Session 2426

CRCD: Low-Power Wireless Communications for Virtual Environments-Course Integration

Julie A. Dickerson, Diane T. Rover, Carolina Cruz-Neira,
Robert J. Weber, Eric Eekhoff, Bernard Lwakabamba,
Feng Chen, and Zheng Min

Iowa State University, Ames, IA, 50011

I. Project Overview

This project combines research from the areas of wireless communications, low-power embedded systems, virtual environments, and human factors in an interdisciplinary program. Education in the hardware and software of virtual reality (VR) systems serves as a test-bed for training engineers in a truly interdisciplinary environment. The ultimate goal of this project is to create a set of integrated courses that cover real-time software, embedded systems, design of virtual environments, and design of practical wireless devices. The research part uses the C6, a three-dimensional, full-immersion, synthetic environment in the Virtual Reality Applications Center (VRAC) at Iowa State. The research goal is to design and implement low power wireless communications systems for wearable sensor networks in virtual environments.

In order to integrate across a range of classes from communications system to software engineering, we have introduced the concept of a central design document. The purpose of the central design document is to introduce students in diverse disciplines to the problem to be solved. The many sub-topics of this research provides an ideal case study and design projects for students from embedded system, wireless communication, VLSI design, and real-time software courses. A full understanding of the current system and the requirements of the new system is crucial for performing the research. The design document describes the characteristics of the current system, analyzes the requirements for wireless systems in VR, and specifies problems that need to be addressed.

The design document concept is being tested for the communications systems laboratory and in a course on user interactions for virtual environments. The central design document defines the system and its requirements for the students. Supplementary documents, one on the requirements for the wireless system and one on the software engineering, give more specific information about the virtual environment.

Previous activities

New laboratory experiments were added to existing courses in communications to enforce the concepts of hardware/software co-design and human factors issues[1-3]. One example of these first experiments is a lab exercise for the communications course that characterizes the complex electromagnetic environment inside the C6 virtual environment that contains multiple types of wireless devices such as LANs and cordless phones as shown in Figure 1. A second example is implementation of different methods for interference mitigation such as direct-sequence spread spectrum and adaptive antennas. Our group has studied the latency of the C6 virtual environment and the existing communications protocols for the 802.11 and Bluetooth specifications. These studies were presented in the Communications Systems II class in spring 2002.

The curricular plans for the second year included offering courses in the basic functional skills needed for interdisciplinary teams such as an embedded systems course in spring 2002 that features the specification and analysis of real-time wireless systems. We also identified current best practices for teaching interdisciplinary courses. We are experimenting with different methods of integrating the course skills between the courses. This work led to the concept of the central design document that defines a common goal for a series of courses.

