Exploring Design Factors of Dynamic Surface of Interactive Products

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Abstract
The surfaces of products are one of the most directly accessed parts of a product by users when they use it. Interactive products involve more complexity in conceptualizing the characteristics of their surfaces comparing to static visual artifacts. In this research, we explore whether the different aspects of dynamic surfaces of interactive products affect people's emotional experiences in different ways or not. For this purpose, we identified three different modes of experiencing three different aspects of dynamic surfaces. From our study result of comparing these three modes of experience, we realize that people develop very different emotional responses toward those different aspects, and we then discuss the implications of this result in interaction design.

Keywords
Dynamic surfaces, emotional affects, interaction design

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction
Digital technology has been turning everyday products into black boxes. As the simulation of the hardware design is increasingly software-oriented, the digital aesthetics of the design is aimed at bridging the gap

Figure 1. iPod Click Wheel[1], LG Chocolate Phone[3], Logitech diNovo Edge[12], Optimus-103 Keyboard[14] (from top to bottom)

between functions and arbitrary forms of product [2]. Self-explanatory surface has been one of the primary design considerations to provide users with information about what products can do and how they can be used [8]. Moreover, surfaces of interactive products become more diverse and dynamic beyond static buttons and screen interfaces. New types of interactive surfaces have been introduced in forms of touch screen or sophisticated surface with digitally enhanced tangible interfaces. They do not only improve usability but also influence visual forms and experiential qualities of digital products. For example, the click wheel interface of iPod enables efficient navigation of tremendous amount of music data as well as different feelings of touch interaction [1]. Also, the status of interaction can be directly displayed on buttons [3, 14] or combined with other mechanical parts, which would give clear guidance for interaction and new visual aesthetics [12].

Accordingly, products with same functions can bring different user responses according to their impression or behavioral experience with various surfaces, and sometimes users' impression on one product may change before and after interacting with it because their expectation on how a product may behave according to its visual appearance can be very different from how the product actually behaves. For example, although users may be confused with what a product interface indicates, they may be stimulated by its interesting ambiguity, and finally be satisfied with its richness of dynamic interaction. On the contrary, users may feel comfortable with clear indications of a product surface at first, but they may easily get bored with its mundane interactions. Those feelings of confusion, clearness or curiosity from the dynamic surface of an interactive product can affect satisfaction or disappointment in actual use of product.

This study is motivated to explore various aspects of dynamic surfaces of interactive products in relation to their affects on users' overall experience with products. Although there have been increasing interests in affective and rich interaction with digital products, many studies have mainly considered visual or usability aspects of interfaces. Our study, however, focuses more on the relationship among different aspects of dynamic surfaces and their affect to user responses toward a product over the process of interaction.

To this end, we first propose a simple model to visualize three key aspects of dynamic surfaces of an interactive product and their corresponding modes of user experience with the product (Figure 1). We then introduce our four design examples which are devised to represent four different designs of each of the aspects of dynamic surfaces to examine whether the different aspect of dynamic surfaces change users' responses toward the product or not, and if it does, how they affect them differently. Finally we discuss implications of our suggested perspectives and concepts in interaction design based on the analysis of the study results.

A Model of Dynamic Surfaces of Interactive Products

We define a dynamic surface of an interactive product as a composite design element containing input and output interfaces that also determine the appearance of a product and its usability. A surface of an interactive product can be identified as a dynamic one due to its behavioral aspect. Nonetheless, we also view that a dynamic surface incorporates other aspects, which are also common to rather static surfaces such as visual appearances and affordances. The former corresponds to a visual aspect of a surface, and the latter corresponds to a functional aspect of a surface since it is about which function the form affords. In this regard, we propose a simple model of a dynamic surface of an interactive product (Figure 2) including those three aspects of the dynamic surface, namely, *visual, behavioral, and functional*. These three aspects of a dynamic surface are also related to three different modes of user experience, namely, *perception, interaction, and understanding*. Specifically, the visual aspect of a dynamic surface is about how the surface looks like at the mode of visual perception. The behavioral aspect of a dynamic surface is about how the surface is manipulated at the mode of interaction, excluding the functional or cognitive aspects of the surface, which is actually covered at the mode of understanding a use of the surface.

