Wearable 3D Graphics for Augmented Reality:
A Case Study of Two Experimental Backpack Computers

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Abstract

Graphical mobile augmented reality applications will only be effective if the wearable computers on which they run are capable of high-performance 3D graphics. However, no current commercial wearable system provides the graphical performance of even a typical modern desktop computer. In this paper, we describe two different experimental wearable graphics computers designed for prototyping augmented reality applications requiring fast 3D graphics. We explain the system requirements and design decisions that resulted in these architectures.

1. Introduction

Recent decreases in size and price have made mobile computing a part of everyday life. Laptops that are faster than last year's desktops, hand-held personal digital assistants, and mobile phones with integrated web access are rapidly becoming commonplace. However, none of these devices offers 3D graphics performance comparable to that of modern desktop systems. Possible explanations for this include the stronger demand for low power consumption, which is not met by current 3D graphics accelerators, and the absence of an acknowledged mobile "killer" application that would require this functionality.

We believe that head-tracked 3D augmented reality (AR) could be the basis for such an application. AR is a display paradigm that registers, from the user's perspective, information directly with objects and locations in the surrounding environment. For example, registered graphics could include 2D annotations (e.g., text labels with leader lines) as well as 3D graphics (e.g., wireframe or textured models), overlaid on the real world. AR has the potential to revolutionize many areas including medicine [13], maintenance [4], training [9], tourism [5], and games [12]. A wearable augmented reality system could make these capabilities ubiquitous, allowing users to routinely create and access virtual information associated with relevant parts of the real world, indoors and outdoors.

Two specialized needs have long been recognized in the AR (and VR) research communities [3,10]. First, a graphical AR system must be capable of rendering 3D graphics appropriate to the user's task at interactive frame rates. For all but the simplest scenes, this performance can only be achieved if 3D hardware acceleration is used. Second, stereo graphics can greatly improve the user's sense of depth. Furthermore, when binocular virtual material is overlaid on real objects viewed directly in AR, correct stereo graphics is essential to match the ocular vergence needed to view the real objects. This can be especially important when precise manipulation or navigation tasks are to be performed in these environments.

Previous attempts to address these needs have included mobile systems based on commercial luggable [5] and desktop [1] systems. In contrast, earlier wearable computers have stressed portability over graphics performance or resolution in both research [11] and commercial [14] systems, or have offloaded graphics processing to a remote server accessed through radio [8].

This paper describes the design and development of two different experimental wearable graphics computers with 3D graphics acceleration, shown in Fig. 1. This work is part of BARS, a collaborative project between the Naval Research Laboratory and Columbia University. Through BARS, we are developing software systems and interaction techniques to support multiple collaborative users wearing mobile AR systems linked to other users interacting with VR technologies. Most of the size and weight of each BARS system is accounted for by its position and orientation trackers, power supplies, backpack frame, and head-worn display, which are unmodified off-the-shelf components. We concentrate here on the board-level computers that we have assembled to drive these systems. Section 2 of this paper describes the project requirements that motivated us to build our own computers. In Section 3, we present the design of two
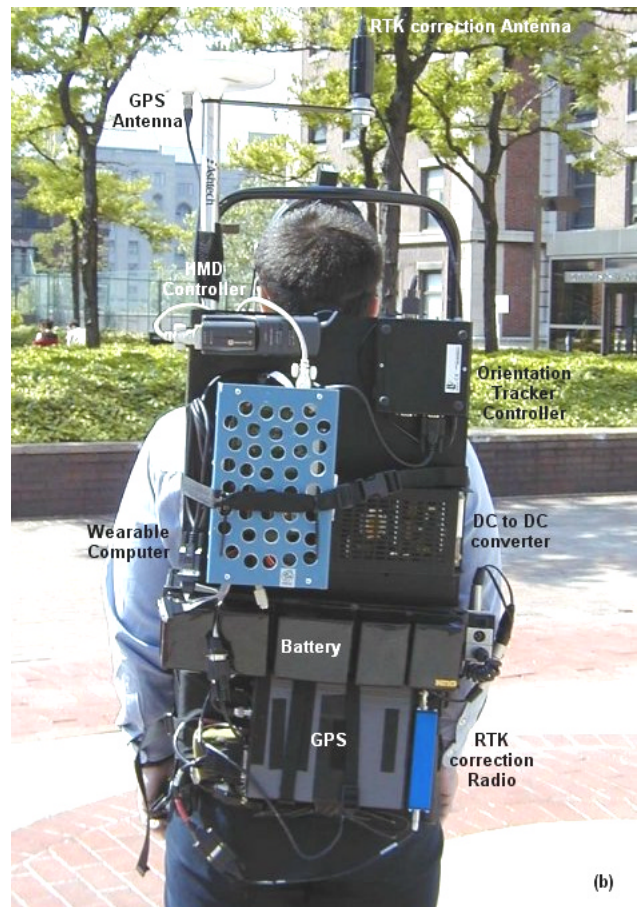
Figure 1. Backpack based wearable augmented reality systems. (a) NRL system. (b) Columbia system.

complementary systems that make different tradeoffs. Section 4 presents our conclusions.

