Declaration of Jacob Robert Munford

1. My name is Jacob Robert Munford. I am over the age of 18, have personal knowledge of the facts set forth herein, and am competent to testify to the same.

2. I earned a Master of Library and Information Science (MLIS) from the University of Wisconsin-Milwaukee in 2009. I have over ten years of experience in the library/information science field. Beginning in 2004, I have served in various positions in the public library sector including Assistant Librarian, Youth Services Librarian and Library Director. I have attached my Curriculum Vitae as Appendix A.

3. During my career in the library profession, I have been responsible for materials acquisition for multiple libraries. In that position, I have cataloged, purchased and processed incoming library works. That includes purchasing materials directly from vendors, recording publishing data from the material in question, creating detailed material records for library catalogs and physically preparing that material for circulation. In addition to my experience in acquisitions, I was also responsible for analyzing large collections of library materials, tailoring library records for optimal catalog

search performance and creating lending agreements between libraries during my time as a Library Director.

4. I am fully familiar with the catalog record creation process in the library sector. In preparing a material for public availability, a library catalog record describing that material would be created. These records are typically written in Machine Readable Catalog (herein referred to as "MARC") code and contain information such as a physical description of the material, metadata from the material's publisher, and date of library acquisition. In particular, the 008 field of the MARC record is reserved for denoting the date of creation of the library record itself. As this typically occurs during the process of preparing materials for public access, it is my experience that an item's MARC record indicates the date of an item's public availability.

5. I have reviewed Exhibit 1005, "Cyberguide: A mobile context-aware tour guide" by Gregory D. Abowd, Christopher G. Atkeson, Jason Hong, Sue Long, Rob Kooper and Mike Pinkerton (hereto referred to as 'Abowd') as presented in *Wireless Networks* October 1997.

6. Attached hereto as Appendix AB01 is a true and correct copy of the cover, spine, title page, table of contents and complete 'Abowd' from *Wireless*

Networks October 1997 held by the University of Pittsburgh. I secured this appendix myself in person. In comparing AB01 to Exhibit 1005, it is my determination that Exhibit 1005 is a true and correct copy of 'Abowd'.

7. Attached hereto as Appendix AB02 is a true and correct copy of the MARC record describing *Wireless Networks* as held by the University of Pittsburgh. I secured this record myself from the library's online catalog. The 008 field of this MARC record indicates *Wireless Networks* was first cataloged by the University of Pittsburgh as of April 3, 1995. The 'Holdings Information' field on page 2 of the library record indicates this journal was held by this library in perpetuity from 1996 - 2003. This date range indicates the library's collection includes the October 1997 publication of *IEEE Communications Magazine* containing "Abowd". The book bindery sticker on page 25 of AB02 indicates multiple volumes of *Wireless Networks* owned by the University of Pittsburgh spanning 1996-1997 were sent off to a book bindery sometime during January - March 1998.

8. Attached hereto as Appendix AB03 is a true and correct copy of complete 'Abowd' from *Wireless Networks* October 1997 held by Carnegie Mellon University as 'p421-abowd.pdf'. I secured this appendix myself in person. In

comparing AB03 to Exhibit 1005, it is my determination that Exhibit 1005 is a true and correct copy of 'Abowd'.

9. Attached hereto as Appendix AB04 is a true and correct copy of the MARC record describing *Wireless Networks* as held by Carnegie Mellon University. I secured this record myself from the library's online catalog. The 008 field of this MARC record indicates *Wireless Networks* was first cataloged by the Carnegie Mellon University as of January 22, 1999. The 'Holdings Information' field on page 3 of the library record indicates this journal has been held by this library in perpetuity since 1999. This date range indicates the library's collection includes the entirety of *IEEE Communications Magazine* via ACM Digital Library, including the October 1997 edition containing "Abowd".

10. Considering the MARC record data of each library in concert with the book bindery sicker, it is my determination that the October 1997 edition of *Wireless Networks* was made available and accessible to the public by the University of Pittsburgh shortly after initial publication and certainly no later than March 1998. Based on journal availability, it is my determination that 'Abowd' was made available and accessible to the public in October 1997 shortly after initial publication via *Wireless Networks* October 1997.

11. I have reviewed Exhibit 1038, "A Collaborative Wearable System with Remote Sensing" by Martin Bauer, Timo Heiber, Gerd Kortuem and Zary Segall (hereto referred to as 'Bauer') as presented in *The Second International Symposium on Wearable Computers* (1998).

12. Attached hereto as Appendix BA01 is a true and correct copy of the cover, spine, title page, table of contents and complete 'Bauer' from *The Second International Symposium on Wearable Computers* as held by Carnegie Mellon University. I secured this appendix myself in person. In comparing BA01 to Exhibit 1038, it is my determination that Exhibit 1038 is a true and correct copy of 'Bauer'.

13. Attached hereto as Appendix BA02 is a true and correct copy of the MARC record describing *The Second International Symposium on Wearable Computers* as held by Carnegie Mellon University. I secured this record myself from the library's online catalog. The 008 field of this MARC record indicates *The Second International Symposium on Wearable Computers* was first cataloged by Carnegie Mellon University as of August 5, 1998. This date is prior to the date of the Symposium itself and therefore it is my determination that CMU cataloged this copy in advance of the formal

publication of the material for the purpose of releasing the material expediently upon the date of formal release. In my experience as a cataloger, this is a common practice for time-sensitive materials. Considering this information, it is also my determination that Carnegie Mellon University made 'Bauer' available to the public shortly after the dates of the symposium, October 19-20, 1998.

14. I have been retained on behalf of the Petitioner to provide assistance in the above-illustrated matter in establishing the authenticity and public availability of the documents discussed in this declaration. I am being compensated for my services in this matter at the rate of $100.00 per hour plus reasonable expenses. My statements are objective, and my compensation does not depend on the outcome of this matter.

15. I declare under penalty of perjury that the foregoing is true and correct. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: 12/19/19

Jacob Robert Munford

Appendix A

Appendix A - Curriculum Vitae

Education

University of Wisconsin-Milwaukee - MS, Library & Information Science, 2009
Milwaukee, WI

- Coursework included cataloging, metadata, data analysis, library systems, management strategies and collection development.
- Specialized in library advocacy and management.

Grand Valley State University - BA, English Language & Literature, 2008
Allendale, MI

- Coursework included linguistics, documentation and literary analysis.
- Minor in political science with a focus in local-level economics and government.

Professional Experience

Researcher / Expert Witness, October 2017 – present
Freelance
Pittsburgh, Pennsylvania

- Material authentication and public accessibility determination. Declarations of authenticity and/or public accessibility provided upon research completion. Depositions provided on request.
- Research provided on topics of public library operations, material publication history, digital database services and legacy web resources.
- Past clients include Apple, Fish & Richardson, Erise IP, Baker Botts and other firms working in patent law.

Library Director, February 2013 - March 2015
Dowagiac District Library
Dowagiac, Michigan

- Executive administrator of the Dowagiac District Library. Located in Southwest Michigan, this library has a service area of 13,000, an annual operating budget of over $400,000 and total assets of approximately $1,300,000.

- Developed careful budgeting guidelines to produce a 15% surplus during the 2013-2014 & 2014-2015 fiscal years.
- Using this budget surplus, oversaw significant library investments including the purchase of property for a future building site, demolition of existing buildings and building renovation projects on the current facility.
- Led the organization and digitization of the library's archival records.
- Served as the public representative for the library, developing business relationships with local school, museum and tribal government entities.
- Developed an objective-based analysis system for measuring library services - including a full collection analysis of the library's 50,000+ circulating items and their records.

