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Effects of Tactile Augmentation and Self-Body Visualization on Affective Property Evaluation of Virtual Mobile Phone Designs

Abstract

Product design is an iterative process that involves, among other things, evaluation. In addition to the intended functionality of the product, its affective properties (or "Kansei") have emerged as important evaluation criteria for the successful marketing of the product. Affective properties refer to consumers' psychological feelings about a product, and they can be mapped into perceptual design elements for possible design modification toward higher customer satisfaction. Affective properties of products in design can partially be assessed using the near photorealistic graphic rendering feature of the desktop computer-aided design tools, or rapid prototyping tools that can produce physical mock-ups. Recently, immersive virtual reality systems have been suggested as an ideal platform for affective analysis of an evolving design because of, among other things, the natural style of interaction they offer when examining the product, such as the use of direct and proprioceptive interaction, head tracking and first-person viewpoint, and multimodality. In this paper, the effects of tactile augmentation and self-body visualization on the evaluation of the affective property are investigated by comparing three types of virtual environments for evaluating the affective properties of mobile phones. Each virtual environment offers different degrees of tactile and self-body realism. The effectiveness of these virtual environments is evaluated, compared to a control condition: the affective assessment of using the real product. The experiment has shown that the virtual affective evaluation results from the three systems correlated very highly with that of the real product, and no statistically significant differences could be found among the three systems. This finding indicates that tactile augmentation and the high-fidelity self-body visualization had no effect on the evaluation of the affective property. Nevertheless, the experimental results have indicated the importance of enhanced interaction with tactile augmentation for evaluating the property of texture, and have shown that VR systems have the potential for use as affective evaluation platforms.

1 Introduction

Broadly speaking, product design is often viewed as an iterative process of specifying/adjusting (user) requirements, synthesizing/modifying solutions,

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and evaluating the solutions. Designers and engineers often have a hard time trying to resolve requirement conflicts between the affective properties and the technical feasibility (e.g., functionality and manufacturability). In many cases, satisfying the intended functionalities of the product is given a higher priority, because the affective aspect can only be evaluated after the design through field-testing.

Nevertheless, a product's affective properties (or "Kansei" in Japanese) have emerged as an important factor for the successful marketing of the product. Thus it became necessary to equally emphasize the affective properties as important evaluation criteria in the design process, preferably in the early stages (McDonagh, Bruseberg, & Haslam, 2002; Nagamachi, 1995).

Affective properties refer to consumers' psychological feelings about a product, and studies have shown that they can be roughly mapped into perceptual design elements for possible design modification toward higher customer satisfaction (Han, Kim, Kim, & Yun, 2002; Hong, Kim, & Han, 2002; Kim, Han, Yun, & Kwahk, 2002; Yun et al., 2001). Affective properties of products "in design" (as opposed to after design) can be partially assessed using the near photorealistic graphic rendering feature of computer-aided design tools, or using rapid prototyping tools that can produce a physical mock-up. These models can be, for example, presented to a particular (e.g., males in their 20s) subject group (representing the main customers) to extract the mapping relationship between the induced feelings and the design features.

Recently, immersive virtual reality systems have been proposed as a more effective platform for affective analysis of an evolving design because of, among other things, the natural style of interaction these systems offer when examining the product, such as the use of direct and proprioceptive interaction, head tracking and first-person viewpoint, and multimodality (Sherman & Craig, 2003; Stuart, 2001), compared to a desktop graphic rendering. Note that physical mock-ups, the other alternative in product evaluation, are limited in size and cannot simulate internal behavior (e.g., moving parts, embedded software, etc.).

In this paper, the effects of tactile augmentation and self-body visualization on affective evaluation are investigated by comparing three types of virtual environments (VEs) for evaluating the affective properties of mobile phones with a control condition: the affective assessment using the real product. Each virtual environment offers different degrees of tactile and self-body realism. The first is the conventional desktop system in which a realistic graphic rendering is shown through a CRT monitor, and keyboard/mouse-based interaction is used to examine and simulate the behavior of the mobile phones. The second environment uses an immersive display with visual, aural, and tactile feedback, and direct interaction with a spatial context. The third environment is similar to the second and only differs in that it shows the real hands (instead of virtual hands), using a computer vision technique. These VE configurations are included in the study based on the prior research results that reported the user's changed perception due to providing tactile augmentation and showing of realistic self body parts in direct interaction (Hoffman, 1998; Slater & Usoh, 1994).

The initial hypothesis and intuition is that the immersive virtual environments providing tactile feedback, especially the one showing the real hands (implemented in a wireless fashion), would produce results that correlate more highly with that of the real environment than that of the desktop environment. The hypothesis is based on many prior research results that have shown the change in user perception of the surrounding (virtual) environment (or user-felt presence) due to the VR elements such as first-person viewing with head tracking, proprioception, multimodality, and so on (Hendrix & Barfield, 1996; van der Straaten, 2000; Welch, Blackmon, Liu, Mellers, & Stark, 1996). Although the user-felt presence is not equivalent to feelings about a specific product, there seem to be grounds to think that the same argument can be extended to perception about virtual products.

This paper is organized as follows. In Section 2, work related to this research is first reviewed. In Section 3, a more detailed background explanation to the initial hypothesis is given and the details of the implementation of the three virtual product evaluation platforms (one desktop VR and two immersive VR-based) to be compared to the real product are explained. In Sections 4 and 5, the evaluation indices for affective properties and the experiment procedure are described, respectively. In Section 6, the findings and analysis are discussed. Finally, the paper concludes with a summary and plan for the future in Section 7.

2 Related Work

VR may be well suited for design applications. Naturally, there have been many attempts to apply VR to CAD and scene modeling (Aukstakalnis, 1992; Davies, 2002; Liang & Green, 1994; Murakami, Nishimura, Impelluso, & Skelton, 1998). The main research issue is whether VR, or more narrowly 3D multimodal and immersive (and even stereoscopic) interfaces, would produce a faster, better, and more intuitive design tool. The results have been mixed; using VR only seems more productive for specialized design applications (e.g., large scale designs, designing at the scene). In fact, VR systems are not well suited for some design tasks that require 2D sketching and alphanumeric data input. Another useful application of VR in the context of product development is simulation. For instance, for domains involving human factors such as airplane and land vehicle design (Davies, 2002), factory layout (Waller & Ladbrook, 2002), assembly planning, and reachability analysis (Steffan, Schull, & Kuhlen, 1998), VR has proven its usefulness against its desktop counterpart. Design review has become one of the major productive applications of VR. Accomplishing design evaluation tasks in immersive virtual environments enables designers to evaluate and iterate through multiple alternative designs more quickly at low cost.

Kerttula, Salmela, and Heikkinen (1997) have developed a VR-based mobile phone development and evaluation platform (coincidentally to our application domain). With their system, the user can evaluate the designed product on a stereoscopic desktop display. The objective of our study is to validate that such a system would indeed elicit emotional responses similar to real products.

In fact, the main objective of virtual reality is to fool the user into believing that she or he is in another synthetic environment. This concept is often called presence and dubbed informally as the feeling of "being there" (Slater, Usoh, & Steed, 1994). Various studies on presence have indicated the importance of interaction, multimodality, and context of use (Slater, 2002; Witmer & Singer, 1998), which are distinguishing features of VR from desktop computing environments. Likewise, it is believed that these are very important in affective evaluation of virtual products, since eliciting emotions or affective properties similar to those of the real scene is one aspect of presence. One of the major topics in the study of presence is how presence can be measured. Similar to the methods of affective engineering, a subjective questionnaire is often used to measure the level of presence for a given virtual environment (Kim & Biocca, 1997; Lessiter, Freeman, Keogh, & Davidoff, 2001; Lombard & Ditton, 2000; Sadowski & Stanney, 2002; Schubert, Friedmann, & Regenbrecht, 1999; Slater et al., 1994; Witmer & Singer, 1998). Physiological signals and user behaviors are also starting to be used to measure presence (Meehan, 2000; Prothero, Parker, Furness, & Wells, 1995; Sheridan, 1996; Wilson & Sasse, 2000). However, no work has been reported on comparing the affective properties of a virtual object (or product) with real counterparts.