2. Project Requirements

NRL's system was intended to be a relatively lightweight platform for enhancing the situation awareness of Marines in urban environments [2]. The system provides crucial information registered on top of the environment. Line graphics delineate the contours of hidden infrastructure or personnel without occluding the view; labels identify features in the environment.

Columbia's system was intended to support a wide range of research, including our previous outdoor applications; for example, one allows users to experience hypermedia documentaries embedded in the surrounding environment [6]. Head-tracked shaded 3D graphics and text are shown in combination with 2D graphics on a hand-held computer connected by a wireless network, and supplemented by sound. Texture mapping is used to present 3D building models and omnidirectional imagery.

We identified a set of needs common to both projects:

1. 3D graphics acceleration for interactivity at SVGA resolution (needed to drive the Sony Glasstron LDI-D100B head-worn displays that we use).

2. Flexibility for rapid modification/expansion, including internal card slots, and external serial ports and/or PCMCIA slots.
3. Ease of development using standard desktop operating systems such as Linux or Windows NT.
4. Exclusive use of off-the-shelf components.
5. Relatively low (DC) power and weight (but see below).

However, certain characteristics of our applications and research emphases demanded different treatment:

1. NRL intended to develop entirely in Java, and C/C++ with OpenGL, constraining the CPU to be a Pentium 166MHz or higher, according to tests with our applications. Columbia needed to support existing code using a high-level interpreted language (Repo) and distributed infrastructure (Coterie) [7], in addition to new code in Java/Java3D, necessitating a faster CPU.

2. NRL demanded stereo support for better depth perception and registration accuracy during calibration of the real and virtual environment (at the expense of shaded graphics and texture mapping, if necessary), while Columbia was willing to make the tradeoff in favor of rendering quality over stereo in some applications.

3. Columbia required sound for its hypermedia documentaries, while currently NRL does not.

3. Design Choices
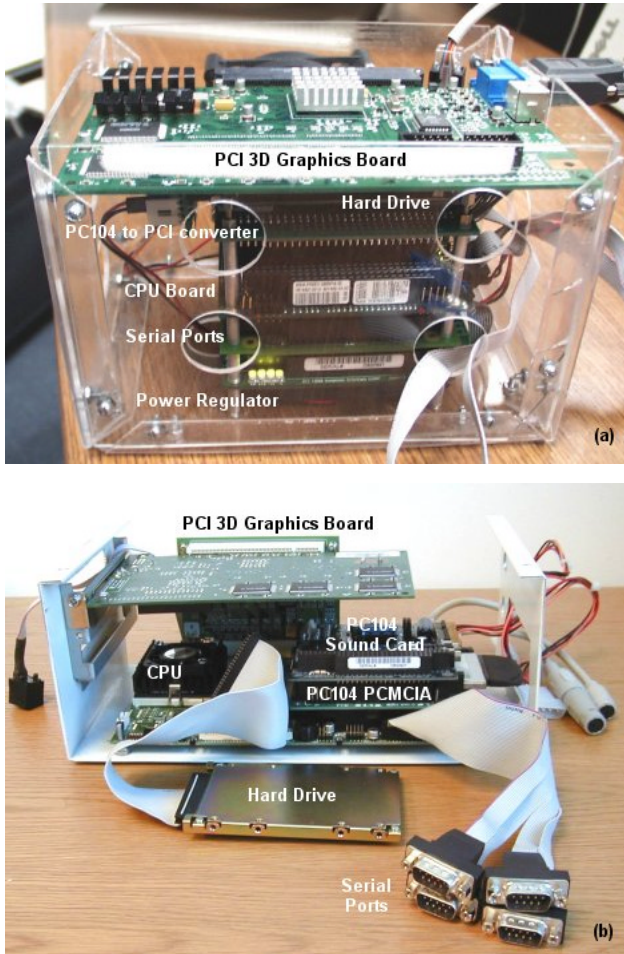
Figure 2. Closeups of wearable 3D graphics computers. (a) NRL system. (b) Columbia system.

