Applying Augmented Reality and Haptics to Evaluate Dynamic Prototypes of Mobile Devices

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ABSTRACT

The current inability to realistically simulate and test dynamic user interfaces of mobile device prototypes is one of the prime limiting factors to successful product launches. Current processes provide very little insight into inter-relationships among physical form of the product, the human-machine interface and the applications that run on those devices. In this paper, we present a technique that provides a common platform where product designers, user interface developers and software programmers can interactively visualize and test their new concepts by exploring and touching a 3D virtual reality prototype using Augmented Reality and Haptics. This simulation tool can enhance or even replace traditional prototyping and facilitate testing of the prototype at various points of the design cycle.

Keywords: Augmented Reality, Product Design, Virtual Reality Prototyping, User Interface, Haptics, Simulation

1 INTRODUCTION

With drastic advancements in mobile electronic devices that flood the market everyday, traditional techniques of product development and testing have become insufficient in communicating product concepts. Among the factors that determine a product's success, usability and time-to-market play a significant role today. Usability of a product highly depends on the extent of prototyping that was done during its design. With the advent of concepts such as Rapid Product Development (RPD), there is greater demand to develop products efficiently and within a very short period of time. Introduction of PDAs, touch screen phones, and other mobile electronic devices which are heavily dependent on their complex User Interfaces (UI) have made it harder for designers to express their ideas during initial stages of product conception and design. Traditional methods such as paper prototyping [1], which provide an idea of the concept, are not very intuitive, leaving other collaborators or users open to confusion. Especially new dynamic interactions, such as drag and drop or swipe, are impossible to convey through story boards. Existing tools for creating and testing UI are two-dimensional in nature. Further, they are operated on a computer through a mouse or keyboard, which is a very different form of interaction when compared to the final product.

Foam, cardboard, rapid prototypes, and other kinds of traditional solid prototyping methods are totally deprived of any kind of interactive UI simulation ([2] and [3]). Computer-Aided Engineering (CAE) methods and other kinds of solid modeling provide the designer an opportunity to explore the product from different perspectives, but lack any facility for UI simulation and cannot mimic final-user interactions.

Software developers are forced to test their new applications on computers (via emulators), existing mobile devices or custom-made devices with bulky attachments. Though these systems provide some insight into how the application functions, they fail to provide realistic experiences as using the actual final hardware. Further, interaction styles are completely ignored while using these alternatives.

The goal of this project is to provide product designers, UI developers and software programmers, a tool to interactively simulate and iteratively test new mobile application concepts along with the proposed physical design, using natural tactile interactions in virtual environments (VE).

2 RELATED WORK

User Interface Prototyping: The quest for better UI has driven some research into using alternative methods and development techniques. Sá and Carriço [4] created wooden frames similar in size and weight to the proposed design and provided slots on top where designer/users could swap screening cards containing stages of the UI. Krauß and Krannich [5] utilized HTML pages on existing mobile devices to test the UI in mobile situations. Though this method helps accessing the effectiveness of the UI, its interactions might not be authentic due to differences in the physical form factor. Pering [6] demonstrated a method to test UI concepts through the BUCK device. This system simulates dynamic UI on the laptop screen while the user enters keys on the BUCK that interfaces to the keyboard port. This system does not address change in hardware or form factor and also reduces efficiency of interaction since the point of input and the display are distanced from each other.

Virtual Reality Prototyping (VRP): is an active field of research where computer graphics and virtual reality are used to experience a non-existent product for design evaluation or discussion purposes. At this stage, we would like to make a clear distinction between Virtual Prototypes (VP) and VRP, the latter being our subject of concern. Wang [7] describes a Virtual Prototype (or digital mock-up) as "a computer simulation of a physical product that can be presented, analyzed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model." It should be noted that a VP does not necessarily have a visual representation or graphical simulation while VRP works completely on the basis of Virtual Reality (VR) technology. Thanks to its rapidity and highly inexpensive nature compared to physical prototypes, VRP is a preferred technique in the design of complex products. Though not a new field, recently VRP techniques have been extensively used for mechanical product development in fields such as automotive and aircraft design with a focus on physical and structural design evaluation. In the past two decades, multiple research groups around the world have been working on using VRP technologies to simulate both behaviors and functions of portable electronic devices.