November 2010 - January 2013
Librarian & Branch Manager, Anchorage Public Library
Anchorage, Alaska

- Headed the 2013 Anchorage Reads community reading campaign including event planning, staging public performances and creating marketing materials for mass distribution.
- Co-led the social media department of the library's marketing team, drafting social media guidelines, creating original content and instituting long-term planning via content calendars.
- Developed business relationships with The Boys & Girls Club, Anchorage School District and the US Army to establish summer reading programs for children.

June 2004 - September 2005, September 2006 - October 2013
Library Assistant, Hart Area Public Library
Hart, MI

- Responsible for verifying imported MARC records and original MARC cataloging for the local-level collection as well as the Michigan Electronic Library.
- Handled OCLC Worldcat interlibrary loan requests & fulfillment via ongoing communication with lending libraries.

Professional Involvement

Alaska Library Association - Anchorage Chapter
- Treasurer, 2012

Library Of Michigan
- Level VII Certification, 2008
- Level II Certification, 2013

Michigan Library Association Annual Conference 2014
- New Directors Conference Panel Member

Southwest Michigan Library Cooperative
- Represented the Dowagiac District Library, 2013-2015

Professional Development

Library Of Michigan Beginning Workshop, May 2008
Petoskey, MI
- Received training in cataloging, local history, collection management, children's literacy and reference service.

Public Library Association Intensive Library Management Training, October 2011
Nashville, TN
- Attended a five-day workshop focused on strategic planning, staff management, statistical analysis, collections and cataloging theory.

Alaska Library Association Annual Conference 2012 - Fairbanks, February 2012
Fairbanks, AK
- Attended seminars on EBSCO advanced search methods, budgeting, cataloging, database usage and marketing.

Appendix AB01

WIRELESS
NETWORKS

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Advances in Wireless Networking

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Cyberguide: A mobile context-aware tour guide

Gregory D. Abowd [a], Christopher G. Atkeson [a], Jason Hong [a], Sue Long [a,b], Rob Kooper [a] and Mike Pinkerton [a]

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Future computing environments will free the user from the constraints of the desktop. Applications for a mobile environment should take advantage of contextual information, such as position, to offer greater services to the user. In this paper, we present the Cyberguide project, in which we are building prototypes of a mobile context-aware tour guide. Knowledge of the user's current location, as well as a history of past locations, are used to provide more of the kind of services that we come to expect from a real tour guide. We describe the architecture and features of a variety of Cyberguide prototypes developed for indoor and outdoor use on a number of different hand-held platforms. We also discuss the general research issues that have emerged in our context-aware applications development in a mobile environment.

1. Introduction

Future computing environments promise to free the user from the constraints of stationary desktop computing, yet relatively few researchers are investigating what applications maximally benefit from mobility. Current use of mobile technology shows a slow evolution from our current desktop paradigm of computing, but the history of interaction shows that the adoption of new technology usually brings about a radical revolution in the way humans use and view technology [11]. Whereas the effective use of mobile technology will give rise to an interaction paradigm shift, it is difficult to predict what that shift will be. We follow the advice of Alan Kay, therefore, and choose to predict the future by inventing it. Our approach is to think first about what activities could be best supported by mobile technology and then determine how the technology would have to work. This applications focus is important to distinguishing our work in mobile computing.

In April 1995, we formed the Future Computing Environments (FCE) Group within the College of Computing and the Graphics, Visualization and Usability (GVU Center) at Georgia Tech to promote such an applications focus. Our group is committed to the rapid prototyping of applications that benefit from the use of emerging mobile and ubiquitous computing technologies. Quick development of these futuristic applications allows us to predict and shape what our everyday lives will be like when today's novel technology becomes commonplace.

Applications for a mobile environment should take advantage of contextual information, such as position, to offer greater services to the user. In this paper, we present the Cyberguide project, a series of prototypes of a mobile, hand-held context-aware tour guide. Initially, we are concerned with only a small part of the user's context, specifically location and orientation. Knowledge of the user's current location, as well as a history of past locations, are used to provide more of the kind of services that we come to expect from a real tour guide. We describe the architecture and features of a variety of Cyberguide prototypes developed for indoor and outdoor use on a number of different hand-held platforms. We also discuss the general research issues that have emerged in our experience of developing context-aware applications in a mobile environment. Some of these research issues overlap with those that we have considered in applying other applications of ubiquitous computing technology.

The general application domain which has driven the development of Cyberguide is tourism, but we have found it necessary to be even more focused in our research. The initial prototypes of Cyberguide, therefore, were designed to assist a very specific kind of tourist – a visitor in a tour of the GVU Center Lab during our monthly open houses. Visitors to a GVU open house are typically given a map of the various labs and an information packet describing all of the projects that are being demonstrated at various sites. Moving all of the paper-based information into a hand-held, position-aware unit provided a testbed for research questions on mobile, context-aware application development.

The long-term goal is an application that knows where the tourist is, what she is looking at, can predict and answer questions she might pose, and provide the ability to interact with other people and the environment. Our short-term goal was to prototype versions of Cyberguide on commercially available PDAs and pen-based PCs in which context-awareness simply meant the current physical position and orientation of the Cyberguide unit (and since it is hand-held, this locates the user as well). Position information improves the utility of a tour guide application. As the prototypes of Cyberguide evolve, we have been able to handle more of the user's context, such as where she and others have been, and we have increased the amount in which the tourist can interact and communicate with the place and people she is visiting.

1.1. Overview

This paper is an extended version of an earlier report on Cyberguide [7], we discuss the evolution of the Cyberguide design and prototype as well as what future research areas our experience has uncovered. We begin in section 2 by describing scenarios for the use of context-aware mobile applications. In section 3, we provide context for our research within the area of applications-centered mobile computing. The generic architecture of Cyberguide is explained in section 4. We will describe in section 5 the initial realization of the generic components of the Cyberguide architecture, a series of prototypes developed for the Apple MessagePad. We will then describe in section 6 how the initial indoor prototypes were extended for use outdoors and for greater interaction with the environment. We conclude in sections 7 and 8 with a discussion of significant issues for context-aware applications development and how our past experience will influence our future development plans.

2. Scenarios for a mobile context-aware application

This section outlines some possible uses for future mobile context-aware applications. Some of these uses are currently being implemented and some are futuristic. We begin with our initial assumptions about what technology we expect Cyberguide to use. Tourists are usually quite happy to carry around a book that describes the location they are visiting, so a reasonable packaging would be in the form of a hand-held device. The ideal hand-held device will have a screen and pen/finger interface, access to substantial storage resources – possibly through an internal device such as a CD drive, or through substantial communication and networking resources (cell phone, pager, data radio interface) providing access to other storage servers (such as the Web) – an audio input and output interface with speech generation and potentially sophisticated voice recognition, and a video input and output interface. The video input (a video camera) could be pointed at the user to interpret user gestures, or pointed at the environment to interpret objects or symbols in the environment. The video output could be integrated into the main screen or be a separate video display device, such as an attached screen or heads up display on glasses worn by the user.