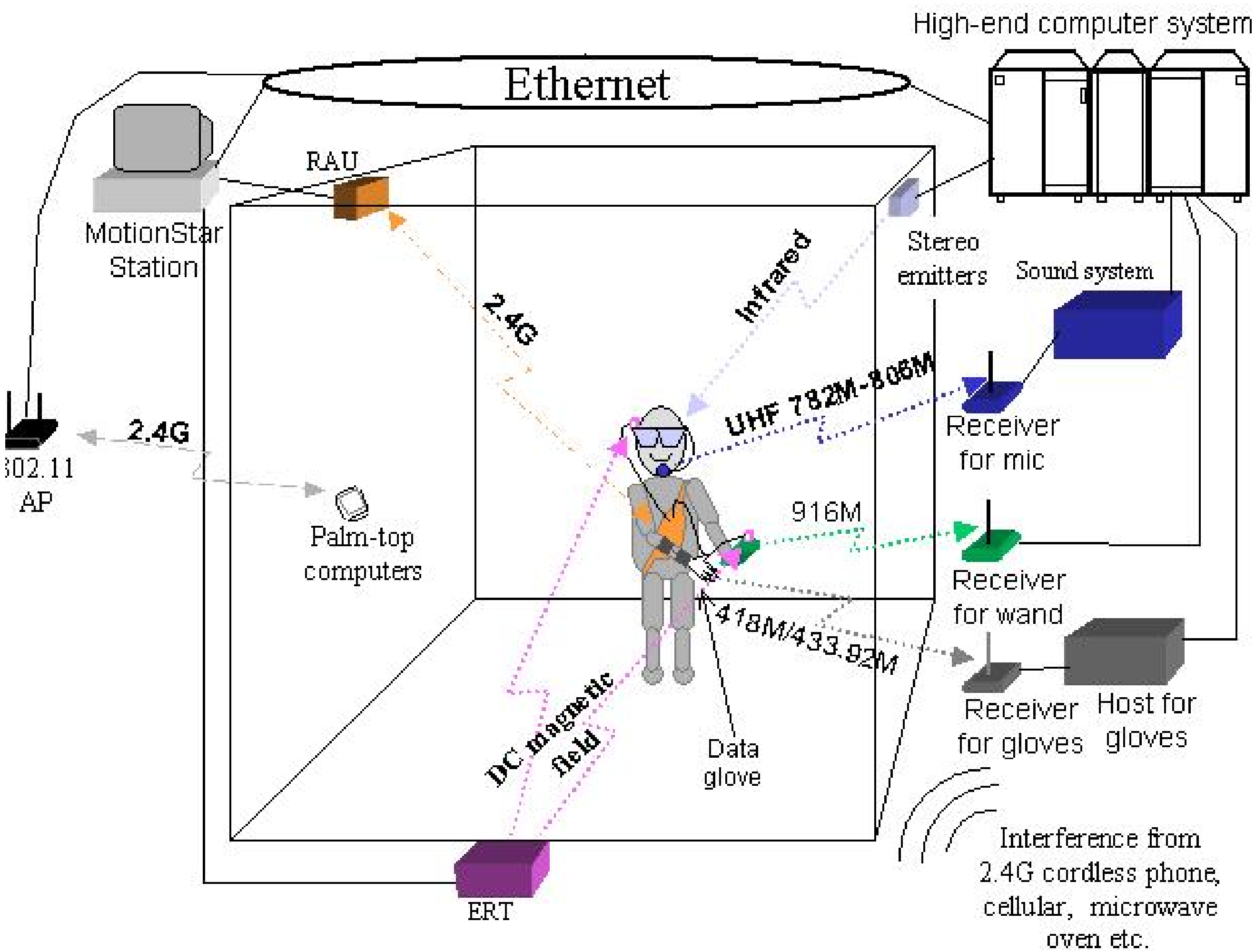

Figure 1. A user in the C6 virtual reality system communicates with his/her environment using a wireless tracking system, infrared shutter glasses, 6-D wands, and data gloves. These devices must be designed in a way of avoiding interfering between devices in the environment.

II. Curriculum Development and Integration

This project covers a broad range of curricular areas. Table I summarizes the courses that are being developed and enhanced as part of this CRCD project. The difficult part of this project has been to tie these courses together while allowing students to specialize in their area of interest. This lead to the idea of creating a central design document that described the C6 virtual reality system and its requirements for human-computer interaction.

The central design document describes the top-level characteristics of the current system, analyzes requirements for the wireless system in virtual reality, and specifies problems that need to be addressed. This document is being used in the communications systems laboratory for a final project on wireless communications and in the course on user interface design for virtual environments to create a common framework.

Title/Instructor	**Level**	**Req/ Elec**	**Freq-uency**	**Credit Hours**	**Innovation**
Design of Interactive Virtual Environments /Cruz-Neira, Weber, Dickerson	Grad	Elect	2 years	3	Hands-on advanced virtual reality hardware and software, evaluation exercises
Real-time Software Engineering for Virtual Environments/Cruz-Neira	Senior/ grad	Elect	1/year	3	Projects on current software challenges for time-critical response of multi-processed environments
Communications Systems and Laboratory/ Dickerson	Senior	Tech Elect	1/year	4	New wireless communications experiments, studies in interference
Introduction to Digital Signal Processing/ Dickerson	Senior	Tech Elect	1/year	4	Experiments in adaptive signal processing for interference nulling
Embedded Systems /Rover	Senior/ grad	Tech Elect	1/year	3	Structural and behavioral characteristics of systems and high-level design methodology for requirements, rapid prototyping and system optimization
Communication Circuits/ Weber and Dickerson	Grad	Elect	2 years	3	New wireless laboratory demonstrations and projects relating to the C6

Table I: List of courses affected by this CRCD project. The central design document unifies these courses by explaining the overall problem.