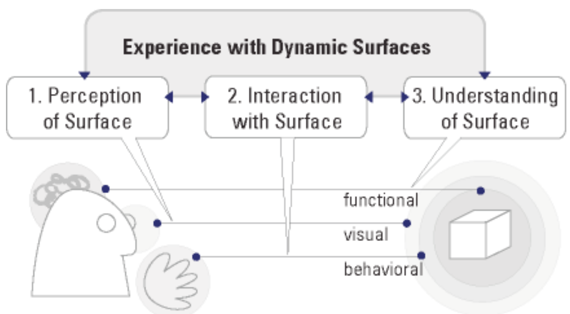

Figure 2. Three modes of experiencing dynamic surfaces

By distinguishing three modes of experience and three aspects of a dynamic surface, we aim at investigating how user responses dynamically change in relation with corresponding the three different surface aspects during the overall experience.

Related Studies:

There have been many attempts to understand interaction aspects of digital products with focus on their dynamic surfaces. Traditionally, Gibson defined the concept of surface as what separates medium from the substances of the environment and suggested the concept of affordance, which has given much insights for interaction designers on how to induce appropriate user reaction to a designed interface [8]. Bolz suggested a fundamental contemplation about the meaning of surface based on philosophical and socio-cultural perspectives [2]. He emphasized the role of design for digital aesthetics of products through meaningful connection between form and function as the form can no longer be determined by the function in the design of micro-electronic black boxes. Vallgarda suggested the concept of computational composite, a composite material with computational abilities to control transitions between states in the other components of the composite [17]. This perspective of computer as material opens up a potential design space for interactive surface where traditional input-output interfaces are flexibly combined and seamlessly melted into digital products, enabling aesthetic expressiveness as well as extended functionalities.

Based on those new interpretations about surface or material of digital products, many researchers have explored aesthetics of interaction beyond visual appearance or efficient use. Dunne emphasized the notion of para-functionality enabling poetic experience in everyday life [7]. Djajadiningrat suggested that aesthetics of a product are shaped according to its functions and roles, and its interactions must be judged by their sensory and conceptual aesthetic qualities [5]. Aesthetics of interaction moves the focus from ease of use to enjoyment of the experience [15].

Emotion is getting more attention as a critical consideration for aesthetic and experiential qualities of using interactive products. Starting from Norman's notion of "Attractive things work better" [13], many studies have claimed that users' perception of usefulness or ease of use can be influenced by their affective responses [9]. There have been many studies about how those emotional impressions are related to users' perception and behavioral intention from cognitive perspectives [18]. Meanwhile, several studies have focused on how specific visual elements, such as shape, color or texture, influence affective quality of interactive products from design perspectives [4, 6]. However, as new styles of interactions introduce new aesthetics of use, their dynamic aspects also need to be considered as design elements not only as functional features or static visual elements. In our previous research [11], we extensively argued for the importance of the dynamic part of an interactive product in terms of forming aesthetic interactions.

The research we present in this paper focuses on understanding experience quality of interactive products not only from their visual surfaces (corresponding to the visual aspect) or functional aspect (understanding mode) but also their dynamic surfaces (corresponding to the behavioral aspect). We are also interested in understanding how different design elements influence on user responses with focus on affective experience to find out how their responses would change before and after actual use of dynamic surfaces (corresponding to the functional aspect). The reason we focused on users' affective responses is that we consider them as integrative qualities that cover the overall experience of using interactive products reflecting responses to visual aesthetics and functional satisfaction.

User Study

We planned a user study to measure user responses with focus on affection at each mode of experiencing dynamic surfaces of interactive product and to compare any differences among them. For that, we designed four types of alarm clock radio interfaces (Figure 3) and presented them in different forms such as static images and interactive prototypes to measure different affective qualities at the three modes of experiencing each aspect of a dynamic surface that we suggested—i.e. *visual*, *behavioral*, and *functional* aspects.

Four design examples were conceived based on various combinations of design elements, applying the following two design criteria, namely (1) *distance between input and output elements*, and (2) *level of specificity of indications for input and output elements*.

These two design criteria are applied in order to describe how a dynamic surface is composed and how its three aspects are combined according to three modes of experience. The distance between input and output elements can be a continuum from total separation (like button and display screen) to integration (like touch screen), influencing the relation between visual and behavioral aspects of dynamic surfaces. For example, both input and output elements may be represented on the visual aspect of a dynamic surface, or output elements may be hidden and only