Behavioral simulation: Ye et al. [8] first successfully demonstrated an implementation of VRP of mobile devices using haptic feedback and stereoscopic displays. However, this implementation did not feature simulations of the wireless device UI. Jo et al. [9] implemented a method to simulate user interfaces in virtual environments using flash animations. As an alternative to completely immersive environments, Ha et al. [10] used Augmented Reality as a medium to build a virtual prototype of a portable gaming device. This method featured complete simulation of the UI and vibrotactile modules for enhanced tactile feedback. Komerska and Ware [11] investigated usage of haptic input as a method to operate 2D menus. Even though these previous works were successful in putting forth the idea of applying VP to development of mobile devices, they either did not support dynamic simulations of the UI or lacked natural interactions with it. There is a real need for the user to touch the virtual prototype and play with it in a realistic manner as they would do with the real product ([7] and [12]).

Functional simulation: Virtual Prototype of a pen-like phone model with a simple UI was modeled by Kerttula et al. [13]. The system featured stereoscopic displays along with haptic feedback and some basic logic of interactions implemented using Java and OMI/TOOLS to simulate target OS and processor functioning. Due to its lack of graphics/haptics collocation the system provides reduced immersion to the user and thereby limits their experience to unrealistic interactions. Furthermore, the system is too complex requiring a lot of time and resources involved in developing such applications. Tuikka and Salmela [14], and Salmela and Kyllönen [15] demonstrated collaboration on virtual prototyping via the World Wide Web. They used VRML and Java to build the UI and the logical models and make them available online. These systems lacked any kind of haptic interactions and did not feature stereoscopic views. Park et al. [16] described a method using product models, multimedia content data, Human-Machine Interface (HMI) functional models and finite state machines (FSM) to build functional VRP with stereoscopic displays. The interactions to this system were via traditional keyboard and mouse inputs and, thus, ruled out chances of accurately studying mobile device interactions. Further, in the above methods ([13], [14], [15] and [16]), the whole logical model had to be built from scratch. In a fast paced product development approach, this does not work out to be a feasible option and sometimes become redundant. Additionally, the logical models once built, cannot be directly used in the final implementation, limiting their use to just the prototyping stage. Liukkunen et al. [17] successfully combined UI and mobile application testing into a single environment using a SystemC-based approach for emulating target operating systems and hardware. This research does not take into account the physical model and purely focuses on mobile application simulation. It does not feature any 3D visualization and users get to interact with 2D menus and interfaces on a computer with traditional input methods.

3 NEW DESIGN CYCLE

The most common design process in mobile device literature today is sequential in nature, lacking a fluent interaction between the UI and CAD teams, which develop and test their work independently. The final results are then combined at a late stage just before the final production (Fig. 1) ([12], [17] and [18]). This model presents a huge drawback since new product development cannot afford to ignore how the UI and the form factor affect and influence each other. Additionally, independent testing increases probability of overlooking interdependency issues as each team would only be concerned with problems related to their own domain. This problem is caused by the lack of simulation tools that could help both teams to validate the results and interrelationship of their developments at early stages of the design cycle.

