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Design evaluation of information appliances using augmented reality-based tangible interaction

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ABSTRACT

In this paper, we propose an approach to tangible augmented reality (AR) based design evaluation of information appliances, which not only exploits the use of tangible objects without hardwired connections to provide better visual immersion and support more tangible interaction, but also facilitates the adoption of a simple and low cost AR environment setup to improve user experience and performance. To enhance the visual immersion, we develop a solution for resolving hand occlusion in which skin color information is exploited with the use of the tangible objects to detect the hand regions properly. To improve the tangible interaction with the sense of touch, we introduce the use of product- and fixture-type objects, which provides the feelings of holding the product in his or her hands and touching buttons with his or her index fingertip in the AR setup. To improve user experience and performance in view of hardware configuration, we devise to adopt a simple and cost-effective AR setup that properly meets guidelines such as viewing size and distance, working posture, viewpoint matching, and camera movement. From experimental results, we found that the AR setup is good to improve the user experience and performance in design evaluation of handheld information appliances. We also found that the tangible interaction combined with the hand occlusion solver in the AR setup is very useful to improve tangible interaction and immersive visualization of virtual products while making the user experience the shapes and functions of the products well and comfortably.

1. Introduction

Information appliances are products that allow users to access information in an interactive way. Their functional behaviors expressed as human–machine interaction (HMI) tasks are becoming more complicated and convergent, but their development cycles are getting shorter as customer needs are diversified and changing fast. Developers are more forced to reduce time to market, to satisfy the needs as much as possible, and to make the efficient and extensive use of prototypes during the product development process [1,2]. They are furthermore asked to avoid making physical prototypes and to develop virtual prototypes that can be used like real products.

With the recent advances in computer technology, virtual prototyping (VP) has been considered as a promising concept to meet these requirements. It is based on the virtualization of the product that allows designers to consider various alternatives at an early stage of the product design process [1,3]. During the last two decades, the concept of VP has been employed and implemented in various fields including automotive, airplane, and home appliance industries [1,4–6]. Most of previous works on VP have been focused on visualization [1,3], assembly and disassembly testing [7,8], manufacturing process simulation [9,10], structural analysis [1,5], ergonomic analysis [1,3,11], and design review [1,11,12]. In recent years, there has been a proliferation of works on design evaluation and usability test of information appliances [13–17]. Virtual reality (VR) technologies have been mainly employed to conduct those works, but augmented reality (AR) technologies have recently emerged as good solutions that combine the advantages of VP and physical prototyping. However, it is still very demanding and challenging to develop a VP system for engineered products (including information appliances) that provides the people involved in the product development with tangible user interaction, realistic visualization of the products, and vivid simulation of their functional behaviors in a virtual environment setup available at low cost and accessible with ease to the relevant people, and thereby helps them to make the products more complete and malfunction free before production.

In this paper, in an effort to achieve such a goal, we propose an approach to tangible AR-based design evaluation of information appliances, which not only exploits the use of simple physical objects without hardwired connections to provide better visual

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immersion and support more tangible interaction, but also facilitates the use of a simple and low cost setup to improve the user experience and performance in design evaluation.

To enhance the visual immersion during user-product interaction, we develop a solution for removing visual confusion caused by hand occlusion. It first detects hand regions in a real world image and refines the rendered image of virtual object by subtracting the hand regions from the rendered image. Then, it superimposes the refined image onto the real world image to obtain an image in which the occlusion is recovered. Skin color information is exploited with the use of tangible objects to detect the hand regions properly. To improve the tangible interaction with the sense of touch, we introduce the use of product- and fixture-type tangible objects. The product-type object is used to acquire the position and orientation of the product. The fixture-type object is used to recognize the position of the user's index fingertip and to enable the user to create HMI events by touching product buttons with his or her fingertip. To improve user experience and performance in view of hardware configuration, we investigate four possible AR environment setups to adopt a simple and cost-effective setup that adequately meets guidelines such as viewing size and distance, working posture, viewpoint matching, and camera movement. We assessed the accuracy of the AR-based tangible interaction and found that the interaction can be applied to the design evaluation of a wide variety of information appliances whose button size is not less than 5 mm. From experimental results, we found that the adopted AR setup is good to improve the user experience and performance in design evaluation. We also found that the tangible interaction combined with the hand occlusion solver in the AR environment setup is very useful to improve tangible interaction and immersive visualization of virtual products while making the user experience the shapes and functions of the products well and comfortably.