III. Central Design Document

The design of virtual reality systems is difficult due to the cross disciplinary nature of the task. This is exacerbated by a lack of understanding between the disciplines. Part of this project is to explore using a common design problem across classes in the respective disciplines to bring students to an understanding of the issues in the other disciplines, therefore facilitating cross-discipline development. When the individual parts are created independently, the system as a whole becomes very difficult to integrate. However, if the student has an understanding of the problem as a whole and at least a rudimentary understanding of the issues of the other parts of the development, integration can be eased.

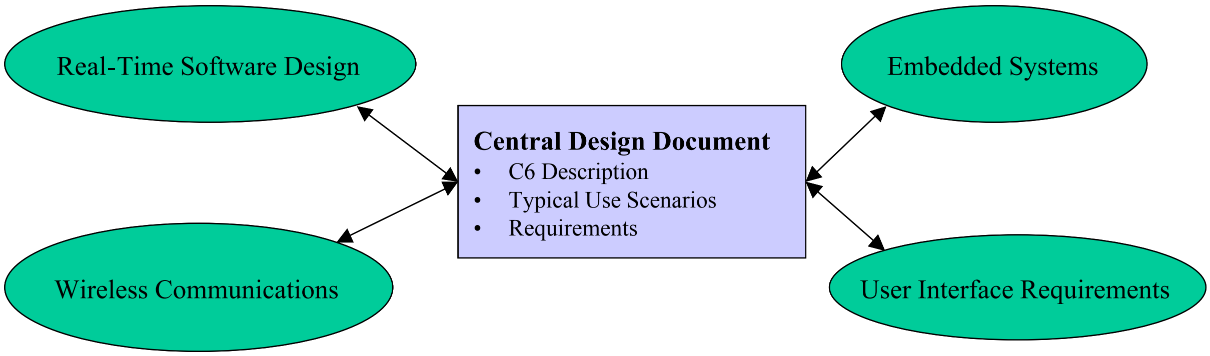

Figure 2: The central design document defines the c entral problem and the user interaction requirements. Supplementar y documents define specific requirements for different areas.

The first part of the design document introduces the C6 virtual environment and the problems with the existing system. Next, common C6 usage scenarios are described to explain how to students how their work fits into the larger problem. Appendices to the document give the specific requirements for different parts of the system such as the wireless subsystem and the software engineering. Figure 2 shows the structure of this document.

Some excerpts from the document are given below:

Introduction
The Wireless Communications for Virtual Environments Research Group is working on improving the performance of the interaction devices in the C6, a three-dimensional, full-immersion, synthetic environment. The interaction device system is a complex system which crosses the boundaries on a number of disciplines, including: wireless communications, digital signal processing, VLSI circuit design, embedded systems, software engineering, virtual reality, and human-computer interface (HCI) design.

The central element of this effort focuses on the performance of the interaction system used in the C6 virtual reality system. The C6 is a fully enclosed VR system in the form of a 10X10X10 cube, with projections onto each surface. Effective Virtual Reality systems require user interaction with the environment. Traditional systems use wired devices to implement the interaction devices. This, however, is not possible within the fully enclosed space of the C6. For this reason the interaction devices within the C6 must be wireless devices. The current system is not able to meet the performance needs of real-time interaction in an immersive environment. Problems with the current system include: instability, interference, difficulty in adding new devices, and unacceptable system latency, etc. To provide a better immersive environment, a robust, standalone, high speed, wide bandwidth wireless network is necessary to handle input devices provided by different vendors, and output devices in the future. This is coupled with the challenges of developing new devices and integrating the next system with the Virtual Reality software systems.

A high-end computer system generates and outputs high-resolution real-time images and projector project those images onto the screens. With a pair of special glass/goggles, the user can perceive stereoscopic scenes, so that he can gain the feeling of immersing in a virtual world. If necessary, a three-dimensional sound system provides sound to achieve higher immersion. Figure 1 gives a visual representation of a number of the systems.

To correctly and precisely generate the visual and auditory output, the system needs to “know” the user’s position and orientation[4]. In addition, to provide interaction between the system and the user, the system needs more information about the users' action and posture. Thus many trackers are used. These trackers are attached to the user's body parts or devices that the user is using. They can capture the position and orientation of the user and parts of his body to provide the system information about the user's position, action and posture. Additionally, the user may use multiple devices to interact with the system. Many of these output devices may be attached to the user's body to provide other perceptual channels, such as force feedback and tactile feedback.