On the other hand, several approaches such as Kansei engineering (Nagamachi, 1995), product personality assignment (Jordan, 1997), and sensorial quality assessment (Bandini-Buti, Bonapace, & Tarzia, 1997; Bonapace, 1999) were proposed for affective design. (See the reference cited in Jordan, 2002, for a comprehensive survey of these approaches.) Among the approaches, Kansei engineering developed by Nagamachi about 30 years ago has been applied to (and its effect verified in) many different product domains such as automobiles, electronics and appliances, home and office supplies, and so forth, in order to establish a Kansei model to incorporate the user's feelings into the respective product design (Nagamachi, 1995, 2002). In the case of mobile phones, Han et al. (2002) and Yun et al. (2001) developed a model that can predict affective satisfaction level based on the 56 design feature selections (e.g., color, keypad style, overall shape, location of the power button, etc.). This model exhibited quite a high predictability with an r^2 value of 0.7, and furthermore included an algorithm to identify the critical design features according to the importance of a particular affective property (Han, Kim, Yua, Hong, & Kim, 2004; Hong et al., 2002).

3 Features of Virtual Affective Evaluation Systems

In this section, we consider which features are important for design evaluations with virtual products to be as effective as the real product samples. These features are implemented in the three virtual evaluation systems and tested if they are indeed influential. We note that in this study, the mobile phone has been selected as the target design whose affective properties are sought, under the assumption that it represents a class of designs that are portable (small-sized) and interactive (e.g., MP3 players, PDAs, pagers, walkmans, palm top computers). This influenced the selection of important system features to be examined in this study.

3.1 Requirements of Virtual Affective Analysis System

The foremost requirement of any analysis system to study virtual affective properties would be to provide sufficient *visual realism,* especially for the product itself (as opposed to the scene that the virtual product is included in). The problem is that it is difficult to quantitatively specify the amount of required realism. While current computer graphic rendering and modeling tools offer photorealistic image quality and high geometric correspondence, there are other visual cues such as texture, internal depth, and concavity that computer graphics cannot convey effectively. In this study, all the tested platforms use the same graphic model, that is, the platforms provide the same visual quality for each virtual mobile phone (see Figures 2, 3, and 4 later in the paper), and we investigate if other factors such as direct interaction with tactility make any difference in judging the affective properties of a mobile phone. Another related requirement is to have the virtual product match the real one in terms of *size*. We believe that this is especially important for small-sized products such as a mobile phone.

Our second requirement for a satisfactory platform to analyze affective properties is *reconfigurability;* that is, the system should easily allow testing of many similar design alternatives. Providing reconfigurability in terms of the visual or aural feedback is relatively easy (just create a new or modify an existing model and render; then reprogram the sound feedback), however not so for tactile feedback (if this feature was indeed necessary). We will come back to this issue later in the section. As part of reconfigurability, we believe that the ease in the *change of context* is very important. The context refers to a particular scenario or surrounding scene in which the product is examined. For instance, different affective responses may be obtained when the mobile phone is used at home, in an office, outdoors, and under different situations. Testing many real design mock-ups under many different situations would be practically impossible. Desktop CAD systems are also not so amenable to creating different product usage contexts. However, virtual environments can easily accommodate such contexts.

The third probable requirement for sufficient affective evaluation of small-sized hand-held products is *direct interaction*. A related requirement to direct interaction is the *provision of tactile/haptic modality* in addition to the usual and relatively easy to provide visual and aural interaction. It has been generally established that multimodality increases the effectiveness of the interaction in virtual environments (Popescu, Burdea, & Trefftz, 2002). In addition, it has been found that users prefer multimodal interfaces over unimodal interfaces (Clow & Oviatt, 1998; Oviatt, 1999; Oviatt, DeAngeli, & Kuhn, 1997). Haptic feedback, in particular, is one of the most important modalities when direct manipulation is required in the task (Popescu et al., 2002).

However, current haptic/tactile devices and technologies are still far short of providing practical solutions to generating realistic force/texture feedback. The popular ground-based systems such as Sensable's PHANToM, can only simulate the forces and surface textures at the point of contact (Massie & Salisbury, 1994; Sensable Technologies Inc., 1994). An exoskeleton glove device like the CyberGrasp system (Immersion Co., 1998) is very expensive and inconvenient to use.

An alternative approach is to use a "prop." A prop is an interaction device that represents the virtual object (to be interacted with), and whose shape and/or appearance match that of the actual physical object (Hinckley, Pausch, Goble, & Kassell, 1994). Props can be spatially registered with virtual objects providing inexpensive physical feedback to the user. Hoffman (1998) refers to the technique as tactile augmentation. Props allow us to add inexpensive physical and tactile feedback, significantly increasing presence for immersive environments and establishing a common frame of reference between the device and desktop 3D user interfaces. The introduction of tactile augmentation allows us to explicitly control the realism of virtual environments. The disadvantage of props is that each prop only represents one object.

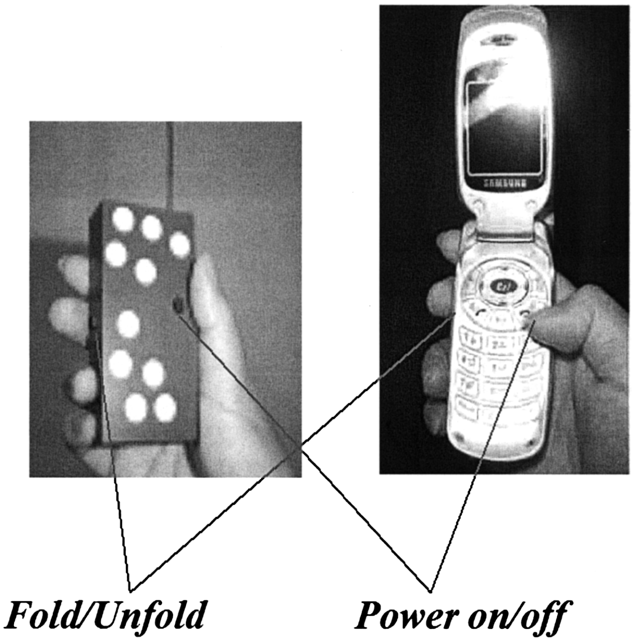


Figure 1. *The prop used to replace actual mobile phones is simply a rectangular box with wireless event generating switches. The switches are wireless and send pushbutton events to the mother station through RF control (the black line on top is the antenna). There are yellow dots on the prop, which are markers for vision-based tracking.*

In the light of this, designing a prop (or interaction device) that looks exactly like the actual phone (to be tested) is not only restrictive in its applicability, but also defeats the very purpose of using virtual products (that is, we would like to eliminate the need for building physical mock-ups or prototypes as much as possible). Our proposal is to design a reconfigurable prop that represents a family of products. For instance, as for the mobile phones we are testing, the designed prop is just a flat rectangular box (as most mobile phones are roughly rectangular) with pushbutton switches on it (this is of course not what the user would see but only feel in the hand). Figure 1 shows the prop used in our experiment to provide the tangibility and interactive feeling of mobile phones. Currently, we include only two switches for a few simple functions. Certainly, more such event generators (i.e., dials, buttons, etc.) can be added to suit the particular purpose of the system. Note that the Fold/Unfold button does not exist on actual mobile phones, but it is put on the left side of the prop similar to the position of the side buttons on actual mobile phones. This position is already familiar to mobile phone users, although the functionality is different. The tracked prop can appear in the virtual space as a variety of mobile phones even though the size and shape of what appears on screen and what is held in the hand are not perfectly matched. We hypothesize that the benefit of having the tangibility outweighs this disadvantage.

The use of a representative prop (that is, one that only represents the actual object, but is not the actual object itself) necessitates the use of a head mounted display (HMD; as opposed to a desktop or projection display) so that the virtual product (or mobile phone) can be rendered at the position of the prop in the virtual space without distraction. This setup entails the use of an HMD, which does inconvenience the user and make the overall system more expensive. There are HMDs with reasonable resolution that are quite affordable, in the range of $2,000, which is comparable to the price of an LCD monitor. The HMD model used in our experiment, i-Visor DH-4400 VPD, only weighs about 120 g and was designed for prolonged TV watching or game

Figure 2. *Virtual space with a virtual mobile phone and virtual hands (Environment II).*

Figure 3. *The same virtual space of Figure 2, but with real hands (Environment III).*

playing. We project that the narrow field of view (FOV) of these low-end HMDs will not be a significantly negative factor because the target product is small enough to fit within the screen. However, another problem with the HMD is that, in the virtual space, users have to interact with the target product using virtual hands, and this is expected to drop the feeling of directness and realism. Not knowing how significant this factor will be, we propose two VR platforms: one that shows virtual hands (see Figure 2) and another that shows the real hands, using a computer vision technique (see Figure 3). Thus, overall, we believe that the benefit of having a passive haptic feedback outweighs the disadvantage of having to resort to the HMD.