Although this paper follows the approach given in [17], its contribution is that it addresses not only the development of the hand occlusion solver and the tangible AR interaction with sense of touch, but also the investigation to adopt a simple and cost-effective setup, both of which can greatly improve user experience and performance in design evaluation.

The rest of the paper is organized as follows: Section 2 summarizes the related works on the VP of engineered products especially based on AR technologies. Section 3 describes the framework of the proposed approach. Section 4 describes the solution for resolving hand occlusion, and Section 5 describes the tangible AR interaction using the product- and fixture-type objects. Section 6 discusses the adoption of a simple and cost-effective hardware setup. Section 7 describes system implementation and experimental evaluation to demonstrate the quality and usefulness of the proposed approach. Section 8 closes the paper with some remarks.

2. Related works

Various technologies including virtual reality (VR), tangible user interface (TUI), and augmented reality (AR) have been utilized to support the VP of engineered products (including information appliances). Most conventional solutions for supporting VP were based on VR technology in which software and hardware tools including head mounted displays (HMD), data gloves and haptic devices are combined to provide realistic display of products in a simulated environment and to offer various interaction and evaluation means. To name a few, Park et al. [13] suggested virtual prototyping of consumer electronic products by embedding functional behavior simulation into VR techniques for design evaluation, and Kanai et al. [16] presented similar approaches to 3D prototyping for design evaluation and usability assessment of digital products in which user interface description languages are properly utilized. With VR-based prototyping solutions, however, it is not easy to acquire immersive visualization and tangible interaction by low cost VR devices.

Many alternatives to VR-based solutions have been proposed, which adopted tangible user interface (TUI) [18,19] and augmented reality (AR) [20,21]. In TUI, physical objects and ambient spaces are used to interact with digital information. Hardwired connection is often employed using electronic components. Toolkits such as Phigets [18] and d.tools [19] were presented to provide visually prototyping physical user interfaces. Tangible interfaces are quite useful because the physical objects used in them have properties and physical constraints that restrict how they can be manipulated. However, it is difficult to change and evaluate an object's physical properties dynamically. AR techniques can naturally complement TUI by providing a natural environment which augments the real world scene with 3D virtual objects [20,21]. However, AR is limited in providing a feeling like touching physical objects although it can create the realistic appearance of the virtual objects.

The TUI and AR have been combined each other into the form of tangible AR to overcome the limitations of the TUI and AR approaches while retaining their original benefits. In a general context, tangible AR belongs to mixed reality (MR). In tangible AR, each virtual object is registered to a physical object and the user interacts with virtual objects by manipulating the corresponding physical objects in an AR environment, which makes user interaction tangible and intuitive. There has recently been a proliferation of works on tangible AR-based interaction and virtual prototyping for improving product design process.

The concept of integrating hardware and software in AR environments has been presented by many research groups. Basically, electronic components or devices are incorporated with physical objects to make input interfaces, and virtual images generated with such interfaces are augmented onto some of the physical objects in an AR environment setup which is mostly equipped either with a video-see through HMD or a camera and an LCD monitor. Various kinds of components or devices (*e.g.*, micro switches or buttons, RFID devices, magnetic or infrared sensors, communication controllers, data gloves) are used to support direct and tangible interfaces which are hardwired or wireless.

Verlinden et al. [22,23] applied the concept of spatial AR [24] to the design process in which digital images are projected on physical objects manufactured by a rapid prototyping technique. Lee and Park [25] proposed an AR-based system which combines AR techniques with physical blue foams to provide tangible feeling and natural appearance of a product in an AR environment using a video-see through HMD. Nam [26] presented a sketch-based platform to support user interface design by conducting hardware–software integrated simulations in which micro switches hardwired to physical objects are used to create input signals in a video-see through HMD setup. Kanai et al. [27] suggested the use of a glove-type wearable RFID R/W device and a physical mockup with small RFID tags attached to its faces for testing the usability of information appliances in an AR environment. The RFID tags represent the control buttons of a product and physical contacts can be detected when the user touches the buttons with the glove-type device. Their approach can provide intuitive tangibility but the touch feeling is not sufficiently natural. Aoyama and Kimishima [15] proposed a mixed reality system for evaluating designability and operability of digital appliances in which a video see-through HMD, a data glove, and a physical object with a marker are combined with magnetic sensors to provide the visualization and tracking of a virtual product, to identify the position and direction of the user's thumb, and to provide the pseudo feeling of touching product buttons in an MR environment.