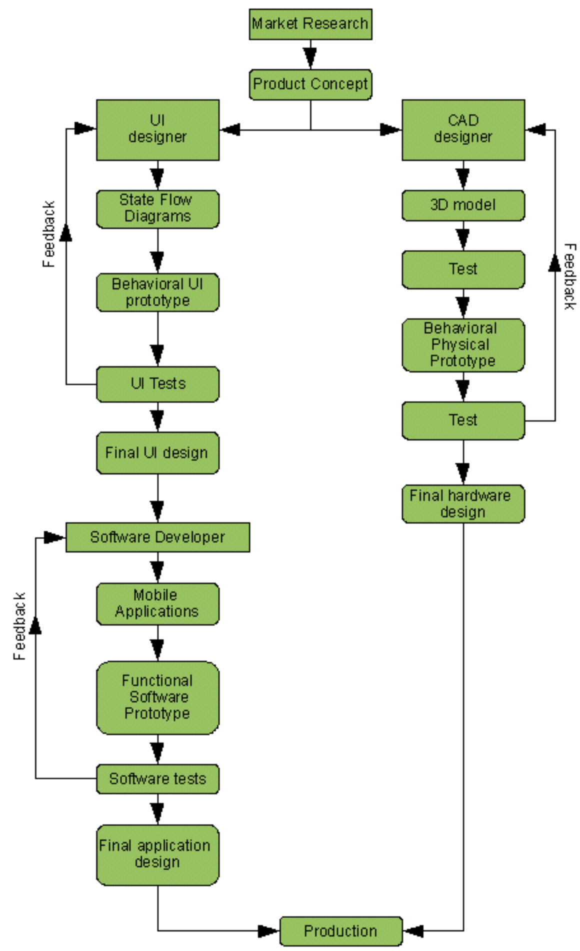

Fig.1. Traditional design process.

Fig. 1 shows a general outline of the current design process. Fig. 2 features the new design model and contrasts that with the existing design process. Unlike a sequential design environment, this model enables concurrent design. Once the market research is complete and the overall product concept has been defined along with its specifications, UI and CAD designers could start working simultaneously on their initial ideas. CAD designers could model the first cut of their design and process it suitably for haptic interactions. Meanwhile, UI designers could work on the State Flow Diagrams to decide on the sequence of menus and their inter-connectivities.

The VRP presented in this paper can be used in two stages of the product development cycle. First, the VRP acts as a Behavioral Virtual Reality Prototype (B-VRP) with the embedded browser, providing a light application that only simulates behavior of the UI making it an easy tool for UI testing. By combining the CAD (hardware) and UI (software) concepts at a very early stage of the design cycle, the VP can facilitate the testing and discussions on the physical design, HMI, the UI, their interactions, and interdependencies with other team members or users for valuable feedback. During this stage, designers can gain insight into alternative design models, features or modes of interactions. This is also a crucial stage where teams down the design path, can raise concern over certain design decisions or issues and get them resolved. Based on the obtained feedback, the CAD and UI designers could make necessary revisions to the current design and test them again until the optimum result is obtained. Suitable inclusion of 3D models of electronic components for the mobile device's interiors is also done to study fit and analyze space conflicts.

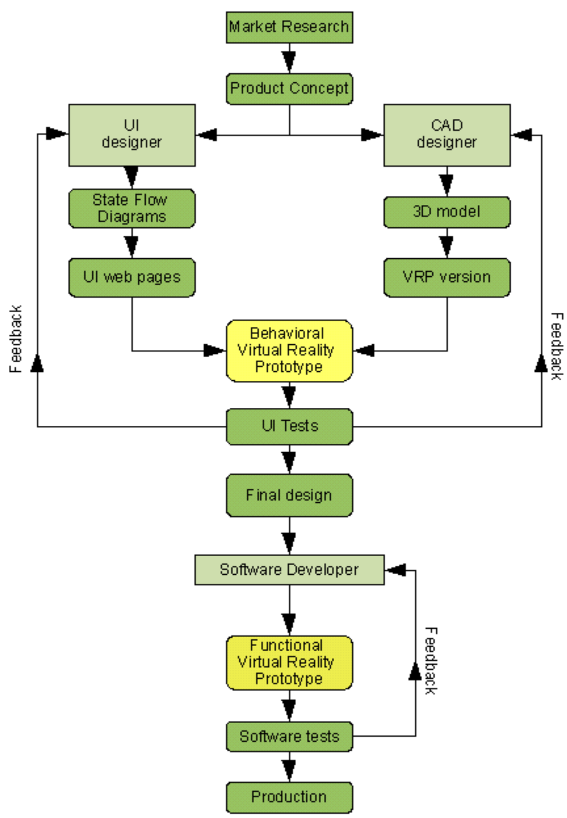

Fig.2. New design process.