A final preferred, but not easily satisfiable, requirement for an ideal VR platform for affective property analysis is that it must be reasonably *free from device problems* in terms of usability and cost. Aside from the HMD (even though it is a relatively cheap model), a tracker is required to track the movement of the head and hand(s). While the first VR platform that shows virtual hands uses a conventional magnetic 6D tracker (called the Polhemus FASTRAK) which is quite expensive and cumbersome to use due to its wires, the second VR platform that shows real hands uses a camera and markers to track the position/orientation of the prop, a significant improvement in terms of both usability and cost. We still decided to use wired trackers in the experiment to purposely include that VR factor in the result.

To summarize, according to the presupposed requirements of a VR-based system to analyze the affective outcome, three experimental setups are proposed according to the number of hypothetically desired system features. All of them offer highly realistic visual and aural feedback, but differ in the style of interaction. The first is the conventional desktop system in which a realistic graphic rendering is shown on a CRT monitor; a keyboard/mouse-based interaction is used to examine and simulate the behavior of the mobile phones (referred to as Environment I). Both the second and third systems are immersive-VR-based and both offer visual, aural, and passive haptic (using the reconfigurable prop) modalities in interacting with the product using an HMD and a way to reconfigure their content to create various product usage scenarios and sceneries. They differ in that one shows virtual hands (referred to as Environment II), and the other, real hands (referred to as Environment III). The image segmentation technique used to show the real hands in the second VR platform may introduce an incoherent image, because of the size and shape

Table 1. *The Proposed Requirements for a VR-Based Affective Analysis System and the Related Factors Tested in the Three Experimental Setups*

Three important properties of VR-based affective evaluation system	Environment I (desktop VR)	Environment II (immersive VR 1)	Environment III (immersive VR 2)
Visual realism[a]	Low (cursor)	Medium (virtual hand)	High (real hand)
Provision of context[b]	None	None	None
Direct interaction/tactility[c]	Low (no tactility)	Medium (tactility /virtual hand)	High (tactility/real hand)

[a] The graphic realism of the mobile phone designs were held the same. The realism differed in terms of the representation of the hand.

[b] The effect of context provision in the three test platforms was not treated as a factor in the experiment as Environment I (desktop VR) is limited in that capability.

[c] The degree of direct interaction and tactility differed by the use of props and the representation of the hand.

difference between the actual phone and the prop. That is, the actual user's hands segmented from the camera image are holding the prop, not the actual phone, thus when the virtual phone image is overlaid on top of the user's hands, the fingers may look unnatural or a slight occlusion problem can occur (see Figure 3). However, as already mentioned, it has the advantage of inducing more directness in terms of interacting with the target design. Table 1 summarizes the proposed requirements for a VR-based affective analysis system and the related factors tested in the three experimental setups. The details of the system architectures are described in the subsequent subsections.

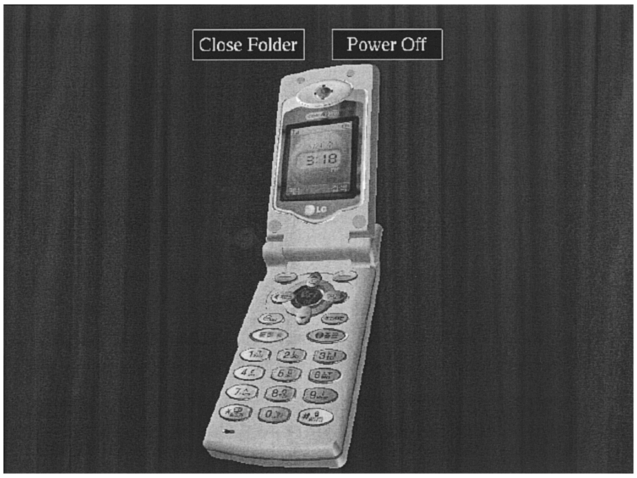


Figure 4. *Mobile phone shown on a desktop monitor (Environment I).*

3.2 The System Architectures of the Three Tested Virtual Platforms

In this section, the details of the system architecture and some implementation details of the three proposed VR systems for the analysis of the affective impact of mobile phones are described. The basic architecture of the three systems is the same, except for the user interface part.

3.2.1 Environment I: Desktop VR Platform. Figure 4 shows what the user saw on the desktop monitor and interacted with using the mouse. The mobile phones to be evaluated were modeled using the Autodesk 3Ds Max modeling tool, and looked quite realistic, employing texture mapping techniques and lighting effects. The virtual model could be translated, rotated and scaled by keyboard press, mouse clicks, and by mouse dragging. Simple behaviors like pressing the buttons and opening/closing the phone folder could be invoked and a simple sound feedback was provided (e.g., button press beeps, sound effects for power on and off, etc.). The image resolution used for rendering

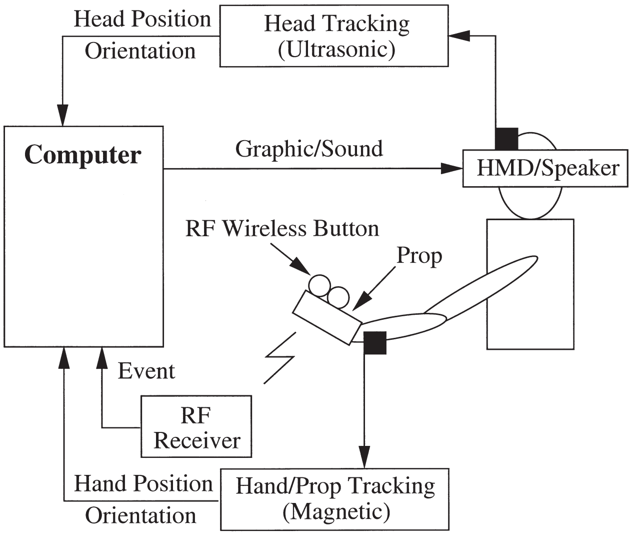


Figure 5. *The architecture for Environment II, the immersive VR version.*

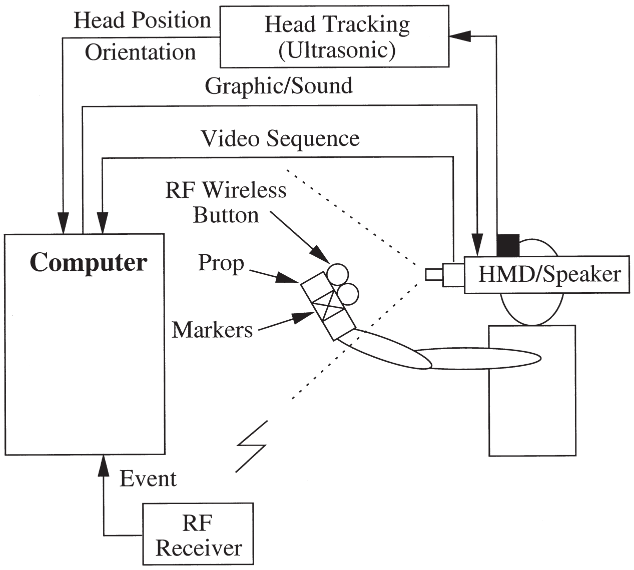


Figure 6. *The architecture for Environment III, the mixed reality version.*

the virtual model was 800 × 600, which was the same resolution as the HMD used in the immersive VR platforms (described in Sections 3.2.2 and 3.2.3).

3.2.2 Environment II: Immersive VR Platform 1. Figure 5 shows the architecture of the virtual reality platform comprising the computer that processed the sensor input and rendered the virtual scene with the virtual hands, virtual mobile phone, sound effects, and so forth. One ultrasonic sensor was used to track the viewpoint (i.e., head tracking) and another magnetic sensor for the arm. The choice was simply due to the operating range and accuracy. The ultrasonic sensor was much more accurate but had only limited operating range, while the magnetic sensor's accuracy was very much affected by the surrounding environment. It was assumed that the head would not move much while the hand needed a wider working space. Only one sensor was used to track the hand and the prop. The arm was rendered automatically by a simple inverse kinematic relation and using the position and the orientation of the hand/prop (see Figure 2). The visual quality of the rendered virtual mobile phones was same as that for the desktop VR platform.