Common use scenario:
The user walks around in the C6 and presses buttons on the wand to help navigate in the virtual environment, which is much larger than the C6 chamber. For instance, pressing button 1 may mean accelerate, while button 2 means stop. Many virtual objects in the virtual space are manipulated using a wand or glove. In some cases, a palmtop computer is needed to perform more complicated operations. During the running of the application a tracker attached on the user's head “tells” the system where the head is located and how it is oriented. A tracker on the wand or on the glove tells the computer where his hand is. The system can also know the user's gestures through information provided by the data glove. These trackers and the glove provide data flow periodically, while the wand button signal occurs infrequently.

All trackers and device are connected to the system through a wireless system so that the user can perform any action without limitation from cables. Furthermore, it is preferred that the user does not notice the trackers attached on his body or some other devices, so that he can gain better immersion experience. The use of wireless systems is crucial for the virtual environment to achieve a high level of immersion.

Structure of current system and its limitations
The scenario described in the previous section is based on virtual reality applications running on the current C6 system. The hardware/software structure behind of these scenarios is demonstrated in Figure 3. The focus of this diagram is the input/output devices and wireless communication system they are using. The whole system can be divided into three subsystems, namely, VR Juggler, main computer, and devices.

VR Juggler is a C++ based VR application development environment[5-7]. It is designed to simplify the development of VR applications, allowing developers to focus on the application domain instead of spending most of their energy on every aspects of system programming. It hides the complicated hardware details from developers, and provides them with a suite of flexible and easy-to-use application programming interfaces (APIs). Developers only need to implement the program pieces required for solving the real-world problem, placing these pieces into a programming framework. VR Juggler takes care of the common tasks needed by many VR applications, e.g. Opening display windows and loading device drivers. More than that, VR Juggler provides additional functionalities designed to help developers to debug, evaluate, and run their applications.

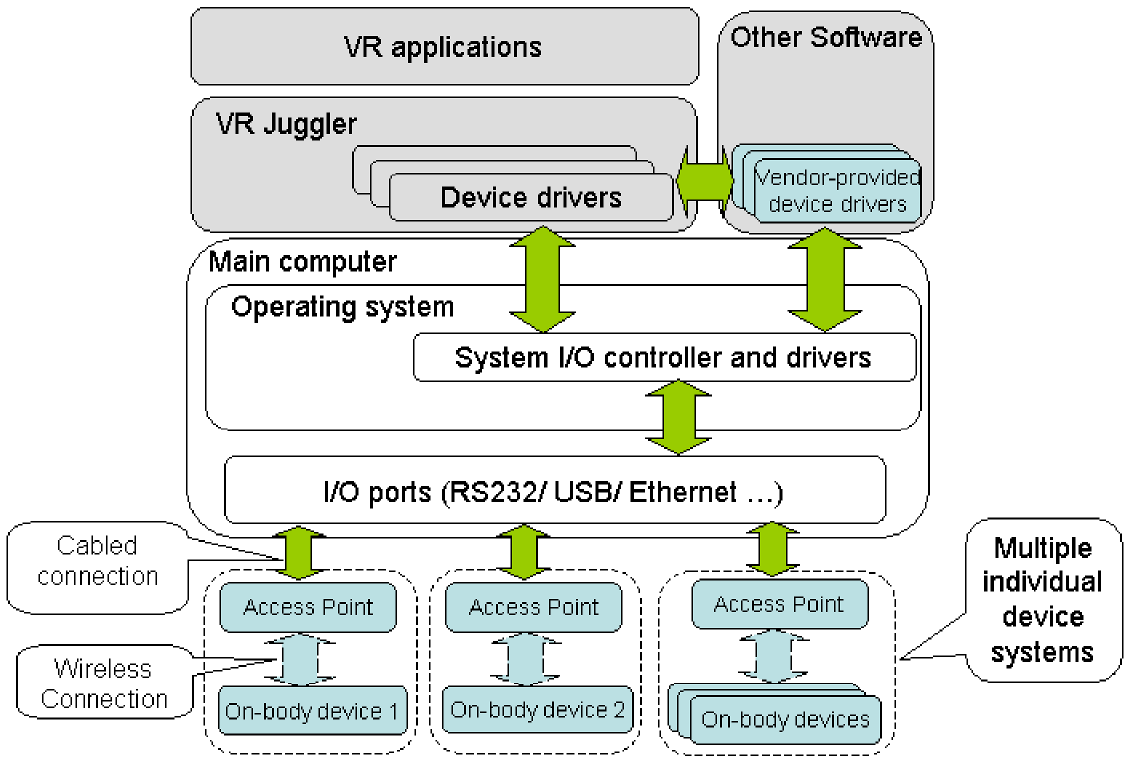

Figure 3. Structure of current system

Requirements for Interactive Systems in the C6

The requirements for the C6 virtual environment are[2,4,8,9]:

From the programmer's point of view

- Uniformity: All devices use unified programming interface so that it is easy for programmers to use various devices.
- Robustness: The system should be able to support sufficient number of devices and multiple users.
- Extendibility: It should be easy to introduce new devices into the system.

From the application user's point of view:

- Plug and play: Plugging in and removing a device should be very simple and adding or removing devices should not interrupt the application.

- Exception handling: When encountering a device failure, the system may keep working under a certain predefined mode rather than exiting or crashing.
- Lightweight and proper mass distribution: The user would not be aware of existence of device.
- Long working time without recharging or changing battery.

IV. Using the Design Document in the Wireless Communication System Laboratory

The communication systems sequence at Iowa State University consists of two lecture classes and a hands-on laboratory. The sequence prepares undergraduate students to effectively work in the communications industry. A student who finishes this sequence will have the mathematical background and understanding to be able to analyze and design basic analog and digital communication systems.

The Communication System Laboratory covers the practical aspects of modern communications. A theoretical model may provide excellent performance in a simulator, but the real-world model may not provide the same level of performance. Students also learn how to perform in real-world work environments by solving problems in groups. The laboratory gives the students a chance to implement a wireless communications system for a real-world application.

The laboratory course began with a pre-test to measure the students' knowledge in communications system concepts. A post-test will also be given at the end of the course to assess their performance and improvements. The students first complete a set of experiments designed to introduce them to each part of a communication system such as the antennas, demodulators, and interference. The students then are introduced to the CRCD design document and given a tour of the C6 virtual environment and its surrounding electromagnetic environment. After this initiation, they are presented with the requirements for a wireless communications system for virtual environments. The final project will involve creating a wireless communication system that processes sensor information and relays it to the VR Juggler virtual environment simulator.

Requirements for Wireless Communications Systems

The requirements for a wireless communications system in the C6 virtual environment are summarized below[2]:

- Bandwidth: although current applications usually use only three to five devices -- a wand and two trackers, plus a glove or a palmtop computer. The future application will need much more data to provide better human-computer interaction. To roughly estimate the bandwidth, a motion capture application is considered because in such an application, up to 30 trackers could be used while trackers generate more data than other devices. Each set of tracking data contains 12 bytes, at the rate of 200 Hz. That is about 1Mb "raw" data per second. When multiple users are involved, this value needs to be doubled or tripled. The practical bandwidth also depends on the function and security issues.
- Latency: Previous research in human factors has found that the total latency of the VR system should not exceed 100ms. This total latency includes both software and hardware

latency[10,11]. The image refresh rate should be no less than 60Hz or 17ms. Since the software portion usually consumes more than half of the available time, the hardware latency must less than 8ms. This hardware latency includes data transfer time and the sensor reaction time, thus the latency introduced by wireless system should be even lower.

- Heterogeneous data flow: the update rate and the size of data from different devices could be significantly different. Some devices (e.g. tracker) generate high rate complex data while others generate aperiodic data (e.g. the wand).
- Communication functions
  - Communication system design should be modular, so that when the selected communication standard is changed, only the transceiver changes.
  - The communication system should use off-the-shelf wireless products as much as possible.
- Power consumption and weight: The wireless system should be lightweight and should be able to run for at least two hours without battery recharging or replacement.
- Security: The system should be secure from jamming and simulation data should not be accessible to other users.

Environment Testing Design

The goal is to interface the digital signal processing (DSP) board with the transceiver. The transceiver will be the radio frequency (RF) front-end of the communication system. It will receive information from another user/PC and send the information to the DSP board, which will sample and process the information via a pre-programmed executable program. This interface provides the basic components of the bi-directional communication link. Once the finished product is functioning, it can be used to test and predict what issues might arise within the environment surrounding the C6 (e.g. interference caused by other wireless devices in the area).