One major application of mobile context-aware devices are personal guides. Museums could provide these devices and allow users to take personalized tours seeing any exhibits desired in any order, in contrast to today's taped tours. In fact, many museums now provide portable devices for just such a purpose, but what we are envisioning is a device that would allow the tourist to go anywhere she pleases and be able to receive information about anywhere she is. Walking tours of cities or historical sites could be assisted by these electronic guidebooks. The hand-held devices could use position measurement systems such as indoor beacons or the Global Positioning System (GPS) to locate the user, and an electronic compass or inertial navigation system to find user orientation. Objects of interest could be marked with visual markers or active beacons or recognized using computer vision. Some objects, such as animals at a zoo or aquarium, might be difficult to mark but could be recognized with simple computer vision and some assistance from the environment (indications that this is the elephant cage, for example). The personal guide could also assist in route planning and providing directions. Some of these functions are currently being provided by automobile on-board navigation systems.

There are other ways to assist users. Consider a traveler in Japan that does not speak or read Japanese. The hand-held device could act as a pocket multilingual dictionary, actually speaking the appropriate phrase with the appropriate pronunciation to a taxi driver, for example (or even showing the appropriate Kanji and an associated map on the screen). A device that included video input or a scanner could assist in reading signs or menus. A device that could show stored images might be able to show a shopkeeper the desired object or favorite meal. Another more futuristic use is to assist the user by recognizing faces at a cocktail party and reminding the user who people are.

Real-time communication allows a personal device to act as an agent for the user. A personal guide to a theme park could make reservations at particular rides, and alert the user when the reservation was available. The device could also tell the user which rides had the shortest lines. Similar approaches are currently being used for automobile traffic management in major cities.

An important application of context-aware devices is enhanced reality. A heads up display could provide "X-ray" vision for the user. While surveying a building for renovation, the location of hidden plumbing or electrical conduits could be indicated to the user, based on information from sensors and/or building plans. At an archeological site a visitor could be provided with various overlays indicating what used to be above the current ground level as well as what is below the current ground level.

Context-aware devices can also be used as tools. Simple sonar devices are used to make room measurements today. It would not take much to have a hand-held device that both videotaped and mapped a room along with user commentary. An ecological field study or an archeological dig could be assisted by a device that automatically recorded the context of a particular find, including noting the surrounding objects. Consider an electronic field guide that assisted the user in recognizing plants or insects.

One of the most interesting applications of context-aware devices is to support group interaction on a tour or in a classroom, for example. Participants in a live demonstration of some new technology could use their personal device to help steer the demo using majority voting or consensus among the viewers. Each participant could run a personalized version of the same demo by expressing their own choices. In this case context is which demo a participant is participating in or attending to, and the personal machine may switch to another context if it detects the user is attending to that context instead.

Many tourists take records of some sort of their travelling experiences, either by taking pictures or videos or by composing a travel diary. Imagine the possibilities if the recording of these experiences could be more efficiently and accurately recorded. A drive across the country could result in a trail superimposed upon a map, and clicking on the trail would reveal an image of what you could see at that moment – an automatically-generated spatial index into your memories.

These are but a few of the possibilities we can imagine that a context-aware application can provide for the tourist. We have investigated many of these possibilities already and report on them later.

3. Related work

In thinking about and developing a location-aware application, we were greatly influenced by work such as the PARCTab at Xerox PARC [15], the InfoPad project at Berkeley [8], the Olivetti Active Badge system [14] and the Personal Shopping Assistant proposed at AT&T [3]. We wanted to build useful applications that might take advantage of the hardware developed in the PARCTab and InfoPad projects. We did not want to build our own hardware, so we have a different focus from all of these projects. There are a number of commercially available and relatively inexpensive hand-held units that would suffice for our purposes, such as the Apple MessagePad with the Newton Operating System[1], a MagicCap[2] machine or a pen-based palmtop/tablet PC. We chose to work initially with the Apple MessagePad 100 with Newton 1.3 and pen-based PCs running Windows for Pen Computing 1.0. Each platform was available for $150–500 with relatively powerful development environments. This low cost of hardware was critical to the success of Cyberguide because it made it possible to put a number of units in the hands of many students, all with different ideas that they were allowed to investigate.

For positioning, we considered the Active Badge system, but rejected it for reasons of cost and long-term objectives. The Active Badge system combines position detection with communication. For room-level granularity of position, this is reasonable since the communications range is on par with the position resolution. With Cyberguide, it is not clear that positioning and communication systems should always share physical resources. Certain versions of our prototype did; other prototypes did not. We provided for the separation of the wireless communications capabilities from the positioning system, so we could seek out more cost-effective solutions for both.

[1] MessagePad and the Newton Operating System are registered trademarks of Apple Computer, Inc.

[2] MagicCap is a registered trademark of General Magic, Inc.

We tried to pay attention to the higher level conceptual design of Cyberguide, but we have not been as general in our handling of context-aware mobile objects as has Schilit [13].

4. Architecture of Cyberguide

From the beginning, we have viewed Cyberguide as a family of prototypes and not just a single prototype, so it made sense to think about a conceptual design, or architecture, that captured the essence of the mobile tour guide. We have divided the system into several independent components, or building, and have found it useful to present those components both in terms of the generic function and personified in terms of the people a tourist would like to have available while exploring unfamiliar territory. The overall system serves as a tour guide, but we can think of a tour guide as playing the role of cartographer, librarian, navigator and messenger. The services provided by these components are:

- *Cartographer* (*map component*). This person has intimate knowledge of the physical surroundings, such as the location of buildings, interesting sights within a building, or pathways that the tourist can access. This component is realized in our systems by a map (or maps) of the physical environments that the tourist is visiting.
- *Librarian* (*information component*). This person provides access to all of the information about sights that a tourist might encounter during their visit. This would include descriptions of buildings or other interesting sights and the identities of people associated with the areas. The librarian can answer specific question about certain sights ("Who works in that building?" or "What artist painted that picture?" or "What other demonstrations are related to what I am looking at?"). This component is realized as a structured repository of information relating to objects and people of interest in the physical world.
- *Navigator* (*positioning component*). The interests of the tourist lie relatively close to their physical location. Therefore, it is important to know exactly where the tourist is, in order to show the immediate surroundings on the map or answer questions about those surroundings ("What am I looking at?"). The navigator is responsible for charting the location of the tourist within the physical surroundings. This component is realized by a positioning module that delivers accurate information on tourist location and orientation.
- *Messenger* (*communications component*). A tourist will want to send and receive information, and so the messenger provides a delivery service. For example, when visiting an exhibit or demonstration, the tourist might want to speak with the owner of the exhibit. If the owner is not present, the tourist can leave a message. In order to find out where other tourists are located, each

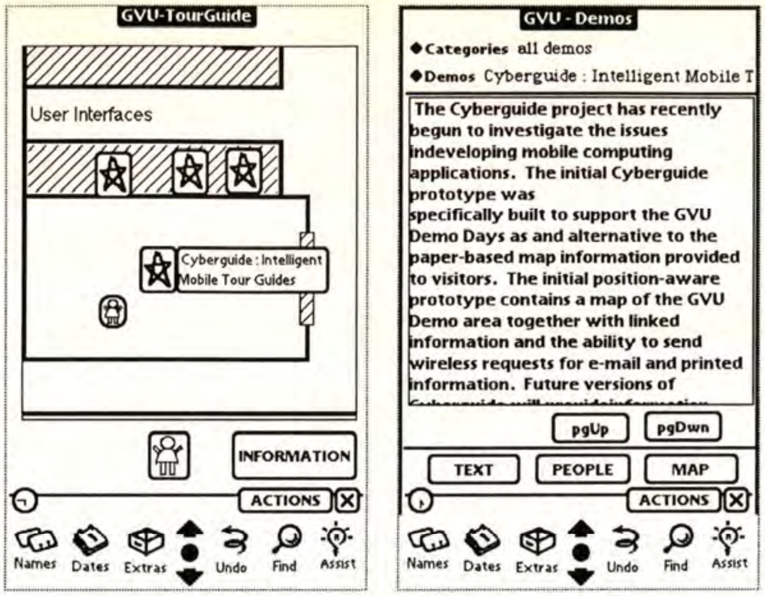

Figure 1. The map (left) and information (right) interfaces of the initial Cyberguide MessagePad prototype.

tourist can communicate her current location to some central service that others can access. It might also be desirable to broadcast information to a set of tourists ("The bus will be leaving from the departure point in 15 minutes."). This component is realized as a set of (wireless) communications services.