For both Environments II and III, an HMD, called the i-Visor DH-4400 VPD, was used. It had a 31.5° diagonal FOV with a resolution of 800 × 600. As explained previously, wireless button devices were attached to the prop to simulate the keys and buttons of the actual mobile phones. Both systems used the Logitech 3D mouse for head tracking.

3.2.3 Environment III: Immersive VR Platform 2 (Mixed Reality). In Environment III, a camera system (Point Grey's Dragonfly) attached to the HMD was used to track the prop and segment the image of the hand/fingers holding the prop (see Figures 6 and 7). In order to track the prop using computer vision, ten yellow markers were put on the blue colored rectangular prop (see Figure 1). From the markers, the position and orientation of the prop were computed and transformed into the world coordinate on which the virtual mobile phone was drawn first (the camera parameters are known because the pose of the camera relative to the head is fixed and known, and the head is being tracked). An algorithm called the ICP (Besl & McKay, 1992; Wunsch & Hirzinger, 1996) was used to

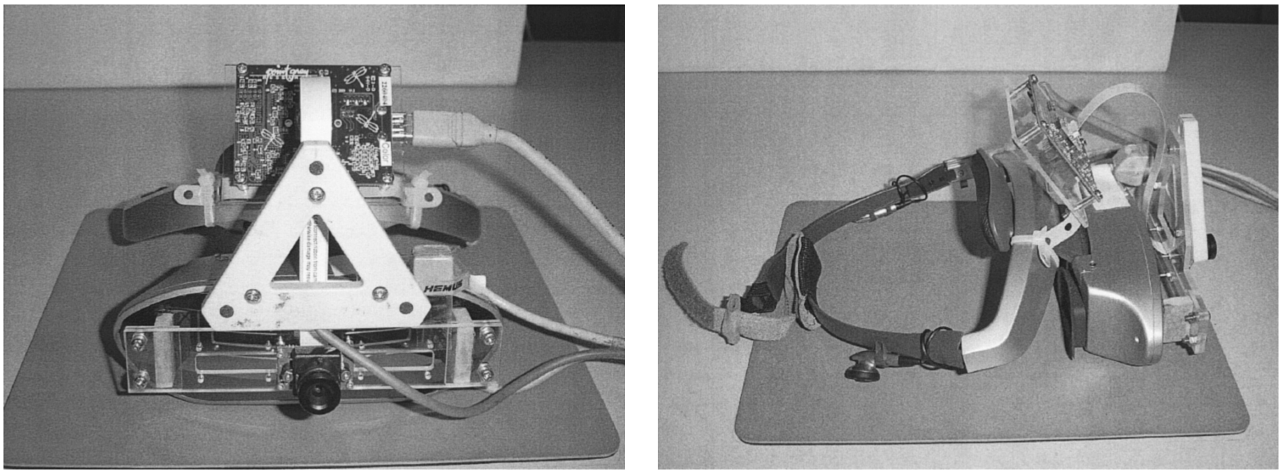


Figure 7. *The camera system, head tracker, and HMD used for Environment III (the mixed reality version). In Environment II (the immersive VR version), the same physical configuration was used, but the camera system was deactivated. (left) Front view. (right) Side view.*

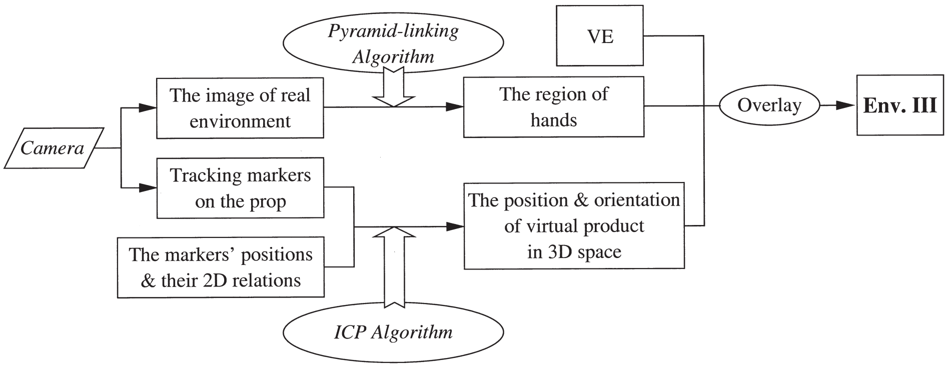


Figure 8. *Tracking the prop and extracting the hand image in Environment III.*

continuously track the ten markers between successive frames. In the meantime, the hands/fingers were segmented out of the image using an algorithm called Pyramid Linking (Burt, Hong, & Rosenfeld, 1981; Jahne, 1997) and overlaid on the virtual image, which had the same visual quality as in the immersive VR platform used in Environment II. This way, the finger image was not occluded by the mobile phone. Figure 8 illustrates the entire process.

In Environment III, each phone design was aligned with the prop according to the location of the power button since the location of power buttons for most (folder-type) mobile phones is similar. There was no serious problem due to the slight mismatch in the position of the power button (which was used as the reference for the graphic overlay). The size of the physical button on the prop was less than that of the virtual power button on each mobile phone design, which was smaller than users' fingers (or thumbs). On the other hand, the location of the side button on the prop was different from those on the different phone designs. However, this mismatch did not introduce any serious problem either, since users tried to find the side button by using touch only and usually pushed it without looking at it. According to our observation in the experiment, none of the participants

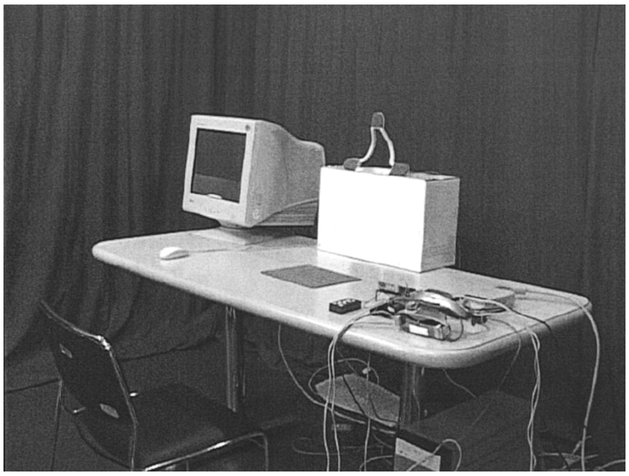


Figure 9. *The physical space in which the experiments are carried out (Environment 0).*

tried to find or pushed the side button by looking at it, nor did they report a mismatch problem. For the same reason, the mismatch between the side button sizes of the prop and the actual phones was also not a serious problem.

3.3 The Control Condition: Real Platform (Environment 0)

Figure 9 shows the real product evaluation environment. It simply consists of a desk on which the mobile phones are put for user, sitting on a chair, to take up and examine. The same physical space was used for the subsequent experiments with Environments I, II, and III (for convenience sake). That is why the figure shows additional equipment such as the monitor (for Environment I), the HMD, and the tracker equipment (for Environments II and III).

The product evaluation indices were extracted from an initial *product evaluation model,* based on prior work by our industrial engineering colleagues (Han et al., 2004). The real products were evaluated based on the extracted evaluation indices in Environment 0. The same evaluation was conducted using Environments I, II, and III, and the results were analyzed and compared to validate our initial hypothesis, for instance, that the VR elements such as the tactile augmentation and the self-body visualization indeed contributed to a more accurate affective assessment.

4 Evaluation Indices for Affective Properties

The affective analysis of (virtual) mobile phones was carried out using an index scheme and scoring method developed by the co-authors in a previous study (Han et al., 2004; Han et al., 2002; Hong et al., 2002). In that study, seven indices were introduced to express the affective feelings of the users toward the product: texture, attractiveness, luxuriousness, granularity, harmoniousness, simplicity, and rigidity. Similar to this methodology, the participants in this study also evaluated and graded the virtual product in the scale of 0 to 100 along the seven representative affective indices. The definitions of these seven indices are given in Table 2.