Wireless Sensor Data Collection System

The goal is to interface the DSP board with several sensors that will be used to interact with a running VR Juggler program in the C6. An interface using the USB ports of DSP board to the computer will be used to create the sensor recognition system. The accelerometer and pressure sensors will capture the user's motion, and that information will be sampled and packaged by the first programmable DSP board. The transceiver will receive information from the first DSP board and send the information to the second DSP board via a wireless link as shown in Figure 4.

The second DSP board will then send the information to the main computer running the VR Juggler application. Finally, the VR Juggler application will use the received information and correlate it to moving the objects in the VR Juggler program. Once a successful end product has been created and tested, it will be used as a model to create a similar system in the C6 virtual environment.

Conclusions

The concept of the design document will be thoroughly tested in spring 2003 when it will be used for senior-level classes in communications systems and embedded systems and graduate courses in communication circuits and virtual reality.

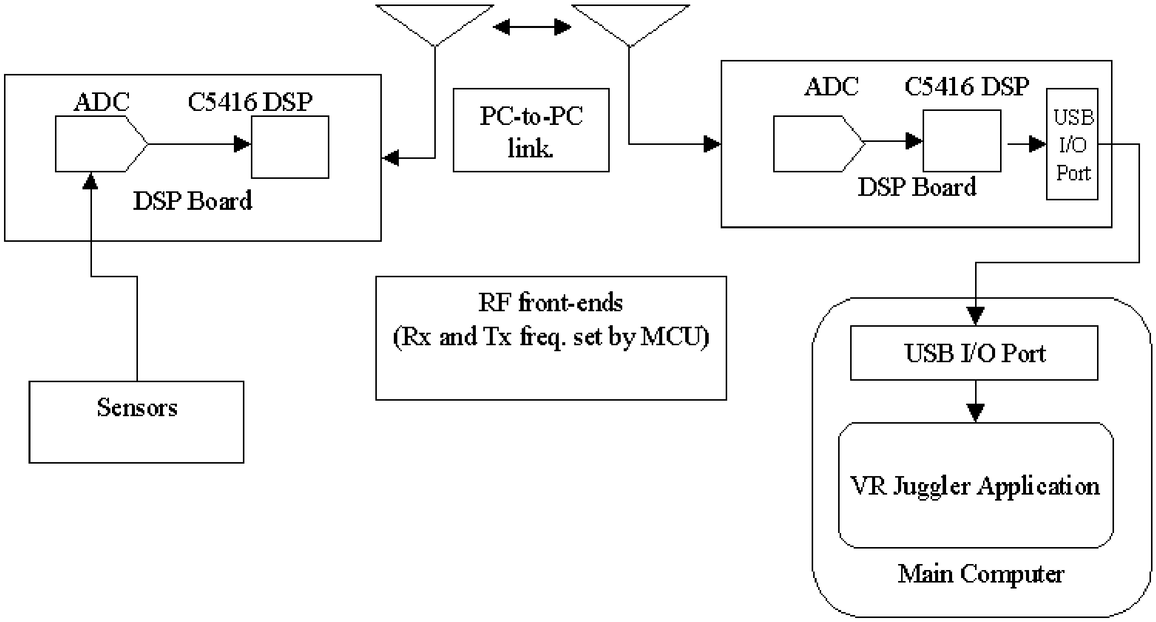

Figure 4. Block diagram of the sensor recognition system

Acknowledgement

This work is funded by grant number 0088071 from the National Science Foundation as part of the Combined Research and Curriculum Development (CRCD) Program.

Bibliography

[1] J. A. Dickerson, D. Rover, C. Cruz-Neira, R. Weber, "CRCD: Low-Power Wireless Communications for Virtual Environments," Invited Paper at the *American Society of Engineering Educators (ASEE)* Conference, Toronto, Canada, June, 2002.

[2] B. Graubard, F. Chen, Z. Min, R.J. Weber, D. Rover, and J.A. Dickerson, "Lessons Learned: Installing a Wireless System in the C6 Virtual Reality Environment," IEEE Virtual Reality Conference, 7th Annual Immersive Projection Technology (IPT) Symposium, Orlando, March 2002.

