# Integrating Hardware and Software: Augmented Reality Based Prototyping Method for Digital Products

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## ABSTRACT
For digital products, the relationship between the hardware and the software is important but their integration is largely achieved in the later phase of the design process. This paper presents new prototyping methods that allow digital product designers to effectively integrate the hardware and the software of the products from the early phase of the design process. The integration is accomplished by accurately overlaying a virtual display onto a quickly made functional hardware prototype using two augmented reality techniques; 1) using a video see through HMD and 2) using video projection. The results of the preliminary evaluation suggest that the early integrated prototypes are effective for design development and user studies.

## Keywords
Prototyping, Hardware Software Integration, Information Appliances, Augmented Reality

## INTRODUCTION
The emergence of new digital products, such as handheld tour guides and devices for a waiter in restaurants, requires effective prototyping for fast and iterative development. Hardware characteristics of these products are tightly coupled with their software, but their integration is very difficult without close collaboration between different parties of the development team. It is common to see the integration only in the later phase, when no serious design improvements can be made.

Software integration on hardware is typically achieved by incorporating display devices. In the early phase of the design process, it is difficult to produce appropriate display devices, such as customized LCDs, due to small production quantity and high cost. The hardware and the software are often separated in the early development and user studies.

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*CHI 2003*, April 5-10, 2003, Ft. Lauderdale, Florida, USA.
ACM 1-58113-637-4/03/0004

In this paper, we present new prototyping methods for digital product designers to effectively integrate hardware designs with associated software applications from the early phase of the design process, so to facilitate fast and iterative design improvements.

## PROPOSED PROTOTYPING METHOD
In the early phase of the design process, soft mockups are used to effectively develop and examine aesthetic and physical qualities of the product. The first step of our prototyping method is to create a soft mockup and incorporate simple switches as basic input interfaces. No electronic circuits or power supplies are required. The next step is to create an early software application using multimedia authoring tools. Microsoft PowerPoint and the embedded Visual Basic for Application programming environment may also be used for developing an interactive software application[1]. The hardware mockup and the software application are then connected via a key encoder which converts the switch signals into key events.

The following step is to integrate the display of the software application running on the computer with the hardware prototype. Two augmented reality systems have been developed using the ARToolkit marker tracking library[2] to accurately register the virtual display on the hardware prototype.

### Video See Though HMD based Integration
In an augmented Reality system using a video see through Head Mounted Display(HMD), the video from the camera attached to the HMD is mixed with the virtual images generated in a computer. In our system, the video is the user's view of the hardware prototype. The virtual image is the display window of software application in the computer. Figure 1 shows a user trial using the system (left) and the user's view on the HMD during the trial (right).

Figure 2 shows the system setup. The user interacts with the hardware prototype. Input interfaces are converted into key events so users can operate the software application developed with the multimedia authoring tool. The

*Figure 1: The user trial using the system (left) and the user's HMD view(right): Camera res:320x240,Display res:800x600*

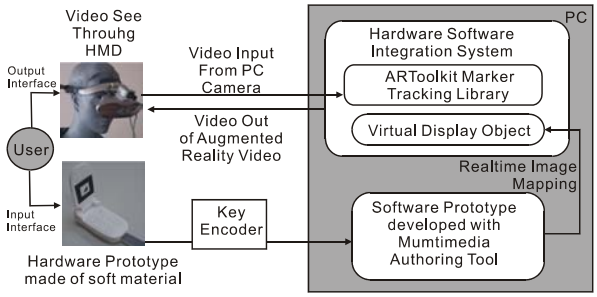


*Figure 2: The configuration of the video see through HMD based system*

software application window is captured and textured mapped onto the virtual object. A real world video captured from the user's eye location is mixed with the texture rendered display object in the ARToolkit application. The mixed video is shown on the user's HMD.

### Projection Based Integration

This system was developed to address some interface issues of the above system; discomfort wearing the HMD, late video response time and low display resolution. The area for the display is leaved in white blank and the virtual display is directly projected onto the hardware prototype using a high resolution video projector. The printed marker is positioned at the back of the hardware prototype and the camera underneath the desk tracks the position of the hardware prototypes while the user's moving the hardware around the desk. Figure 3 shows the system configuration and prototype examples developed with this system.

## PRELIMINARY EVALUATION

We are in process of conducting a formal user study to see the feasibility of the prototyping method. The hardware and the software of several mobile phone prototypes have been developed. Simple tasks of finding (task 1) and recording (task 2) a phone number are used in the initial user study. The completion time, all input key events are automatically recorded. The participants' feedback on the prototypes and the comparison between the real and the prototype phones are also collected.

In general, the initial results suggest that the prototyping method provides effective integration of the hardware and the software. All six participants could successfully accomplish the experimental tasks with both systems. The completion time to accomplish the tasks with the real phone (means/SD of task 1: 17sec/3.3, task 2: 31sec/7.8)

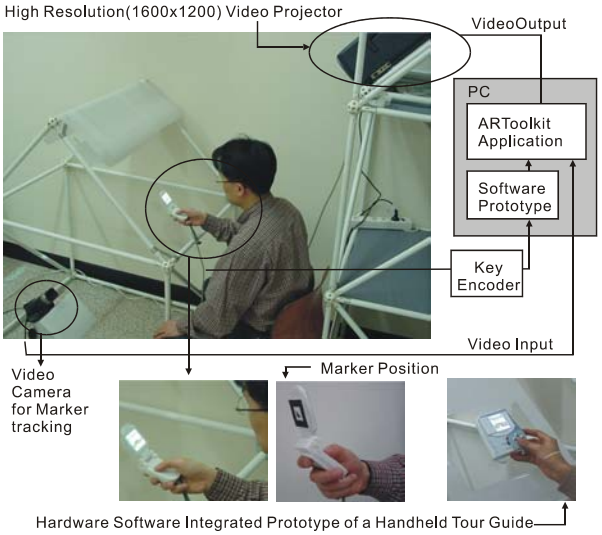


*Figure 3: The configuration of the projection based system (above) and the prototype examples (below)*

were similar to the prototype of the projection based system (means/SD of task 1: 13sec/2.4, task 2: 38sec/6.0) but different from the prototype of the HMD based system (means/SD of task 1: 39sec/14.7, task 2: 91sec/25.1). The participants also reported that the projection based system creates more realistic usage situation than the HMD based one. This was largely due to the interface problems caused by the HMD and the camera. Problems with the video see through HMD based system include the video delay of finger movement, difficulties of recognizing the texts and graphics on the hardware and the narrow camera view angle. In the projection based system, the focus and the projection direction was fixed so the overlaid display was correctly applied only on the specific location of the desk and on the specific angle of the hardware prototype.

## CONCLUSION AND FUTURE WORK

The suggested prototyping methods facilitate the rapid and iterative product development from early phase of the design process. Future work includes to extend the prototyping method for general digital products (e.g. ones with pen based input interfaces) and to carry out a formal experiment to examine the validity of the early augmented reality based prototypes and impacts of technical parameters of the equipments used.

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