5 Experiment

5.1 Evaluation Environment

The physical evaluation environment used in the experiment has been already described in Section 3.3. As seen in Figure 9, the environment was enclosed by a curtain (blue). Although one of the strengths and requirements of a VR evaluation platform is the provision of context and scenarios, this feature was deliberately taken out to make a fair comparison with the desktop system only on the basis of direct interaction with tactile augmentation and self-body visualization. This simple evaluation space was recreated, including the lighting effect, in the virtual space when Environments I, II, and III were used.

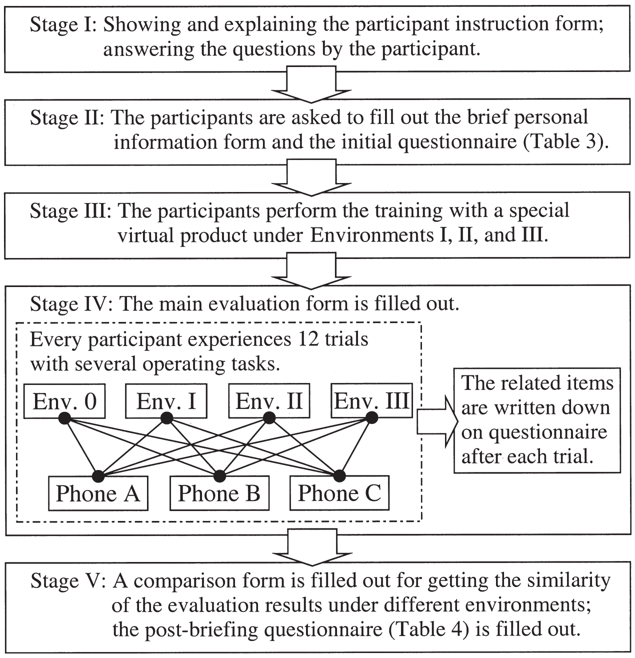
5.2 Experimental Procedure

Thirty-six participants performed the task of examining and operating the three different models of mobile phones in four test environments (that resulted in $3 \times 4 = 12$ different test combinations). Each participant visited our VR lab at an appointed time and experi-

Table 2. *The Definition for Seven Affective Satisfaction Degrees*[a]

Affective indices	Definition
Texture	The image of a product developed by its texture
Attractiveness	Degree to which a product is pleasing, charming, and arousing interest
Luxuriousness	Feeling that a product looks flashy, splendid, or extravagant
Granularity	Degree to which a product is worked out with a great care and in fine depth
Harmoniousness	Feeling that the components of a product are well-matched or in harmony
Simplicity	Degree to which the user feels a product simple or tangled
Rigidity	Feeling that a product looks stout, stable, and secure

[a] Han et al., 2004.


Stage I: Showing and explaining the participant instruction form; answering the questions by the participant.

Stage II: The participants are asked to fill out the brief personal information form and the initial questionnaire (Table 3).

Stage III: The participants perform the training with a special virtual product under Environments I, II, and III.

Stage IV: The main evaluation form is filled out.

Every participant experiences 12 trials with several operating tasks.

The related items are written down on questionnaire after each trial.

Stage V: A comparison form is filled out for getting the similarity of the evaluation results under different environments; the post-briefing questionnaire (Table 4) is filled out.

Figure 10. *The experimental procedure.*

enced 12 trials (1 trial for each combination) in different orders. All of the sessions including training, task, questionnaires, and discussion time lasted approximately one and a half hours. The age of the participants ranged from 21 to 32 years, and among the participants were 10 females and 26 males. All of the participants had their own mobile phones and had used them for more than 2 years. Of the mobile phone types 27 were fold open, 6 were flip open, and 3 were noted as other. Twenty-seven participants used their right hands for operating their mobile phones, and the others used their left hands. The number of participants that had had an experience with a VR system was 27, and the number of participants that had had no experience was 9. The overall experimental procedure is shown in Figure 10.

5.2.1 ***Stage I.*** **Preliminaries.** A participant was first asked to read the participant instructions which elaborated on the purpose of the experiment, the definitions and related concepts of the evaluation indices, points for attention during the evaluation as well as what the participant would be doing.

5.2.2 ***Stage II.*** **Initial Questionnaire Session.** The participant's vital personal information, such as gender, age, and vocation, was collected in this session. In addition, the participant filled out the initial questionnaire shown in Table 3.

5.2.3 ***Stage III.*** **Training Session.** To understand how to operate and carry out the required task in a given system (and avoid misuse), the participants were given a short period of training prior to the actual experiment. The training involved carrying out a task, similar to that of the experimental task, in all of the three test environments, using yet another virtual mobile phone model different from the ones used in the actual test. To avoid the confusion caused by the mismatch between the sizes of the physical button on the prop and the virtual button on the phone model (described in Section 3.2.3), we required

Table 3. *The Initial Questionnaire*

		Answer			
No.	Question	A	B	C	D
1	Do you have mobile phone?	Yes	No		
2	How long have you used mobile phone?	1 year or so	2–3 years	More than 4 years	
3	Open method of your mobile phone.	Folder	Flip	Bar	Others
4	Have you tried the related VR devices before?	Yes	No		
5	Which hand to be used to operate mobile phone in general?	Right hand	Left hand		

that the participants should push the center of the virtual button when using Environment III.

5.2.4 *Stage IV.* Evaluation Session. After experiencing each of the 12 test configurations, the participants rated, on a scale of 0 to 100, the (virtual) mobile phone in terms of the seven evaluation indices for affective satisfaction described in Section 4. In order to enhance the statistical reliability and avoid the ordering effects, the order of the 12 trials were arranged in circular combination for every participant according to the Balanced Latin Square Design Methodology (Montgomery, 2001). Examining the product to assess its affective qualities meant for the users to zoom in and out of the product (desktop case), or bring the product toward or away, rotate, and play with the switches to turn the phone on or off, and open and close its folder.

5.2.5 *Stage V.* Post-Briefing. At the end of the experiment (after trying out all 12 combinations), the subjects graded each of the three test environments in the scale of 0 to 100, as to their similarities to the real environment. They also answered the five questions shown in Table 4.

Table 4. *The Comprehensive Questionnaires*

No.	Question
1	Have you ever used the same or similar mobile phone which was used in this experiment?
2	What was the most difficult affective factor?
3	Was there any abnormal incidence while performing the given tasks?
4	Did you experience any inconvenience in operating the mobile phone?
5	How did you assess the size of the mobile phone when it was shown in the VR system?

6 Results and Discussion

The averages and the standard deviations of the ranked and the original evaluation data on each affective property collected in the evaluation session are summarized in Figure 11. A two-way nonparametric within-subject ANOVA based on ranks was applied to these data. Tables 5 and 6 show the significant factors revealed by the analysis (marked with asterisks) and their statistical details, respectively. There were statistically significant differences among the evaluation environments (systems) for all of the affective properties except for simplicity. However, the SNK (Student-Newman-Keuls) post hoc comparison revealed that only the real environment (Environment 0) was in a different group (see Figure 11), that is, there was no significant differ-