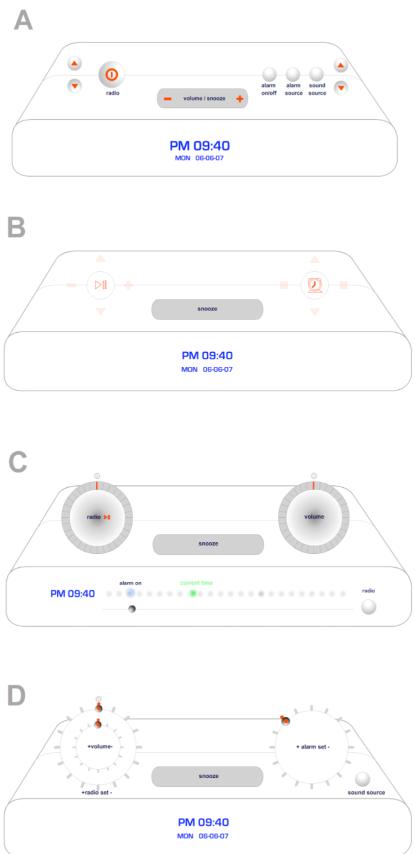

Figure 3. Four examples of alarm clock radio interface

appear on the *interaction* mode of experience. Also, as more physical manipulations such as knobs or sliders are applied in digital products either for intuitive use or retrospective styles, the input manipulation and its output status can be tightly integrated into specific mechanical parts of product. The second criterion we applied is the level of specificity of indications of input and output elements, from very descriptive literal indications to symbolic forms or images. This determines the relation of visual and behavioral aspects to functional aspects of a dynamic surface.

By clarifying interaction aspects and design elements of a dynamic surface of an interactive product, we aim at better understanding its influence on user responses during the overall experience and suggesting a new design perspective to explore experiential and aesthetic potentials of dynamic surfaces of digital products.

Table 1 shows our choices of the four designs, A, B, C, and D, according to the three aspects of a dynamic surface. These four designs are devised (Figure 3) by applying variations of those two design criteria. Specifically, Design A has typical button and screen interfaces with totally separated input and output elements and clear indications of each with text labels. Design B employs input-output integrated touch screen interfaces with their abstract indications of symbolic icons. In Designs C and D, input manipulation and output status are integrated into physical interfaces such as knobs or sliders, with abstract indications for example C and with more accurate and detailed indications for example D.

For the functional aspect of a dynamic surface, we prototyped the exact same features across all the four designs—i.e. setting alarm times, playing radio, and setting current time. By providing various types of design examples, we expect to validate the comparison into more general relationships among affective responses from each mode. Also, we aim at investigating how variations of design elements influence different affective responses in each mode of experience.

We consciously kept the level of visual aesthetics and ease of use equally for all examples. Also by using a simple box-shape and familiar features of setting alarm time and radio channels, we intended to attract participants' attention mainly to various styles of dynamic interactive *surfaces*. All the detailed design decisions of each example are described in Table 1.

	Visual Design Elements	**Input-behavior Design Elements**	**Output-behavior Design Elements**
A	Text labels below buttons, Display screen	Clicking buttons	Number and text display on screen
B	Symbolic icons on buttons, Display screen	Touching buttons	Responsive light transition of buttons, Number and text display on screen
C	Text labels on knobs, Display screen	Rotating knobs	Number and text display on screen
	Slider (with no labels), Timeline lights	Sliding controller	Color transition of timeline lights
D	Circular scales engraved under controllers, Display screen	Rotating controllers	Number and text display on screen

Table 1. Variations of design elements for each example

We applied a semantic differential method to measure users' emotional responses to dynamic surfaces of design examples. Based on related research [10, 13, 16, 18], we selected 12 semantic values under 4 categories that cover general affective qualities of using interactive products: sensorial, pleasure, arousal and reflective affects (Table 2).

Category of Affects	Opposite semantic values	
Sensorial	Attractive	Ugly
	Fragile	Reliable
	Obtrusive	Calm
Arousal	Encouraging	Discouraging
	Engaging	Uninviting
	Stimulating	Dull
Pleasurable	Playful	Serious
	Friendly	Unfriendly
	Enjoyable	Boring
Reflective	Valuable	Worthless
	Unique	Common
	Exotic	Mundane

Table 2. Categories and values for semantic differential rating

We provided participants with the semantic differential questionnaire as a guidance to express their relative affection on a 7-scale between polar opposites of specific values. Participants were asked to fill out this same questionnaire three times for each design example, i.e., after looking at static product images, after interacting with prototypes, and after performing tasks (Table 3). For affective responses at the mode of visual perception (Mode1), we showed static images of all design examples at once so that participants rate semantic values relatively to each example. Then, we asked participants to rate their affective responses after interacting with Flash prototypes of all four examples (Mode2). In those two phases, we specifically asked them not to consider usable or cognitive aspects of interface but just to focus on immediate feelings evoked from its visual and behavioral design elements. Lastly, we gave simple tasks such as setting radio channels and alarm times (Mode3) and then asked to fill out the questionnaire again. In this mode, participants actually reflected usability issues on their ratings. We mixed the order of presenting four design examples in Mode 2 and 3 to prevent any influences from the previous design examples. After completing all ratings, we had a time for debriefing which semantic values were particularly changed comparing ratings from each mode of experiencing dynamic surfaces and which specific design elements influence rating values.