The utility of this architectural decomposition for Cyberguide is that it provides an extensible and modular approach to system development. It is extensible because we can always add further services. For example, we have considered adding an historian whose purpose is to document where the tourist has been and what her reactions were to the things she saw. It is modular because it has allowed us to change the implementation of one component of the system with minimal impact on the rest of the system. For example, we have implemented different versions of the navigator and the librarian without having to alter the other components. Of course, these components are related in some ways; for instance, position information ultimately has to be translated into a location on the physical map. Defining standard interfaces between the components is the means by which we achieve separation between and coordination among the various components.

5. The indoor Cyberguide

In this section, we describe how each of the separate modules in the conceptual architecture have been realized in the initial series of prototypes developed on the Apple MessagePad for use indoors during GVU open houses.

5.1. Map component

The initial map module, shown on the left side of figure 1, contains a map of the entire GVU Center. Passageways and demonstration stations (stars in figure 1) are shown. Only a limited view of the lab can be seen at any given time. The user can scroll the map around and zoom in and out to see alternative views. There is an icon to show the user's location on the map. Using information from the positioning module, we implemented automatic scrolling of the map. If desired, the user's position is updated automatically and the map is scrolled to ensure that the user's current position remains on the visible portion of the map.

5.2. Information component

The information module (shown on the right side of figure 1) contains information about each of the demos on display at the GVU open house. This includes abstracts of the project being demoed, background information on those involved with the project, as well as where to get further information. The location of each demo is marked on the map by a star. The user selects the star icon for a demo to reveal its name. Selecting the name brings up the information page for that demo. The user can also go directly into the information module and search for information for specific demo pages either by category or by project name.

One version of the information module was hard-coded, providing very fast response but requiring a recompilation every time demo information needed to be updated. Another implementation used Newton files, called soups, to store information. The use of soups avoided hard-coding data into the application and simplified demo information updates, but did not have adequate response time. Our third implementation of the information module used Newton Books, the Newton platform documentation viewer, to store the demo information. The use of Newton Books improved our access time considerably, allowing for an automated information update process without requiring data be hard-coded directly into the application. Throughout all

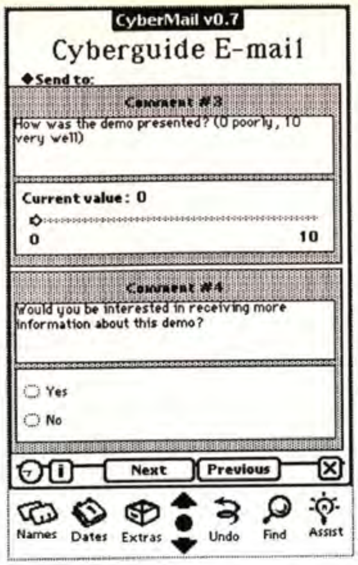

Figure 2. Questionnaire using communications module for delivery.

three versions of our information module, we were able to modify the information module independent of the development efforts of the other modules, validating the modularity of part of our design.

5.3. Communication component

Our initial implementation of a communication module consisted of a wired Internet Appletalk connection from a Apple MessagePad through a Unix Appletalk Gateway. We designed an application level protocol on top of a public domain implementation of the Appletalk protocol for Solaris [4]. This allows us to open a connection-based Appletalk stream from the Apple MessagePad to a UNIX platform. We then invoked our gateway application to repacketize Appletalk packets into TCP/IP packets for transmission over the Internet. This allowed for TCP/IP connectivity from a Apple MessagePad via an Appletalk connection. We could then fetch HTML documents as well as send and receive e-mail. We utilized this functionality within Cyberguide by providing a questionnaire for users to complete, which was sent to the developers as an e-mail message (see figure 2).

5.4. Position component

Position is the obvious starting point for a context-aware mobile device. We considered several methods for sensing the user location. Outdoors, continuous services, such as GPS, can be used. Indoors, however, GPS signals are weak or not available. We considered RF for indoor position measurement, but found off the shelf solutions too expensive.

One solution for an indoor positioning system was to use infrared (IR). Our first positioning system was based on using TV remote control units as active beacons, and using a special IR receiver tuned to the carrier frequency ($\approx$ 40kHz) of those beacons (figure 3). A microcontroller (Motorola 68332) interfaced the IR receiver to the serial port of the Apple MessagePad. We deployed an array of remote controls hanging from the ceiling (figure 3 right), each remote control acting as a position beacon by repeatedly beaming out a unique pattern. The 68332 translates the IR pattern into a unique cell identifier that is sent to the Apple MessagePad's serial port. As the tourist moves around the room and passes into the range of a new cell, the position (indicated by an arrowhead) is updated on the map. Keeping track of the last recorded cell location provides a good guess as to the location the tourist is heading, so we indicate an assumed orientation by pointing the position icon accordingly.

The remote control system is too expensive for large scale use as the cost of the 68332 microcontroller is roughly equivalent to that of the MessagePad.

6. Extending the initial prototype

The first Cyberguide prototypes were completed within 6 months. To test out the genericity of our architectural approach, we decided to develop further prototypes that altered one or more of the major components described in section 4 and increased overall functionality. We describe these extended prototypes here.

6.1. Outdoor positioning

There were several motivations for building a Cyberguide prototype for outdoor use (figure 4). First, we wanted to use Cyberguide over a wider area than the relatively small GVU Center. We also wanted to test the modularity of our design by having to change critical features. The two features that were changed on this prototype were the underlying map and the physical positioning system. We obtained a different map and inserted that into the map module without any problems. For positioning, we replaced the IR positioning module with a Trimble GPS unit attached to the Apple MessagePad serial port. (see right side of figure 4). The GPS unit sends a position in latitude and longitude which was then translated into a pixel coordinate representing the user's current position on the map.

The outdoor positioning system has been tested by two prototypes. We first built a proof of concept tour of the Georgia Tech campus (shown in figure 4). We also developed a more functional outdoor prototype that covered three surrounding neighborhoods of the campus, described later.

6.2. Alternate platforms

In order to verify the platform independence of our conceptual design, we initiated two separate efforts building pen-based PC versions of Cyberguide. These limited functionality PC versions were written using Borland's Delphi environment and Microsoft's Visual Basic. Both were initially installed on Dauphin DTR-1 palmtops running Pen for Windows Computing 1.0.