Architecture. The different requirements in processing power led to the adoption of different architectures for our systems. NRL chose to use a PC104 module (Advanced Digital Logic MSMP5SEV) that supports Pentium MMX class CPUs, while Columbia decided to use an embedded PC motherboard (Advantech PCM-9570), a miniaturized version of a regular ATX motherboard, with fewer expansion slots, which supports Pentium II class CPUs.

Graphics. The lack of sufficiently fast integrated 3D adapters drove us to use desktop graphics hardware. Since the class of small motherboards we considered did not support AGP, we were constrained to use PCI graphics cards. (Because multiple PCI graphics cards, but not multiple AGP cards, can be used in a single computer, manufacturers continue to produce PCI graphics cards.)

Both sites selected the Diamond FireGL 1000 Pro PCI board, which uses 3Dlab's PERMEDIA2 chip with 8MB RAM. This card is OpenGL 1.1 compliant and supports texture compression. It also has hardware quad buffering enabling field-sequential SVGA stereo. As new cards become available, we can upgrade with the same effort required for a desktop system.

	NRL	Columbia
CPU	Pentium MMX 266	Celeron 466
RAM	64MB SDRAM	128MB SDRAM
Native Graphics	C&T 69000	Trident 9525
3D Graphics Board	Diamond Fire GL 1000 Pro	Diamond Fire GL 1000 Pro
Serial Ports	4	4
PCMCIA Slots	0	2
Ethernet	10/100	10/100
PCI slots	1	2
EIDE bus	2	2
Sound	No	Crystal-MM-HP
Permanent Storage	6GB 2.5" Hard Drive	440MB 2.5" Solid State Flash Disk
Idle Consumption with 3D Board	16.12W	28.85W
Full Load Consumption with 3D Board	23.86W	42.07W
Dimensions of computer(cm)	12x13x18	26x15.7x10.2
Weight of computer(kg)	1.18	2.7

Table 1. Comparison of system designs.

Expansion. Both systems support expansion through 32bit 33MHz PCI bus and PC104+ bus. In Columbia's system, expansion is provided by PCI and PC104+ slots on the motherboard, while NRL's system has only PC104+ support built in and uses a PC104 type converter on top of the main board to provide one PCI slot. Columbia added a PC104 PCMCIA module (Advantech PCM-3112) to support storage (IBM Microdrive) and wireless networking, and a PC104 sound module (Diamond Systems Crystal-MM-HP). Both systems have four serial ports that allow us to attach devices, including position (Ashtech GG Surveyor real-time–kinematic GPS) and orientation (InterSense IS300 Pro) trackers and interaction devices.

These decisions, which are summarized in Table 1, led to the construction of a smaller, lighter weight, longer running, but less powerful system for NRL and a larger, heavier, but more powerful (as illustrated in Table 2) and power hungry system for Columbia. This maps well to the requirements that we sketched earlier.

	NRL	Columbia
AWadvs-03 Mean	5.332	11.36
DRV-06 Mean	2.454	4.952
DX-05 Mean	3.96	8.212
Light-03 Mean	0.5347	1.108
ProCDRS-02 Mean	1.833	6.059

Table 2. Viewperf results (1024x768, 60Hz, 16bpp)

It is important to note that both computers rely on a see-through head-worn display, and thus do not have the power overhead associated with a large backlit display. However, unlike most of the users of wearable computers who attempt to minimize the power requirements of their system to preserve battery life, we willingly accept the power overhead of SVGA display devices to benefit from commercial color head-worn displays.

4. Conclusions and Future Work

We have described the design of two experimental wearable 3D graphics computers that are actively used in a collaborative research program in distributed augmented reality. Although our designs needed to address a combination of shared and differing requirements, both have been implemented using only off-the-shelf technology. Both machines are larger and consume more power than they would be if built with custom components. However, the ease with which we designed and assembled them (requiring just a few hours each for actual assembly), and the straightforward upgrade paths that they both present, make them attractive for current experimentation by groups such as our own, whose emphasis is on exploratory software development. The graphics performance of both systems far exceeds current (more expensive) commercial portable computers.

Over the next few months, we expect to upgrade our system to take advantage of new 3D graphics cards (e.g., Elsa Gladiac) as well as new CPUs. We believe that the development of 3D applications for experimental wearable computers could act as a catalyst for the introduction of commercial wearable computers with integrated high-performance 3D graphics processors, eliminating the need to build our own.

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