	Mode1: Visual Perception of Surface	Mode2: Interaction with Surface	Mode3: Understanding of Surface
A	A1	A2	A3
B	B1	B2	B3
C	C1	C2	C3
D	D1	D2	D3

Table 3. Code for sum of rating values in each experience mode

Analysis

We conducted user study as planned above with 15 participants, all university students aging from 23 to 34. Each session of study took about an hour including a debriefing interview. With the study results, we first tried to prove our initial assumption—if users' responses at each mode of experiencing dynamic surface actually change over the course of experiencing those three modes. For that, we quantitatively compared ratings of affective qualities among different modes. For detailed investigation on how much affective responses have been changed, we calculated the sum of differences between each mode's ratings.

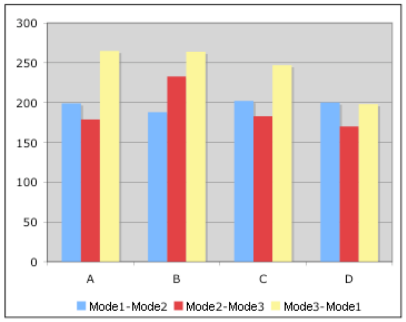

Figure 4. Sum of differences between each mode's rating values of affective quality

Then to understand further about how specific design elements influenced affective responses at each mode, we qualitatively analyzed the debriefing results.

It was noticeable that the sums of differences between Mode1 and Mode3 ratings for Designs A, B, and C were much larger than those between Mode1 and Mode2 ratings and than those between Mode2 and Mode3 ratings (see the yellow bars in Figure 4). In addition, the changes of participants' responses were larger when comparing the responses after the interaction with behavioral elements (Mode2) with the responses after only seeing visual elements (Mode1) than when comparing the responses after the actual use of functions (Mode3) with the responses after the interaction with behavioral elements (Mode2), for most of the designs except Design B (see the blue bars compared to the red bars in Figure 4). Although the results cannot be generalized, this overall pattern of changes in participants' responses supports the idea that users' emotional experiences are much influenced by the behavioral mode of experience with the dynamic surfaces.

Different results from ratings for design B can be explained based on debriefing results about influences of specific design elements. Design B employs a very simple visual appearance with symbolic icon labels and its interaction was quite calm with touch button interface comparing to other examples. Therefore most participants did not perceive significant changes in their affective responses between the visual perception (Mode1) and the interaction mode (Mode2). They felt more confused at the understanding mode (Mode3) comparing to other examples, because visual indications were quite ambiguous and behavioral design elements of touching interface did not give clear cues to understand functional aspects.

We then investigated influences of different design elements on specific affective response in each mode of experiencing dynamic surface with qualitative analysis of the debrief interviews in order to better understand the participants' reasons for the responses through the course of experiencing the three modes for each different design example.

Design A

- **Visual perception:** Mostly A was considered very common and familiar by its first look. Participants could easily expect how it would respond to their manipulation from its clear indications and thus felt comfortable to try any buttons on it.
- **Interaction:** Some participants felt satisfied with its interaction since it was quite clear and efficient with clearly separated input (buttons) and output (screens) interfaces while others felt the same fact as boring and tedious.
- **Understanding:** After task performance, most participants mentioned that their affective responses did rarely change but they actually valued more its clear functional design in terms of efficiency and practicality, which changed their affective response more positive comparing to their low expectations from the visual appearance.

Design B

- **Visual perception:** B appealed to most participants with its simple and delicate visual design. Abstract and ambiguous graphic images stimulated some participants' curiosity while they at the same time confused others.

- **Interaction:** Most participants were satisfied with its touch interface and responsive feedbacks of button status with lights on/off. Some mentioned that the light feedback felt like telling what need to be done as it is integrated with input interfaces and made them more engaged in the interaction. Some were disappointed since its behavioral design elements were basically same with clicking buttons like in design A, although B looked more special from its visuals.
- **Understanding:** During task performance, ambiguity of graphic symbols was often considered confusing. However, participants' responses were quite subjective: some thought the confusion did not overcome the attractiveness, while others were frustrated and felt negative emotions in the end because simply refined surface hides most of information about product use.