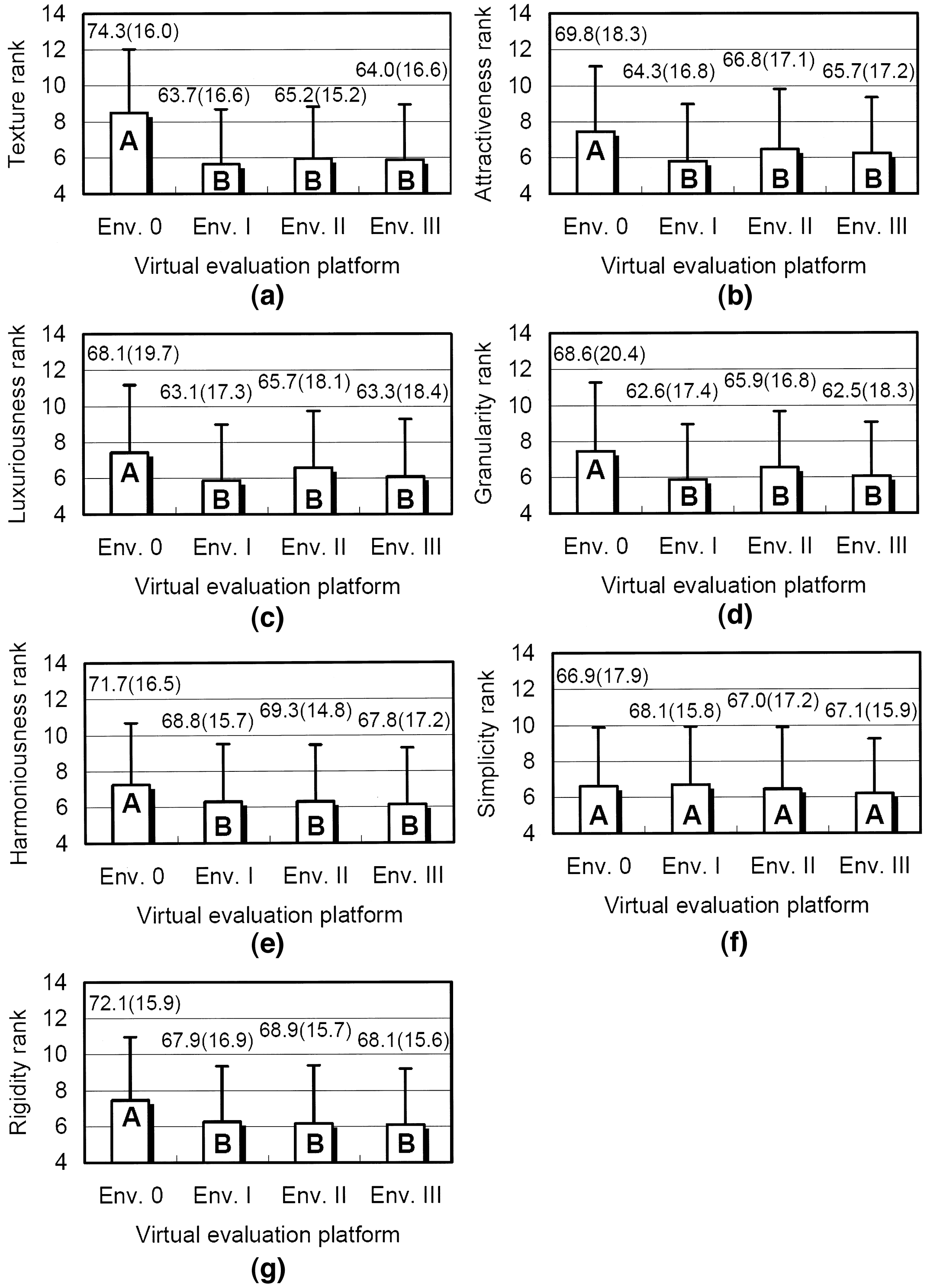


Figure 11. *The means and the standard deviations of the ranked and the original evaluation data on each affective property, and their SNK-grouping results ($\alpha = .05$). Note that A and B indicate the platforms in same group, which had no significant difference from each other, and the numbers above each bar indicate the mean and the standard deviation of the original data.*

Table 5. *Significant Factors (Marked with Asterisks) Revealed by a Nonparametric Two-Way Within-Subject ANOVA Based on Ranks (α = .05)*

SV	Texture	Attractiveness	Luxuriousness	Granularity	Harmoniousness	Simplicity	Rigidity
Product	*	*	*	*	*	*	*
System	*	*	*	*	*		*
Product × System	*		*	*			

Table 6. *The ANOVA Results on each Affective Index*[a]

SV	df	SS	MS	*F*-ratio	*p*
Texture					
Subject	35	0.00	0.00		
Product	2	617.70	308.85	22.90	<.0001*
Product × Subject	70	944.18	13.49		
System	3	589.42	196.47	19.86	<.0001*
System × Subject	105	1038.75	9.89		
Product × System	6	191.43	31.90	4.66	.0002*
Product × System Subject	210	1438.03	6.85		
Attractiveness					
Subject	35	0.00	0.00		
Product	2	1785.95	892.97	74.96	<.0001*
Product × Subject	70	833.93	11.91		
System	3	157.37	52.46	7.79	<.0001*
System × Subject	105	707.13	6.73		
Product × System	6	62.93	10.49	1.68	.1273
Product × System Subject	210	1311.19	6.24		
Luxuriousness					
Subject	35	0.00	0.00		
Product	2	1607.42	803.71	47.58	<.0001*
Product × Subject	70	1182.33	16.89		
System	3	158.29	52.76	7.77	<.0001*
System × Subject	105	712.88	6.79		
Product × System	6	93.82	15.64	3.03	.0073*
Product × System Subject	210	1082.77	5.16		
Granularity					
Subject	35	0.00	0.00		
Product	2	1259.96	629.98	51.17	<.0001*
Product × Subject	70	861.79	12.31		
System	3	162.06	54.02	6.12	.0007*
System × Subject	105	927.11	8.83		

(*continued on next page*)

Table 6 *The ANOVA Results on each Affective Index*[a] *(continued)*

SV	df	SS	MS	*F*-ratio	*p*
Product × System	6	90.30	15.05	2.21	.0430*
Product × System Subject	210	1427.29	6.80		
Harmoniousness					
Subject	35	0.00	0.00		
Product	2	567.60	283.80	14.14	<.0001*
Product × Subject	70	1405.03	20.07		
System	3	82.60	27.53	3.22	.0257*
System × Subject	105	897.24	8.55		
Product × System	6	53.04	8.84	1.21	.3049
Product × System Subject	210	1540.50	7.34		
Simplicity					
Subject	35	0.00	0.00		
Product	2	156.82	78.41	3.41	.0385*
Product × Subject	70	1607.56	22.97		
System	3	15.68	5.23	0.48	.6946
System × Subject	105	1135.65	10.82		
Product × System	6	24.91	4.15	0.56	.7641
Product × System Subject	210	1564.89	7.45		
Rigidity					
Subject	35	0.00	0.00		
Product	2	238.02	119.01	5.55	.0058*
Product × Subject	70	1500.10	21.43		
System	3	133.84	44.61	4.48	.0053*
System × Subject	105	1044.50	9.95		
Product × System	6	49.83	8.31	1.06	.3853
Product × System Subject	210	1639.21	7.81		

[a] The significant factors are marked with asterisks.

ence among the three virtual evaluation systems. This means that our initial hypothesis is rejected. According to this result, direct interaction with tactile augmentation and the high-fidelity self-body visualization had no statistically significant effect on affective evaluation. For affective evaluation, it seems that the visual factors of virtual mobile phone models were vastly more important than any others.

The average affective scores rated with the virtual systems were significantly below the scores given in the real environment (Environment 0). However, the scores rated with the virtual systems correlated very highly with those given in the real environment (see Table 7). This indicates that the VR systems still have potential as affective evaluation platforms, and they may be sufficient to replace the real platform. In addition, the relative rankings among the virtual products (i.e., three mobile phones) evaluated in the immersive platform 1 (Environment II) corresponded with the rankings among the real products on all of the affective indices. For the affective properties of attractiveness, harmoniousness, simplicity, and rigidity, it can be inferred that the rela-

Table 7 *The Spearman Rank Correlation Coefficients Between the Real Platform (Environment 0) and other Virtual Platforms on each Affective Property*[a]

Affective property	The virtual platforms		
	Environment I	Environment II	Environment III
Texture	0.52	0.50	0.48
Attractiveness	0.69	0.68	0.67
Luxuriousness	0.72	0.68	0.72
Granularity	0.68	0.68	0.63
Harmoniousness	0.65	0.63	0.63
Simplicity	0.69	0.66	0.70
Rigidity	0.64	0.52	0.64

[a] $N = 108$, $p < .0001$ for all the coefficients.

tive rankings among the virtual mobile phones evaluated in all the platforms corresponded with those among the real products, since there was no significant interaction between the system and the product factors. For the affective properties of texture, granularity, and luxuriousness on which there were significant interactions between the system and the product factors, however, only the results of the immersive platform 1 (Environment II) showed such a correspondence (see Figures 12, 13, and 14). This means the immersive VR systems can be also used for relative comparisons among products.

