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Tangible augmented prototyping of digital handheld products

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ABSTRACT

Proposed in this paper is a novel approach to virtual prototyping of digital handheld products using augmented reality (AR)-based tangible interaction and functional behavior simulation. For tangible user interaction in an AR environment, we use two types of tangible objects: one is for a product, and the other is for a pointer. The user can create input events by touching specified regions of the product-type tangible object with the pointer-type tangible object. Rapid prototyping and paper-based modeling are adopted to fabricate the AR-based tangible objects which play an important role in improving the accuracy and tangibility of user interaction. For functional behavior simulation, we adopt a state transition methodology to capture the functional behavior of the product into an information model, and build a finite state machine (FSM) to control the transition between states of the product based on the information model. The FSM is combined with the AR-based tangible objects whose operations in the AR environment facilitate the tangible interaction, realistic visualization and functional simulation of a digital handheld product. Based on the proposed approach, a prototyping system has been developed and applied for the design evaluation of various digital handheld products with encouraging feedback from users.

1. Introduction

For most digital handheld products such as a mobile phone and an MP3 player, their functional behavior is very complicated and nearly all expressed as human–machine interaction (HMI) tasks, each of which may trigger the transition between the states of the products. For successful entry of a new product into the competitive world market, it is imperative to reduce time to market as much as possible while precisely converting its demands into actual product forms, features, and functions [1,2]. An essential activity required is the efficient and extensive use of prototypes during the product development process [1,2].

With recent advances in computer technology, virtual prototyping (VP) has been considered as a new and powerful prototyping solution to overcome the shortcomings of conventional prototyping methods. The concept of VP has been widely employed and implemented in many industrial fields including automotive and airplane industries [7,8], but most works have been based on using virtual reality (VR) techniques [3–10], and they have been focused on visualization [2,9], assembly and disassembly testing [10–12], manufacturing process simulation [13,14], structural analysis [2,6], and ergonomic analysis [2,9]. Some works have been conducted on capturing and simulating the functional behaviors of digital handheld products in VP applications [15,16]. In VR-based prototyping solutions, it is not easy to build a virtual environment of fine quality (e.g. making detailed and realistic three-dimensional models) and to acquire tangible user interaction with low cost VR devices. Recently, augmented reality (AR) approaches have been applied as alternatives for developing VP solutions to overcome these shortcomings [17–23].

In order to realize faithfully the virtual design and prototyping of digital handheld products such as mobile phones and MP3 players, it is very important to provide the people involved in product development with tangible user interaction, the realistic visualization of the products, and the vivid simulation of their functional behaviors in a virtual environment. In this paper, we propose a novel approach to virtual prototyping of digital handheld products, which can satisfy such requirements by combining AR-based tangible interaction with functional behavior simulation. We call it *tangible augmented prototyping*.

The proposed approach does not require high-cost devices such as data gloves and haptic devices for user interaction. Rapid prototyping (RP) and paper-based modeling are properly adopted in building AR-based tangible objects whose manipulation in an AR

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environment can improve the accuracy and tangibility of interaction with the products. Rapid prototyping is a manufacturing technology to generate physical objects so-called RP models directly from geometric data without traditional tools easily and rapidly [2,14]. An RP model usually serves the purpose of communicating information and demonstrating ideas. It can also support various kinds of tangibility for experiments and interactions which gives rapid and critical feedback to the product development and evaluation.

The tangible objects, composed of paper and RP models without any hardwired connection using electronic components, are easily available at low cost. This makes the AR environment more accessible to developers, stakeholders, and even consumers. Moreover, the proposed approach suggests how to combine the forms, functions, and interactions of digital handheld products physically and virtually at the same time.

The rest of the paper is organized as follows: Section 2 summarizes previous work related to virtual prototyping. In Section 3, the proposed approach is described with its key components. Section 4 explains the operations of the virtual product model in a tangible AR environment. Section 5 addresses the implementation and application of the product design evaluation system based on the proposed approach. Section 6 describes a preliminary user study to show the usefulness of the approach. Section 7 closes the paper with some concluding remarks and future work to be done.