Design C

- **Visual perception:** C was considered quite unique with its knob and slider interfaces, comparing to A and B. Participants became curious of how they would work for setting alarms and radio channels. At first, two knobs attracted most attention and gave obtrusive impression with its gigantic size while the slider part relatively gave calm impression and its existence was easily ignored.
- **Interaction:** However, after interaction, participants became more interested in the slider part than in knobs due to its playful manipulation and direct coupling with the visualization of output status. They mentioned that it was more fun to move sliders than to click buttons and that different display interface with linear timeline lights may add new features to the product such as schedule reminder more than typical alarm setting.
- **Understanding:** During task performance, they became rather confused with the slider alarm set since the alarm time is indicated as an abstract dot on the linear timeline instead of exact numeric alarm time on a screen. They could not decide whether they like the different time visualization or not. However, they were sure to say that they were willing to try it because it is interestingly unique regardless its ease of use or usefulness.

Design D

- **Visual perception:** Most participants felt interface of D as cluttered and complicate although it is still unique. While C gave a kind of "scary interesting" impression with its uniqueness, many people felt just tired to understand what's going on within D.
- **Interaction:** However, many participants became more drawn to its circular motion and the logistics of its interface during the interaction. Like in case of C, they felt the interaction is quite intuitive as input manipulation and its result status are tightly integrated into physical interfaces.
- **Understanding:** During the task performance, they felt more serious since many visual and physical elements are crammed in the product surface and they felt cognitively overloaded. They became also disappointed since the overall interaction and features of this interface were not very noble comparing to its unique appearance.

They didn't see special benefits of different information visualization and manipulation like in C or any curious and delicate impressions like in B. Reasonable logistics and playful manipulation did not satisfy participants' expectations for uniqueness that were first felt from the visual image.

Conclusion

In this study, we suggest a simple model to understand dynamic surfaces of interactive products by distinguishing three modes of user experience—*visual perception, interaction*, and *understanding*—with the three aspects of dynamic surfaces—*visual, behavioral*, and *functional* aspects. Also, we suggest a new design perspective to design dynamic surfaces by adjusting how input and output elements are combined and represented on each mode of surface. The results from our study that was designed based on these concepts supported that users' responses change through the three different modes of experience in the process of using the dynamic interactive surfaces. We could also investigate how those changes are influenced by particular design elements at each mode. We expect that our approach for study and its results would provide meaningful implications for interaction designers on what to consider in designing dynamic interactive surfaces. Specifically, we suggest the following implications for specific design elements for dynamic surfaces:

- **Implications on visual design elements:** Different visual elements of dynamic surfaces represent clear or ambiguous indications about how the product would work, which determines *users' first expectations about the product*. From the study, we found that transparent indications with too much visual information or discrete functional interfaces do not always result in user satisfaction in use. Sometimes interesting ambiguity stimulates users' intention, which can be linked to positive emotional affects as long as they provide responsive guidance for interaction.
- **Implications on behavioral design elements:** Behavioral elements of dynamic surfaces influence *users' feelings of engagement*. From the study, physical manipulation such as rotating knobs or dragging sliders was considered more playful and people could feel more engaged to those interactions, where input manipulation and its output status are tightly combined into unique physical interfaces. Sometimes the feeling of uniqueness provides users with motivation to explore the functional aspects of products overcoming confusion and frustration with its difficulty of use or ambiguous visual indications. While integration of input and output elements through those physical interfaces provided more engaging experiences, touch button interface, which combines input and its feedback only through changes in visual status, was found to give a little confusion. Rich sensory feedbacks such as tactile or auditory outputs are expected to bring more intuitiveness and engagement with interaction.
- **Implications on functional design elements:** Functional elements of dynamic surfaces influence *users' emotional experience through their task performance,* which can be reflected later as frustration or satisfaction. From the study, we realized that user intentions and expectations are

initially determined by their impressions from visual and behavioral design elements. Appropriate coupling among those aspects is critical to incite users' final satisfaction in using the product with given tasks.

We expect this preliminary attempt to explore design factors of dynamic surfaces will provide a practical perspective for interaction designers to deal with various design elements, from static visual to tactile and rich sensory ones considering appropriate aspects of dynamic surfaces according to its modes of experience with interactive products. In addition, we expect investigation of the relationships between specific affective values that are defined in (Table 3) and different design elements would provide more meaningful design implications, which we are planning to study further as our future work.

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