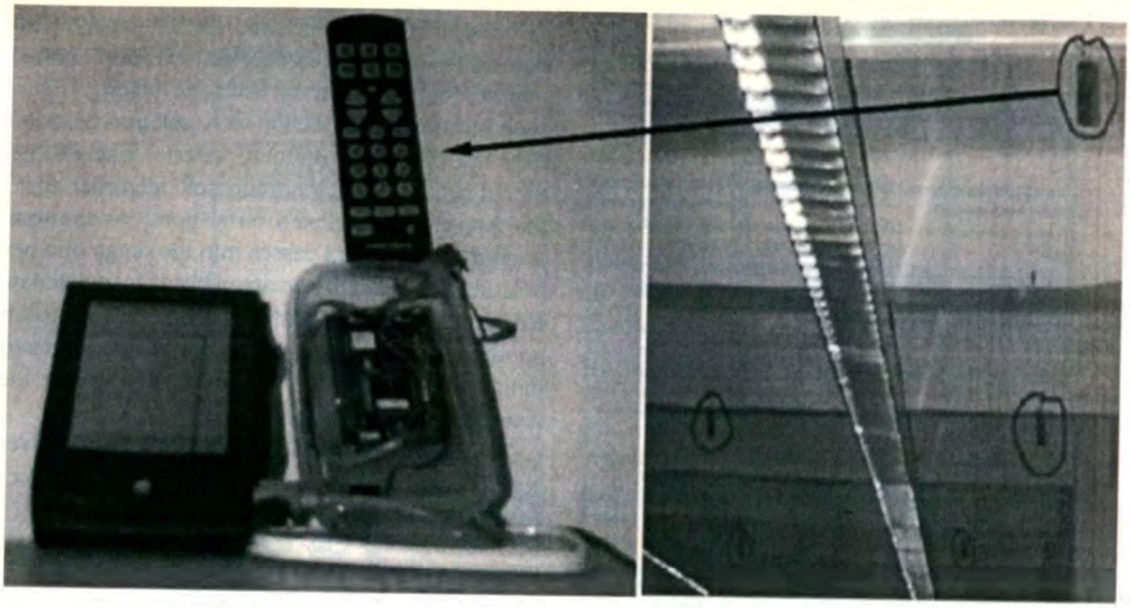

Figure 3. IR positioning prototype (left) and the array of positioning beacons in the GVU Lab (right).

Figure 4. The outdoor Cyberguide (left) with GPS unit (right).

The Delphi version implements the map and information module. Web pages containing demo information are stored locally as database objects using a stand-alone Borland database engine. The information base is extracted from the collection of existing Web pages for GVU projects but stored locally. This information is viewed using a public domain Delphi HTML viewer. Though this provided a very fast response for information queries, it is a long-term disadvantage to have the information base stored locally. Too much in our environment is subject to change. A local and static database is only slightly more useful than a book. This approach to static information storage is used currently for on-board navigation systems on certain rental cars.

The Delphi prototype uses vector-based maps, allowing for arbitrary scaling and rotation of the map and well as path generation. While there are several sources for obtaining vector maps for outdoor regions, it is not so easy for indoors. Consequently, there is a trade-off between the easily generated but limited functionality of bitmap images and the highly functional but hard to generate vector maps for indoor use.

The Visual Basic prototype, shown in figures 5–9 realizes all four components of Cyberguide, including two-way communications, which is discussed next. We implemented historical context by predicting when a user had visited a demo, based on time spent in the area of the demo and interaction with the map. In figure 5, a visited demo is in-

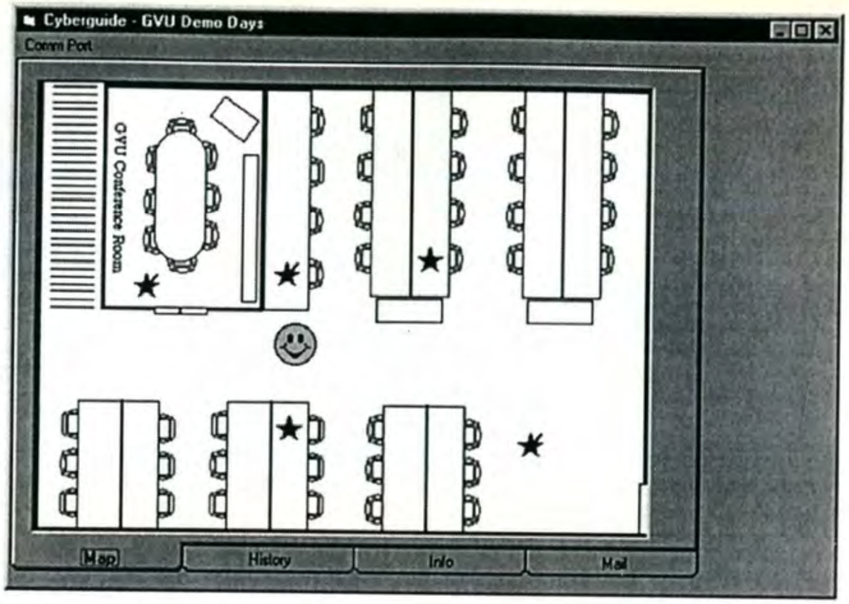

Figure 5. The main map interface of the PC Cyberguide. Checks on demo sites indicate the user has been to visit that demo already, indicating history-sensitive interface.

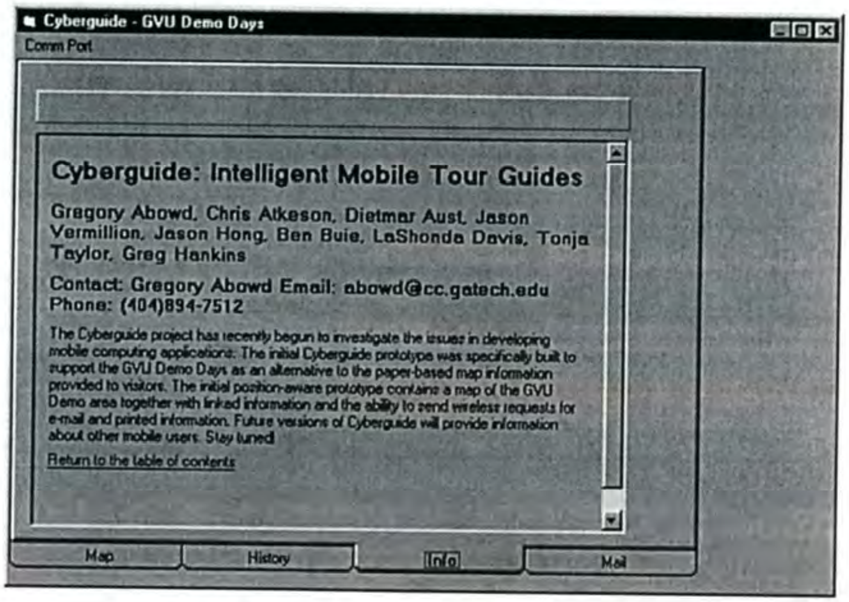

Figure 6. The information browser interface of the PC Cyberguide.

dicated on the map by a checkmark. There is also a separate panel that lists the demos visited. This information could be used, for example, to generate a summary of the day's visit to GVU open house and then mailed off to the visitor. We again made use of a publicly available HTML rendering component to display the project descriptions, still stored locally.

6.3. Increased communication

A number of interesting possibilities are enabled for the tourist in a wireless communication mode. We have spent a good deal of effort building an indoor, low-cost wireless communications infrastructure for Cyberguide. We have built a serial IR network using inexpensive modules from Sharp (the same modules used in the MessagePad). We have written UNIX server software and client software for both the MessagePad and PC. Figure 7 shows how our homemade network connects mobile units to the departmental network. We have defined a simple protocol to support three different kinds of messages: mailing out from a mobile unit to the network (as shown in figure 8); broadcasting from the network to all mobile units (figure 9); and updating positioning information. We implemented this protocol over serial IR instead of some other standard so that we could immediately use all platforms (UNIX, Newton and Windows). Given the appropriate hardware and protocol support (perhaps IRDA), we sencould provide the same functionality more robustly.

