based on the functional and interaction relation between the object's digital enhancement and traditional use.

5 Conclusion

We survey different smart living objects and classify their design choices into different types of digital enhancement. Based on our observations, we identify two important design choices resolving the relation between the object's digital enhancement and its traditional use – (1) whether the object's digital function *enhances* or *distracts* its original function, and (2) whether the object's digital interaction *matches* or *conflicts* with its original interaction. Finally, we formulate design heuristics that the digital enhancement should consider the object's traditional function and interaction, and avoid any conflicts between its digital enhancement and traditional use.

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