There were significant interactions between the products and the environment types for the affective properties of texture, granularity, and luxuriousness. Figures 12, 13, and 14 illustrate the interactions with the SNK-groups depicted in dotted rectangles. For the texture property, the results after SNK grouping showed that products 1 and 2 were in one group and product 3 in another for Environment 0, Environment II, and Environment III, but all of the products were in a single group for Environment I. That is, there was no statistically significant difference among the products in the desktop VR environment (see Figure 12), and thus the tactile augmentation from the prop did have an effect on the evaluation for the texture property (but not so for other affective properties). The post-briefing questionnaires revealed that 15 subjects thought that texture had been the most difficult aspect to evaluate. We believe that the tactile augmentation had a positive effect for the evaluation of texture.

As for the granularity property, the SNK grouping in Environment III (the mixed reality platform) was different from those in the other Environments (see Figure 13). We suspect that is because, in Environment III, the users' hand images were not exactly registered with the virtual products due to segmentation noises and no consideration of depth. Furthermore, there were occasional flickers in displaying the virtual products due to incorrect tracking by markers occluded by the user's hand. It seems that the segmentation noise and flickers also had an effect on the evaluation of the luxuriousness property (see Figure 14).

In the post-briefing questionnaire, five subjects complained of cybersickness. Thirty-two subjects reported that it was somewhat difficult to move and orient the virtual hands in Environment II, and four subjects noticed the prop-tracking problem due to the image flickers. Nineteen subjects reported that they compared the virtual phones to their (virtual) hands in order to assess the size of the virtual products in Environment II and Environment III, and nine subjects said that they did not consider the size at all. From this fact, it can be inferred that the perceived size of

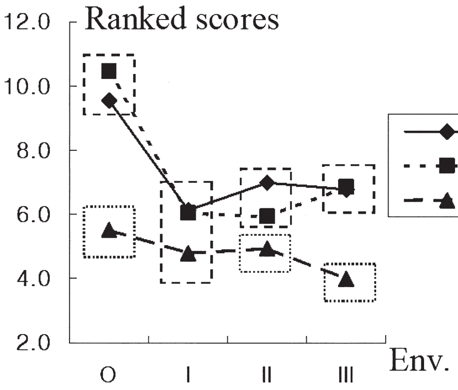


Figure 12. *Interaction graph between products and platforms for the texture property. Note that the dotted rectangles indicate the SNK-grouping results at the fixed level of the platform, that is, the products in each rectangle had no significant difference from each other for each platform.*

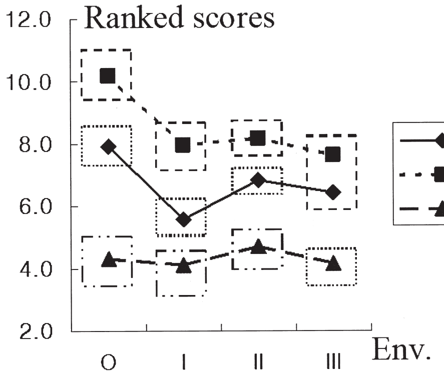


Figure 13. *Interaction graph between products and platforms for the granularity property. Note that the dotted rectangles indicate the SNK grouping results at the fixed level of the platform, that is, the products in each rectangle had no significant difference from each other at each platform.*

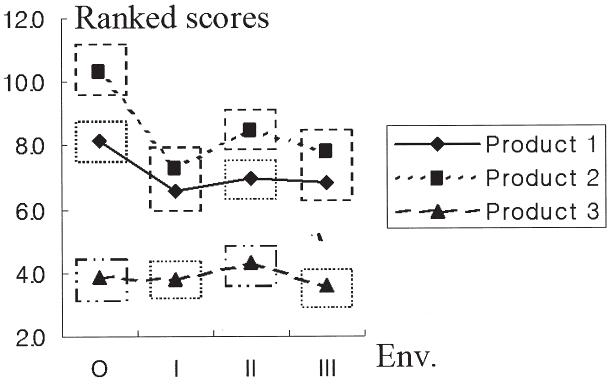


Figure 14. *Interaction graph between products and platforms for the luxuriousness property. Note that the dotted rectangles indicate the SNK grouping results at the fixed level of the platform, that is, the products in each rectangle had no significant difference from each other at each platform.*

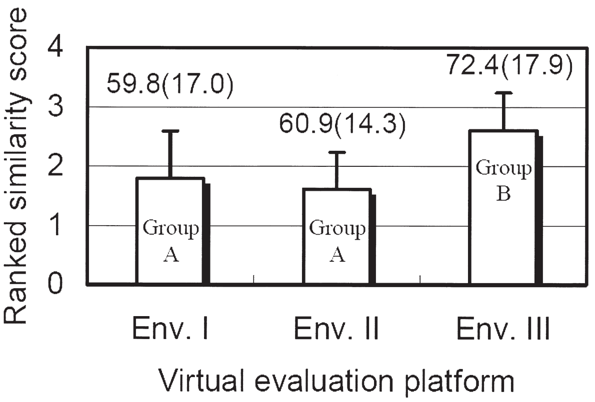


Figure 15. *The means and the standard deviations of the ranked and the original similarity scores and their SNK grouping result (α = .05). Note that the numbers above each bar indicate the mean (standard deviation) of the original score.*

the mobile phones may have influenced users' affective evaluations. In this experiment, the size perception of the products was not a factor under evaluation since the sizes of the mobile phones used in the experiment were similar to each other. However, Environment III could be a good candidate for evaluation of size-related affective properties such as heaviness (Han et al., 2004) or evaluation of the virtual mobile phones of which the shapes are same but the sizes are different, since the platform shows the actual hands in their actual size. Although the HMD used in the platform provided a low resolution of 800 × 600 with a narrow diagonal FOV of 31.5°, the virtual mobile phone and user's hands could be displayed simultaneously. The subject could easily enlarge the projected image of the phone in a natural way by pulling the phone to her (or his) eyes when she (or he) would have liked to observe it in detail.

Figure 15 shows the ranked and the original similarity scores between the real and the three virtual test environments. The one-way nonparametric within-subject ANOVA based on ranks revealed that there were statistically significant differences among the scores ($F_{2,70} = 13.71$, $p < 0.0001$). The SNK grouping test showed that Environment III was in a different group from Environment I and Environment II ($\alpha = .05$). According to the analysis, Environment III, thus, was the environment most similar to the real.

7 Conclusions and Future Work

In this paper, we have investigated the effects of the tactile augmentation and the self-body visualization by comparing three types of virtual environments, namely desktop VR, immersive VR with virtual hands, and immersive VR with real hands, for evaluating the affective properties of mobile phones to those of the real. Our experiment has shown that while the virtual affective evaluation results correlated very highly with those of the real, no statistically significant difference could be found between the three. This finding has rejected our initial hypothesis on the positive effects of the direct interaction with tactile augmentation and the high-fidelity self-body visualization.

On the other hand, the analysis indicated the importance of enhanced interaction with tactile augmentation for evaluating the texture property. This finding was based on the fact that the relative ranking of the evaluated virtual products on the texture property in the immersive VR platforms, which was provided with the tactile feedback through the prop, corresponded with that of the real counterparts, but this was not the case in the desktop VR platform.

In this paper, we did not consider the use of environment context which is expected to be much more effective when using an immersive VR. Our future work is to further investigate these aspects, in relation to the proposed requirements for VR-based affective analysis systems.

References

Aukstakalnis, S. (1992). Virtual reality and experiential prototyping of CAD models. *DesignNet, 1*(1), 62–65.

Bandini-Buti, L., Bonapace, L., & Tarzia, A. (1997). Sensorial quality assessment: A method to incorporate perceived user sensations in product design. Applications in the field of automobiles. *Proceedings of IEA '97.*

Besl, P. J., & McKay, N. D. (1992). A method for registration of 3-D shapes. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 14*(2), 239–256.

Bonapace, L. (1999). The ergonomics of pleasure. In W. S. Green & P. W. Jordan (Eds.), *Human factors in product design: Current practice and future trends* (pp. 234–248). London: Taylor & Francis.

Burt, P. J., Hong, T. H., & Rosenfeld, A. (1981). Segmentation and estimation of image region properties through cooperative hierarchical computation. *IEEE Transactions on Systems, Man, and Cybernetics, 11*(12), 802–809.