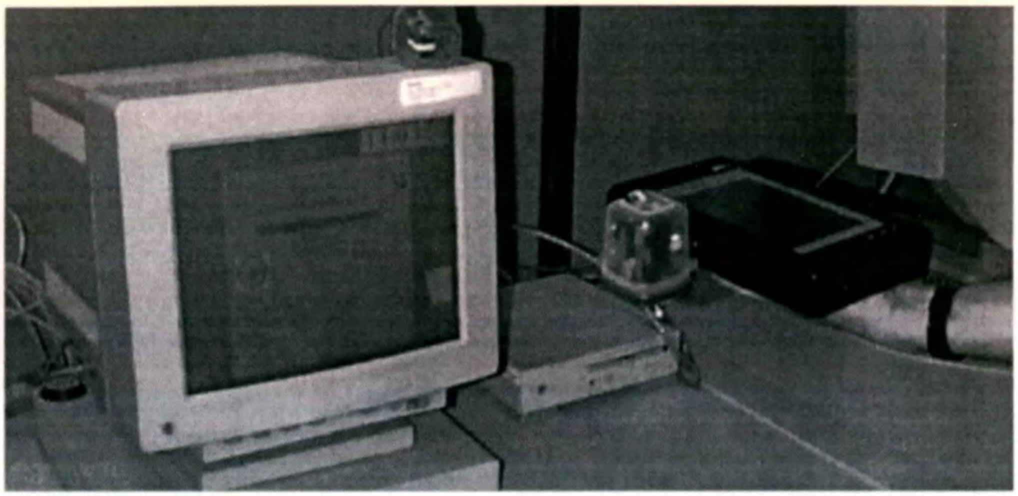

Figure 7. Home-made IR units allow cross-platform communication.

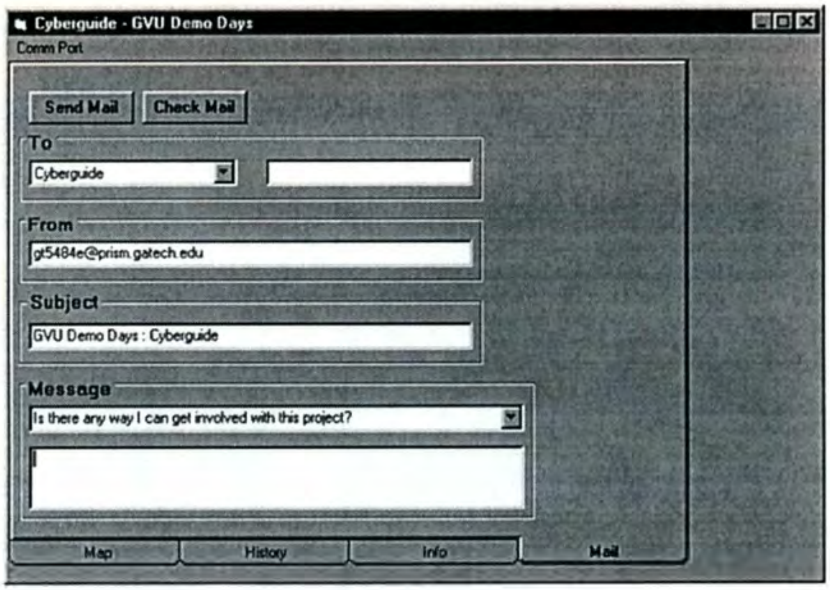

Figure 8. The mail interface of the PC Cyberguide. Addresses are automatically filled in and message templates are supplied upon request.

6.4. Increased interaction with environment

All of our applications of Cyberguide so far have restricted the role of the tourist to browsing, but it is likely that as she visits some place, the tourist will want to keep a record of her experience as advice for herself or others later on. With this idea of increased interaction with the environment and recording in mind, we created another Cyberguide prototype, called CyBARguide, to assist a tourist in pursuit of refreshment at neighborhood establishments in Atlanta. This prototype covers approximately 12 square miles of midtown Atlanta, using multiple maps at varying levels of detail.

Figure 10 shows the map interface on the left and a view of a user-modifiable database for interesting establishments on the right. The tourist can indicate a desired destination and as she moves around, CyBARguide automatically chooses the map of the highest detail that contains both the traveler (indicated by a triangle in figure 10), and the destination (the beer mug with the emboldened border in figure 10). Along the way, if the tourist eyes another interesting establishment that is not currently highlighted on the map, it could be added. Each establishment has a user-modifiable database entry associated with it that reflects both objective (e.g., availability of parking, average price of drinks) and subjective (e.g., ambiance or other comments) information that can be used in the future to plan an evening's excursion. querying of a large amount of information and some minimal routing facilities. We also plan to make the data within the information module modifiable so the user can add personalized information including personal impressions that may be useful for future reference, a type of virtual graffiti. We envision the use of CyBARguide in a mode in which both tourist and proprietors are able to modify the information base. A simple searching

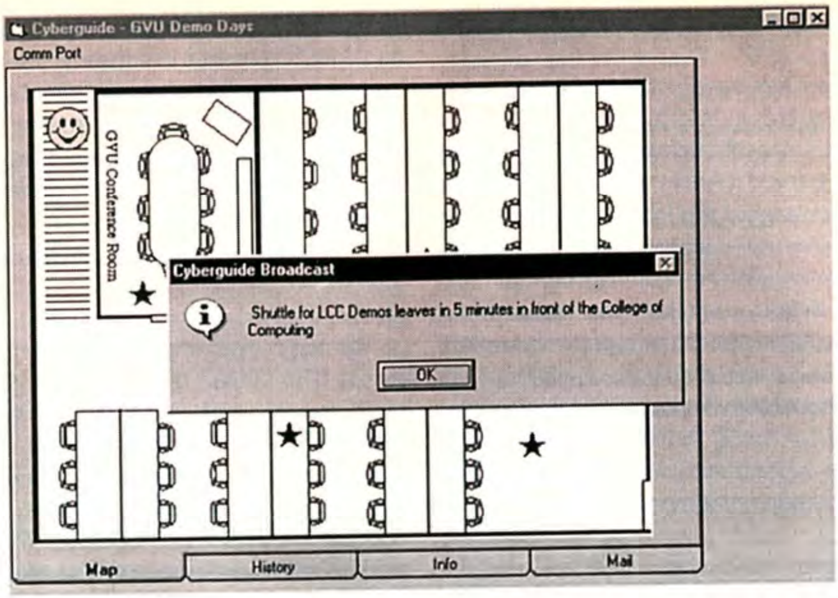

Figure 9. A demonstration of receiving a broadcast message from the Network to an individual Cyberguide unit.