Secondly, the VRP could also be used as a Functional Virtual Reality Prototype (F-VRP). At this stage, the purpose of the VRP is to evaluate functionality of a developed application along with the users' interactions before the actual hardware is ready to deploy these applications. The F-VRP helps study relationships between mobile applications and the physical device or the HMI. Application developers can now simulate and test their designs with the F-VRP, optimizing the application to better suit issues of interaction and dependency on physical design. Once finalized, the software design could be passed on for hardware-software integration and production.

3.1 RATIONALE

As shown in Fig. 3 the proposed system could be broken down into 3 different parts: the ImmersiveTouch [19], the VRP and external applications. The ImmersiveTouch integrates all hardware required for our environment like haptic devices, display, head tracking, speakers, etc. (Fig. 4). The VRP is the application used to simulate the product. Haptics and graphics rendering processes make up the virtual prototyping system. In addition to that, a content engine and a CAD modeler are used in the development or pre-processing stage.

The content engine is usually an external application that provides the content or data to be rendered in the VRP. In case of the B-VRP, the content engine is an embedded browser. For the F-VRP, it is a Software/Hardware emulator for a Mobile Operating System. The content engine creates the image of the virtual device screen and passes on this data to the graphics library as a texture in memory. This texture is then mapped on to the virtual screen of the 3D model.

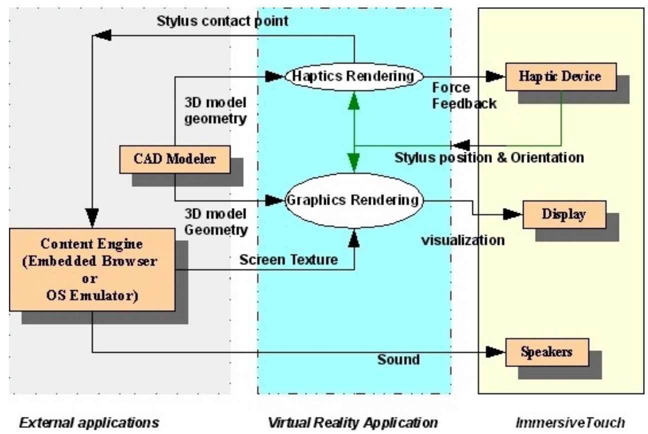

Fig.3. System used for VP.

The 3D model of the mobile device is generated in a CAD modeling package and imported into the VE. Information about the model's geometry is passed to both the haptics and graphics libraries. The haptic device continuously provides information about the stylus' position and orientation. The haptics library detects the contact point between the virtual stylus and the virtual device, as the user moves the haptic stylus over the virtual screen. The 2D coordinates of the contact point is sent to the content engine to update the image. Based on the shape and position of the 3D model and its interaction with the stylus, the haptics library generates force feedback, so different haptic materials (enclosure, buttons, screen, etc.) can be simulated and tested. The haptic materials are mathematically defined by four coefficients in a spring damper model: stiffness, viscosity, static friction and dynamic friction.

4 IMPLEMENTATION

The graphics rendering is based on Open Inventor (Coin implementation [20]). The haptic device is a SensAble [21] Phantom Desktop. The haptics rendering and communication with the haptic device is done by Open Haptics. Pro/Engineer was used to model the PDA. In case of the iPhone, the 3D model and UI textures were downloaded from the internet [22], [23]. LLmozlib [24], the embedded browser engine developed by Callum based on Mozilla [25], was integrated into the application.