Clow, L., & Oviatt, S. L. (1998). STAMP: A suite of tools for analyzing multimodal system processing. *5th International Conference on Spoken Language Processing (ICSLP '98).*

Davies, C. R. (2002). Applications of system design using virtual environments. In K. M. Stanney (Ed.), *Handbook of virtual environments: Design, implementation, and application* (pp. 1079–1100). Mahwah, NJ: Lawrence Erlbaum.

Han, S. H., Kim, K. J., Yun, M. H., Hong, S. W., & Kim, J. (2004). Identifying mobile phone design features critical to user satisfaction. *Human Factors and Ergonomics in Manufacturing, 14*(1), 15–29.

Han, S. H., Kim, K., Kim, G. J., & Yun, M. H. (2002). Usability evaluation methodology for home/office products. *Technical Report (MI-9817-03-0003),* Ministry of Science and Technology of South Korea.

Hendrix, C., & Barfield, W. (1996). Presence within virtual environments as a function of visual display parameters. *Presence: Teleoperators and Virtual Environments, 5*(3), 274–289.

Hinckley, K., Pausch, R., Goble, J. C., & Kassell, N. F. (1994). Passive real-world interface props for neurosurgical visualization. *ACM Conference on Human Factors in Computing Systems (CHI '94).*

Hoffman, H. G. (1998). Physically touching virtual objects using tactile augmentation enhances the realism of virtual environments. *IEEE Virtual Reality Annual International Symposium (VRAIS '98).*

Hong, S. W., Kim, K. J., & Han, S. H. (2002). Optimal balancing of product design features: A case study on mobile phones. *Human Factors and Ergonomics Society 46th Annual Meeting.*

Immersion Co. (1998). CyberGrasp. Available at www.immersion.com/3d/products/cyber_grasp.php. Retrieved September 8, 2006.

Jahne, B. (1997). *Digital image processing.* New York: Springer.

Jordan, P. W. (1997). Products as personalities. In M. A. Hanson (Ed.), *Contemporary ergonomics 1997* (pp. 449–453). London: Taylor & Francis.

Jordan, P. W. (2002). *Designing pleasurable products.* New York: Taylor & Francis.

Kerttula, M., Salmela, M., & Heikkinen, M. (1997). Virtual reality prototyping—A framework for the development of electronics and telecommunication products. *8th IEEE International Workshop on Rapid System Prototyping (RSP '98).*

Kim, T., & Biocca, F. (1997). Telepresence via television: Two dimensions of telepresence may have different connections to memory and persuasion. *Journal of Computer-Mediated Communication, 3*(2). Available at www.ascusc.org/jcmc/vol3/issue2/kim.html. Retrieved June 20, 2004.

Kim, K., Han, S. H., Yun, M. H., & Kwahk, J. (2002). A systematic procedure for modeling usability based on product design variables: A case study in audiovisual consumer electronic products. *International Journal of Occupational Safety and Ergonomics, 8*(3), 387–406.

Lessiter, J., Freeman, J., Keogh, E., & Davidoff, J. D. (2001). A cross-media presence questionnaire: The ITC sense of presence inventory. *Presence: Teleoperators and Virtual Environments, 10*(3), 282–297.

Liang, J., & Green, M. (1994). JDCAD: A highly interactive 3D modeling system. *Computer and Graphics, 18*(4), 499–506.

Lombard, M., & Ditton, T. (2000). Measuring presence: A literature-based approach to the development of a standardized paper-and-pencil instrument. *3rd International Workshop on Presence.*

Massie, T. H., & Salisbury, J. K. (1994). The PHANToM haptic interface: A device for probing virtual objects. *ASME Winter Annual Meeting, Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems.*

McDonagh, D., Bruseberg, A., & Haslam, C. (2002). Visual product evaluation: Exploring users' emotional relationships with products. *Applied Ergonomics, 33*(3), 231–240.

Meehan, M. (2000). An objective surrogate for presence: Physiological response. *3rd International Workshop on Presence.*

Montgomery, D. C. (2001). *Design and analysis of experiments (5th ed.).* New York: John Wiley & Sons.

Murakami, H., Nishimura, Y., Impelluso, T. J., & Skelton, R. E. (1998). A virtual reality-based CAD system for tensegrity structures. *12th ASCE Engineering Mechanics Conference.*

Nagamachi, M. (1995). Kansei engineering: A new ergonomic consumer-oriented technology for product development. *International Journal of Industrial Ergonomics, 15*(1), 13–24.

Nagamachi, M. (2002). Kansei engineering as a powerful consumer-oriented technology for product development. *Applied Ergonomics, 33*(3), 289–294.

Oviatt, S. L., DeAngeli, A., & Kuhn, K. (1997). Integration and synchronization of input modes during multimodal human-computer interaction. *ACM Conference on Human Factors in Computing Systems (CHI '97).*

Oviatt, S. L. (1999). Ten myths of multimodal interaction. *Communications of the ACM, 42*(11), 74–81.

Popescu, G. V., Burdea, G. C., & Trefftz, H. (2002). Multimodal interaction modeling. In K. M. Stanney (Ed.), *Handbook of virtual environments: Design, implementation, and application* (pp. 435–454). Mahwah, NJ: Lawrence Erlbaum.

Prothero, J. D., Parker, D. E., Furness III, T. A., & Wells, M. J. (1995). Towards a robust, quantitative measure for presence. In *Proceedings of the Conference on Experimental Analysis and Measurement of Situation Awareness,* 359–366.

Sadowski, W., & Stanney, K. (2002). Presence in virtual environments. In K. M. Stanney (Ed.), *Handbook of virtual environments: Design, implementation, and application* (pp. 791–806). Mahwah, NJ: Lawrence Erlbaum.

Schubert, T. W., Friedmann, F., & Regenbrecht, H. T. (1999). Decomposing the sense of presence: Factor analytic insights. *2nd International Workshop on Presence.*

Sensable Technologies Inc. (1994). The PHANToM devices. Available at www.sensable.com/products/phantom_ghost/phantom.asp. Retrieved September 8, 2006.

Sheridan, T. B. (1996). Further musings on the psychophysics of presence. *Presence: Teleoperators and Virtual Environments, 5*(2), 241–246.

Sherman, W. R., & Craig, A. B. (2003). *Understanding virtual reality: Interface, application, and design*. San Mateo, CA: Morgan Kaufmann.

Slater, M. (2002). *Course 49: Understanding virtual environments: Immersion, presence, and performance*. SIGGRAPH 2002 Course Notes.

Slater, M., & Usoh, M. (1994). Body centered interaction in immersive virtual environments. In N. M. Thalmann and D. Thalmann (Eds.), *Artificial life and virtual reality* (pp. 125–148). New York: John Wiley & Sons.

Slater, M., Usoh, M., & Steed, A. (1994). Depth of presence in virtual environments. *Presence: Teleoperators and Virtual Environments, 3*(2), 130–144.

Steffan, R., Schull, U., & Kuhlen, T. (1998). Integration of virtual reality-based assembly simulation into CAD/CAM environments. *24th Annual Conference of the IEEE Industrial Electronics Society (IECON '98)*.

van der Straaten, P. (2000). Interaction affecting the sense of presence in virtual reality. *Research Task Final Report,* Delft University of Technology—Faculty of Information Technology and Systems. Available at graphics.tudelft.nl/~vrphobia/intpres.pdf. Retrieved September 8, 2006.

Stuart, R. (2001). *Design of virtual environments*. Ft. Lee, NJ: Barricade Books.

Waller, A. P., & Ladbrook, J. (2002). Experiencing virtual factories of the future. *Winter Simulation Conference (WSC 2002)*.

Welch, R. B., Blackmon, T. T., Liu, A., Mellers, B., & Stark, L. W. (1996). The effects of pictorial realism, delay of visual feedback, and observer interactivity on the subjective sense of presence. *Presence: Teleoperators and Virtual Environments, 5*(3), 263–273.

Wilson, G., & Sasse, M. A. (2000). The head or the heart? Measuring the impact of media quality. *CHI 2000 (Extended Abstracts)*.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments, 7*(3), 225–240.

Wunsch, P., & Hirzinger, G. (1996). Registration of CAD-models to images by iterative inverse perspective matching. *13th International Conference on Pattern Recognition*.

Yun, M. H., Han, S. H., Kim, K., Kwahk, J., Kwahk, J., Hong, S. W., et al. (2001). Incorporating user satisfaction into the look-and-feel of wireless phones. *International Conference on Affective Human Factors Design*.