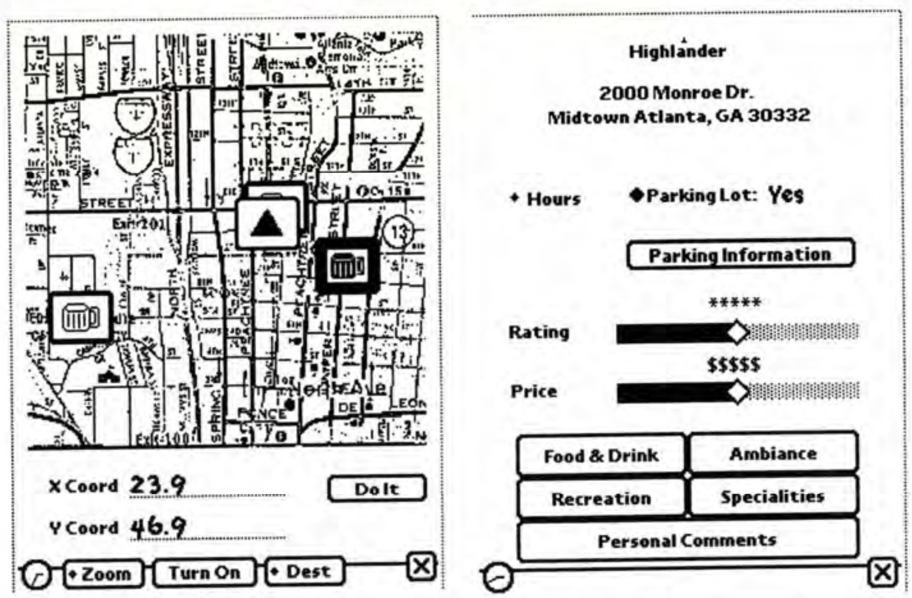

Figure 10. The CyBARguide interface. The left shows the interactive map indicating the user's location (the triangle) and the location of establishments previously visited (the beer mugs). The user modifiable database shown on the right supports the long-term development of touring information for a location.

capability can assist revellers in search of a certain kind of entertainment experience, and additional contextual information, such as the knowledge of where the traveller has been already, the time of day, and what special events (information provided by the proprietors) are currently scheduled, can be used to deliver suggestions for where to go.

7. Issues

Our experience over the last year developing versions of Cyberguide with different features on different platforms has given us a certain amount of insight into the important issues in developing mobile, context-aware applications. In this section, we summarize some of those issues.

Our prototyping efforts were iterative, modifying both hardware and software to improve functionality. Our primary focus, to assess the impact of mobile technology for a specific task, necessitated rapid and inexpensive prototyping. This motivated the use of inexpensive commercially available hardware. When choosing our hardware platform, we considered several mobile hand-held devices before deciding on the Apple MessagePad and various palmtop PCs. One of the driving considerations in purchasing hardware was cost, because we wanted to provide as many units to individuals and groups to maximize the number of ideas investigated. The downside of this decision was a collection of applications that were not very robust, but that negative has been outweighed by the sheer number of options we have been able to investigate and prototype in little over a year.

Over the last year we have used Cyberguide for many GVU open houses. We gathered informal feedback through informal surveys, formal questionnaires and informal user comments. We also observed visitors as they tried to use Cyberguide to maneuver around the lab. During each iteration we incorporated the user feedback and our own reactions to what was good and what was bad into the next iteration on the design. While our major focus was to prototype a context-aware mobile application rapidly, we realize that little can be determined concerning the impact of such technology unless the technology is put in the hands of real users.

7.1. Coupling of positioning and communication

There is an interesting relationship between the positioning and communication systems. Systems such as PARCTab and the Active Badge rely on a close coupling of positioning and communication. This is because the location of any mobile entity is determined by the beacon which receives a communication from the entity. In Cyberguide, the indoor and outdoor positioning system worked by having the beacon inform the mobile entity where it was located. The disadvantage of this latter approach for Cyberguide is that only the mobile entity knows its location. For applications in which you want objects to know about the position of other objects, there must be some sort of communication. However, it can be impossible or undesirable to couple positioning and communication together. For example, if position is coming from GPS, then a separate means of communication must be used. In our current version of indoor IR positioning using the Sharp IR units, we can couple positioning and communication, but the range of the IR link is so limited (3 feet) that communication will be cumbersome. It makes sense to use a short range IR positioning system because position information can be localized to objects of interest. Communication, on the other hand, needs to be uniform throughout some space.

7.2. Communication medium

We have been trying to implement communications services on commercial hand-held units. While communication is important to Cyberguide, there is no obvious appropriate choice for a wireless communication medium to suit our needs. It clearly is not a priority among the manufacturers of these units to provide high bandwidth, cost-effective wireless communications. There are many potential solutions for communications (IR, spread-spectrum RF, cellular packet, cellular modem), but the variety and quality of these services changes so much that manufacturers tend not to build communications devices into the units, for fear of premature obsolescence. Instead, they rely on third party communications solutions with standard interfaces (e.g., PCMCIA). In our experience, there is a need to have high bandwidth communication to the mobile unit and low bandwidth connection back to the network. We do not assume that the hand-held unit will always carry around with it the entire information base or map associated with the area the tourist is visiting. Rather, that information should be provided on demand and relative to the position/orientation of the tourist.

7.3. Map representation

We have experimented with bitmap and vector-based maps. The bitmap representation is easy to obtain (scanning) for any area and is relatively inexpensive to store and display. Scaling and rotation, however, are cumbersome with that representation. Since we were decorating the map to highlight places of interest that were not on the original bitmap, it was difficult to control the display of the decorations after scaling for a zoom in or out. Another problem with the bitmap representation is accuracy with respect to the real-world. In the outdoor version of Cyberguide, we noticed a drift on the positioning system for a certain region of the map attributed to the map itself being out of scale. Also, a bitmap representation is not suited to doing higher level map services, such as generating a path to direct the tourist to a location of interest.

A vector-based representation, on the other hand, is easier to handle in terms of manipulation and additional services such as way-finding, but was not a feasible solution on the interpreted platforms (Visual Basic and Apple MessagePad 100 with Newton 1.3 using the Newton Toolkit 1.5) because it was computationally overwhelming to manage the display (this may be solved with compiling capabilities of later versions of the Newton Toolkit). It is also more difficult to obtain a vector-based map for a large and detailed area. For example, when we built the Delphi prototype, it was not difficult to build a map tool to construct the vector-based map, but it would take a very long time to create a map of the GVU Lab with the detail we already had in the bitmap version. For outdoor use, there are already commercially available structured map databases for large areas, and these are being used in navigational systems in rental cars. However, the size of the map database prohibits local storage on hand-held units, so there is an even stronger argument for high bandwidth downstream wireless connectivity.

7.4. Cross-platform issues

We developed prototypes on multiple platforms to validate our claim of platform independence for the architecture. It was encouraging to see the same indoor positioning system work for both the Apple MessagePad and Visual Basic prototypes. Outdoor positioning is similarly cross-platform, relying on either a serial or PCMCIA interface.

For communication, we also see the need to standardize the interface and protocol. For information services, it is natural to want support for wireless TCP/IP to enable full

Internet capability. The information browsing can then be treated as a Web browsing task, for example. There are efforts already to support TCP/IP for platforms such as the Newton platform, but the bandwidth does not yet support delivery of complex graphics, as we would need for map delivery. Without cross-platform wireless Internet support, we were forced to approximate the connectivity using simple wireless serial connections. These do not provide the reliability nor range that would be necessary for a commercial strength application, but they provided enough of the infrastructure to investigate functional capabilities for the user.

8. Future work

We have worked for a year on Cyberguide. We have always tried to keep in mind the very long term goals of this kind of application, and many of those ideas have been expressed by others and by us in section 2. The following is a list of features that we feel are most important for near-term future versions of mobile, context-aware applications such as Cyberguide.