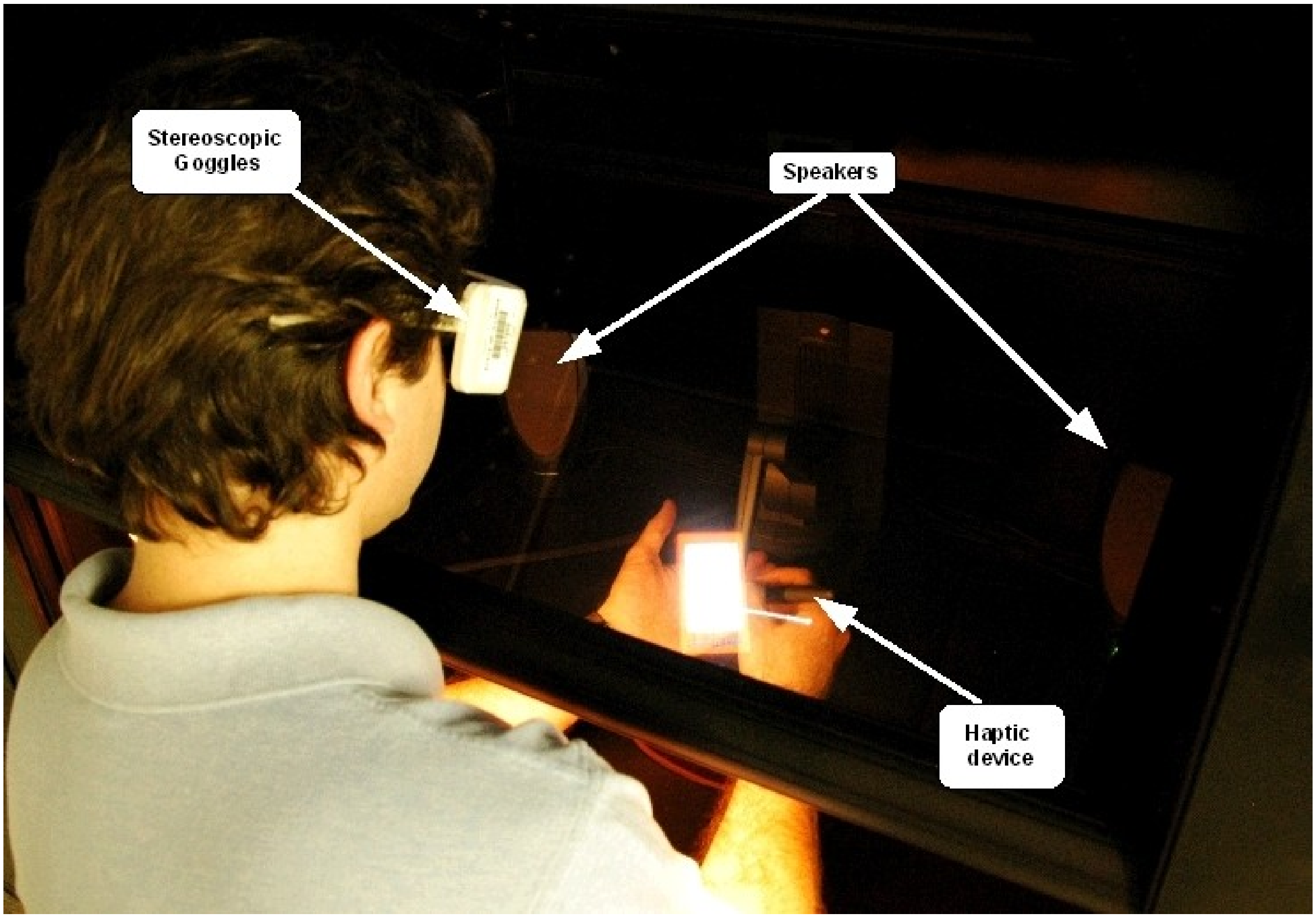

Fig.4. A user interacting with the Functional Virtual Reality Prototype of a PDA in the ImmersiveTouch.

This browser serves as the display of the virtual mobile device. to create a 2D image to be mapped to the 3D screen.

Once the virtual mobile device is designed and modeled in Pro/E, the model is converted to VRML format, so it can be loaded by the application. The internal parts of the device, which would not be visible or accessible by the final user, are removed from the model to be used for real-time simulation. This “clean up” process reduce the number of polygons and helps to maintain an acceptable haptic frame rate (1 KHz).

B-VRP: The UI is developed as a set of State Flow Diagrams (SFD) and then implemented as interlinked offline web pages using Dreamweaver [26]. Menus and icons in each page were also connected with other pages correspondingly based on the SFD. An example of a B-VRP of an iPhone is shown in Fig. 5.

F-VRP: The content for the F-VRP is extracted from Windows CE [27]- OS emulator embedded in the VE. This emulator facilitates programming and testing functionality of a newly developed mobile application by emulating the hardware of the targeted mobile device. A virtual PDA is shown in Fig. 6.