[3] J. A. Dickerson, W. C. Black, C. Cruz-Neira, R. Weber, "CRCD: Wireless Multimedia Communications for Virtual Environments," Invited Paper at the *American Society of Engineering Educators (ASEE)* Conference, Albuquerque, New Mexico, June, 2001.

[4] R. Stuart, *Design of Virtual Environments*: Barricade Books, 2001.

[5] Allen Bierbaum, VR Juggler: A Virtual Platform for Virtual Reality Application Development, MS Thesis, Iowa State University, 2000.

[6] Christopher Just, Performance analysis of a virtual reality development environment: Measuring and tooling performance of VR Juggler. MS Thesis, Iowa State University, December 2000.

[7] VR Juggler web page: http://www.vrjuggler.org/

[8] A. Van Dam, "Implementing Virtual Reality, CHI'94 Tutorial #25: Perspectives on virtual reality," presented at Conference on Human Factors in computing systems, CHI'94, Boston, MA, 1994.

[9] C. Ware and R. Balakrishnan, "Object Acquisition in VR displays: Lag and Frame Rate," *ACM Transactions on Computer Human Interaction*, vol. 1, pp. 331-357, 1994.

[10] M. M. Wloka, "Lag in Multiprocessor Virtual Reality," *Presence: Teleoperators and Virtual Environments*, vol. 4, pp. 50-63, 1996.

[11] K. Park and R. Kenyon, "Effects of Network Characteristics on Human Performance in a Collaborative Virtual Environment," presented at IEEE VR `99, Houston, TX, 1999.

Biographical Information

JULIE A. DICKERSON
Julie Dickerson is an Associate Professor of Electrical and Computer Engineering at Iowa State University. Dr. Dickerson teaches courses in the areas of digital signal processing and intelligent systems. Her primary research areas are bioinformatics and adaptive fuzzy systems applications. Dr. Dickerson received her B.S. in Electrical Engineering from UC San Diego and her M.S. and Ph.D. degrees from the University of Southern California.

DIANE T. ROVER
Diane Rover is a Professor of Electrical and Computer Engineering at Iowa State University. Dr. Rover's teaching and research interests include embedded systems and high-performance computing. She received her B.S. in Computer Science and M.S. and Ph.D. in Computer Engineering, all from ISU. Prior to joining ISU, she was on the faculty at Michigan State University, most recently serving as Interim Department Chairperson.

CAROLINA CRUZ-NEIRA
Carolina Cruz-Neira is an Associate Professor of Industrial Engineering at Iowa State University. Dr. Cruz teaches courses in the areas of computer graphics and software engineering. Her primary research areas are the integration of virtual reality technologies, high-speed networks, and high-performance computing engines for the real-time steering of computationally intensive simulations. Dr. Cruz received her B.S. from the Universidad Metropolitana in Caracas, Venezuela and her M.S. and Ph.D. degrees from the University of Illinois at Chicago.

ROBERT WEBER
Robert Weber is a Professor of Electrical and Computer Engineering at Iowa State University. His research interests are in the integration of different microelectronic sensors, devices, processes, and systems for optical, microwave, and high-speed circuit and system applications. He teaches Microwave Circuit Design, VLSI Communication Circuits, and Fiber-Optic Communications. Dr. Weber received his B.S., M.S., and Ph.D. degrees from Iowa State University. He is author of *Introduction to Microwave Circuits: Radio Frequency and Design Applications*.

ERIC EEKHOFF
Eric Eekhoff is a M.S. Student in Electrical Engineering at Iowa State University. His current research interests are in real-time wireless communication networks. Eric Eekhoff received his B.S. in electrical engineering from Dordt College.

BERNARD LWAKABAMBA
Bernard Lwakabamba is a M.S. Student in Electrical Engineering at Iowa State University. His current research interests are in wireless communication networks. Bernard Lwakabamba received his B.S. in electrical engineering from Iowa State University.

ZHENG MIN
Zheng Min is a M.S. Student in Computer Engineering at Iowa State University. His current research interests are in software engineering and virtual reality. Zheng Min received his B.S. in electrical engineering at Tsinghua

University.

FENG CHEN
Feng Chen is a Ph.D. student in Electrical Engineering at Iowa State University. His current research interests are in low-power low-noise CMOS design for wireless communication. Feng Chen received his B.S. and M.S. in electrical engineering from Nanjing University, China.