2. Previous work

Early attempts at supporting VP were based on CAD and VR systems. Powerful tools including stereoscopic display systems, head mounted displays (HMD), data gloves and haptic devices have been introduced [9] and combined to construct VP systems that provide realistic display of products in a simulated environment and offer various interaction and evaluation means. Bochenek et al. compared the performance of four different VR displays in a design review setting and mentioned that the best approach for design review activities could be a combined technology approach [24]. Park et al. suggested virtual prototyping of consumer electronic products by embedding HMI functional simulation into VR techniques for design evaluation [15,16]. As it is not easy to build a virtual environment of fine quality and to acquire tangible interaction with VR-based systems, many alternative solutions have been proposed.

Greenberg and Fitchett presented toolkits called Phigets that allow designers to explore a tangible user interface (TUI) for interactive product design [25]. Hartmann et al. presented similar toolkits called d.tools for visually prototyping physical user interfaces [26]. In TUI, physical objects and ambient spaces are used to interact with digital information [27]. Hardwired connection is often employed using electronic components. 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. The human computer interfaces and interaction metaphors originating from AR research have proven advantageous for a variety of applications [17,18]. AR techniques can naturally complement physical objects by providing an intuitive interface to a three-dimensional information space embedded within physical reality. However, although an AR interface provides a natural environment for viewing spatial data, it is often challenging to interact with and change the virtual content.

To overcome the limitations of the AR and TUI approaches while retaining their benefits, tangible AR has been suggested [19,20]. Verlinden et al. suggested the concept of augmented prototyping that projects the perspective images of the product on the physical object made by rapid prototyping techniques [21]. The concept of integrating hardware and software in AR environments has been presented [22,23]. Basically, it augments a virtual display onto the soft mockup of a product by incorporating simple switches as basic input interfaces. Prototypes with hardwired connection can provide direct and accurate interfaces, but significant efforts are usually required to implement and build them. Moreover, it is not easy to make them available and accessible to many people who are located at different places.

Although various ways have been proposed to support virtual prototyping of digital products, more research is still needed in the following aspects. The interaction should be intuitive and tangible to help developers and users in product design evaluation to make a product of interest more complete and malfunction free before production. The prototyping environment should be available at low cost without strong restriction of its accessibility to users. Moreover, for effective evaluation of the product, we need to define its behavior through forms, functions and interactions, and to develop a proper way of integrating them in a virtual environment. In this paper, we address these aspects by proposing a prototyping approach called tangible augmented prototyping.

3. Proposed approach

Fig. 1 shows the overall process of tangible augmented prototyping proposed in this paper. There are five main tasks required for relevant prototyping and downstream applications: creation of a product model, acquisition of multimedia contents data, generation of HMI functional model, construction of a FSM, and fabrication of AR-based tangible objects.

Fig. 2 shows a graphical diagram depicting key components used for the proposed approach. In the diagram, a game phone is used as an example of a digital handheld product. A product model, multimedia contents data, an HMI functional model, and an FSM constitute a virtual product model whose operations combined with tangible objects in an AR environment facilitate tangible interaction, realistic visualization, and functional simulation of the product. The visualization of the product in the AR environment is obtained by overlaying the rendered image of the product on the real world environment in real time [17,18]. For tangible user interaction, we play with the AR-based tangible objects to create input events by touching specified regions of the product-type object with the pointer-type object. For functional behavior simulation, we adopt a state transition methodology to capture the functional behavior of the product into the HMI functional model, and build the FSM to control the transition between states of the product using the model. RP and paper-based modeling are properly adopted to build the AR-based objects which support good tangibility for experiments and interactions.

During the process of tangible augmented prototyping, users may detect any problems in the overall appearance, the assembly structure, or the functional behavior of the product. In such cases, product designers correct the problems and update the product model or the HMI functional model. As shown in Fig. 1, the users and the product designers can promote the product design and development by repeating the process with the product model and the HMI functional model updated. In the following subsections, we describe how to acquire the key components used for the proposed tangible augmented prototyping.

3.1. Product model creation

Creating a product model is the most basic step for constructing the virtual product model. The product model includes the