Using Open Haptics for haptic interactions, we programmed the touch and untouch callback functions to send mouse button down and up messages to the content engine along with the 2D coordinates of the contact point. Therefore, the haptic device essentially behaves as a mouse for the content engine. Other functions of the mouse such as motion, drag and drop are also simulated with the haptic device. Since the virtual display content is generated in real time by either a web browser or an OS Emulator, a wide variety of interactions like dragging, selection, etc., with a stylus become possible. Additionally, dynamic content can be built into the web pages via flash to provide a detailed and completely functional UI. Minor level logic could also be built into the web pages for functionality such as calculations, dialing, etc., using JavaScript. Buttons or keys on the 3D model could also be connected to the web pages and provided with some functionality. The Emulator on the other hand has all the logic and functionality built in providing dynamic effects and pages automatically.

GLSL Shaders are used to provide a choice of textures and lighting effects. Additionally, the shaders are connected to functions such that the color of the device could be swapped on the fly from one to the other via simple keyboard operations. The haptic device, in addition to touching the virtual prototype, is also used for rotating and maneuvering the virtual prototype inside the virtual environment. The embedded browser is also capable of rendering WebPages from the Internet, thereby providing designers an opportunity to test UI's applicability and interactions with net based applications such as maps, streaming videos, and email clients. Windows CE emulator equips us with unique capabilities since any application that runs on the emulator would also run on the actual device. This means that the software developer could just port the application tested on the F-VRP directly onto the final device. This is one major advantage when compared to previous attempts at simulating functionality since it avoids duplication of work and reduces the need for testing at later stages.

5 CONCLUSIONS AND FUTURE RESEARCH

In a world where product development cycles are getting shorter and there is growing pressure from the market to introduce drastically different and innovative products within a short period of time, it becomes crucial to have flexible prototyping abilities that can quickly and accurately evaluate usability of product concepts. To stay in competition and produce devices with comfortable user interfaces, it is important to repeatedly revise and test UI concepts.

Fig.5. Behavioral Virtual Reality Prototype of an iPhone interacted with a finger.

This application enables designers and mobile application developers to experiment with their concepts and interactions at a minimal development cost. Additionally, it also makes possible for staff from various teams or divisions in the organization to

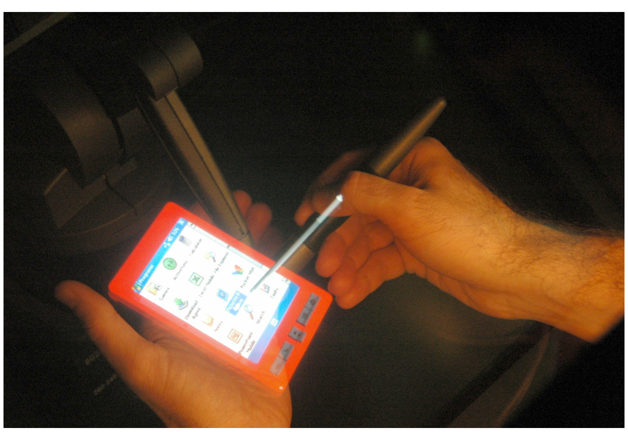

Fig.6. Functional Virtual Reality Prototype of a PDA interacted with a virtual stylus.

visualize and participate even in the early stages of design and foresee upcoming problems. This simulation tool successfully bridges the gap between physical design and UI development, thus, avoiding future confusions due to their interdependencies. Furthermore, due to the integrated nature and the ability to port applications from the prototype directly to the device, the total time required for developing a product reduces thereby contributing to market success. The current system best simulates mobile devices operated with a stylus thanks to the similarities with a haptic stylus. However, future development includes user interactions with multiple haptic devices to simulate multi-touch devices requiring tactile input with fingers.

The presented haptics-based augmented reality simulator could be extended to allow UI design directly on the virtual prototype, defining not only the buttons, menus, and windows, but also the real-time interaction among all these UI components. We foresee this concept of design-on-the-device rather than away from it, to open a multitude of creative opportunities.

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