8.1. Modifiable information base

As a tourist visits a place, she may read about prepared information, but she may also have her own thoughts and reactions to what she sees or may overhear someone else interpret an exhibit in an interesting way that she would like to record. Capturing relevant information along the way and adding that to the information base would be useful. We have been focusing on applications of Cyberguide that emphasize functionality based on knowledge of the user's physical context. Another major theme the FCE group has worked on involves automated capture of user experience to facilitate later access to a rich record of that experience. Most of our work in that area has involved the application of ubiquitous computing technology in the stationary environment of the university classroom [1,2,12] and others have applied it in the meeting room environment [9,10]. We can see a hint of this capture/access problem appearing in CyBARguide as the traveller records impressions of an establishment that may influence their plans later on. It is a natural extension to add this kind of capture facility for the tourist.

We have experimented with capturing contextual information from a traveller to support the automatic authoring of a travel diary.[3] As a user journeys around, a log of time and place is recorded. In addition, the traveller carries a digital camera or video and comments about a day's journey into a microphone. All of these streams of activity can be associated either by time or place, resulting in a rich multimedia record of a vacation. This record is also searchable, which supports queries such as, "What was the name of that charming gift shop we visited shortly after lunch in Albequerque yesterday?" With a suitable combination of positioning system, digital camera and wireless communication, we can create dynamic Web pages that catalog our travel experience for others to enjoy.

[3] Take a look at http://www.gatech.edu/chow/roadtrip for a sample of what we have already done.

8.2. Increased communications

Cyberguides wireless communications is unreliable and short-range, and that has prevented us from moving the information sources off of the hand-held unit. This is a high priority in our future work and we will most likely investigate third party wireless modems with TCP/IP support on the hand-held units. Since we are currently limited to what is in place from commercial vendors, we might now take the time to investigate research platforms such as the InfoPad.

8.3. Improved context awareness

One way to view the capturing activity above is as a way to augment the system's understanding of the tourist's context by remembering what was interesting. We currently have a very limited notion of context in Cyberguide – physical location and crude orientation. We have experimented with capturing historical context (what sights have been visited already), but there are a number of other aspects of the tourist's context that can be useful. For instance, knowing where everyone else is located might suggest places of potential interest. Knowing the tourist's reaction to some exhibits would help in suggesting other related places of interest. Being aware of time of day or day of week may aid in more intelligent user queries of interesting attractions or activities. We feel that the secret to context-awareness is in doing it behind the scenes. The more that can be automatically captured and turned into context, the better. If the user has to explicitly inform the system about context information ("I am currently located here." or "This exhibit is boring to me." or "The museum is currently closed.") then the context is unlikely to be fully utilized.

8.4. Leveraging the Web

In the touring example, we found that much of the information we wanted to display was already available on the Web. Web browsing is now a natural information browsing metaphor. It makes sense to leverage this available information resource and mode of interaction for all of the information needs. The map module then provides hooks or links to the information on the Web, and it is delivered on demand, similar to when a user selects a URL on a browser. There have already been some research [3] and commercial attempts at providing mobile Web browsers.

8.5. Use of vision

In the extreme case, we can think of a communion between the physical and electronic worlds, as suggested by work in augmented reality. Replace the hand-held unit with a pair of goggles and as the user wanders around, information about certain exhibits can be summoned up and overlaid on top of the actual image. Vision techniques can be used to augment the positioning system to inform the system and tourist what the tourist is looking at. We have experimented with vision systems as an extension to Cyberguide. Ultimately, we want to move toward personalized vision systems.

8.6. Ubiquitous positioning system

Our current prototypes are exclusively indoor or outdoor, not both. This is mainly because we had no one positioning system that worked in both conditions. GPS is unreliable indoors and the IR-based beacon system is impractical for us to implement outdoors. We intend to integrate both positioning systems into one application, to allow a tourist to wander in and out of buildings and have Cyberguide automatically switch the positioning system.

8.7. Increased multimedia support

In the context of the GVU open houses, visitors often gather around a demo and stretch to watch the activity on a desktop machine as the researcher describes the related research. We would like to have Cyberguide units in the vicinity of the demonstration be able to pick up a live feed from the demonstration for display on their own unit. Initially, this could be achieved by a simple mirroring of the demonstration machine's display onto the hand-held unit. Ultimately, we envision the visitor "plugging in" to the demonstration and being able to control it from their hand-held unit.

9. Conclusions

We have described research we have been conducting over the past year prototyping mobile, context-aware applications. The main focus of our development effort has been to take an applications focus, tourism in this case, and determine what commercially available hardware can be used to deliver relevant information to the mobile user that is tuned to knowledge of their physical context. We described several iterations on the Cyberguide application, built to support tours through various venues. Our experience prototyping several variations of Cyberguide has clarified our own thoughts on how context-aware computing provides value to the emerging technology promising to release the user from the desktop paradigm of interaction. The experience also has helped to clarify some significant research issues in the continued development of mobile, context-aware applications for future computing environments.

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References

[1] G.D. Abowd, C.G. Atkeson, A. Feinstein, Y. Goolamabbas, C. Hmelo, S. Register, N.N. Sawhney and M. Tan, Classroom 2000 enhancing classroom interaction and review, Technical Report GIT-96-21, Graphics, Visualization and Usability Center, Georgia Institute of Technology (September 1996).

[2] G.D. Abowd, C.G. Atkeson, A. Feinstein, C. Hmelo, R. Kooper, S. Long, N.N. Sawhney and M. Tan, Teaching and learning as multimedia authoring: The classroom 2000 project, in: *Proceedings of the ACM Conference on Multimedia* (*Multimedia '96*) (1996).

[3] A. Asthana, M. Cravatts and P. Krzyzanouski, An indoor wireless system for personalized shopping assistance, in: eds. L.-F. Cabrera and M. Sattyanarayanan, *Workshop on Mobile Computing Systems and Applications* (IEEE Computer Society Press, December 1994) pp. 69–74.

[4] J.F. Bartlett, W4 – the wireless World Wide Web, in: eds. L.-F. Cabrera and M. Sattyanarayanan, *Workshop on Mobile Computing Systems and Applications* (IEEE Computer Society Press, December 1994) pp. 176–178.

[5] B. Krupczak, M. Ammar and K. Calvert, Multi-subsystem protocol architectures: Motivation and experience with an adaptor-based approach, in: *Proceedings of IEEE INFOCOM '96* (1996).

[6] S. Long, D. Aust, G.D. Abowd and C.G. Atkeson, Rapid prototyping of mobile context-aware applications: The cyberguide case study, in: *Proceedings of Conference on Human Factors in Computing Systems – CHI '96* (1996). Short paper.

[7] S. Long, R. Kooper, G.D. Abowd and C.G. Atkeson, Rapid prototyping of mobile context-aware applications: The cyberguide case study, in: *Proceedings of 2nd Annual International Conference on Mobile Computing and Networking* (November 1996).

[8] A.C. Long Jr, S. Narayanaswamy, A. Burstein, R. Han, K. Lutz, B. Richards, S. Sheng, R.W. Brodersen and J. Rabaey, A prototype user interface for a mobile multimedia terminal, in: *Proceedings of Conference on Human Factors in Computing Systems – CHI '95* (1995). Interactive experience demonstration.

[9] S. Minneman, S. Harrison, B. Janseen, G. Kurtenbach, T. Moran, I. Smith and B. van Melle, A confederation of tools for capturing and accessing collaborative activity, in: *Proceedings of the ACM Conference on Multimedia – Multimedia '95* (November 1995).

[10] T. Moran, P. Chiu, S. Harrison, G. Kurtenbach, S. Minneman and W. van Melle, Evolutionary engagement in an ongoing collaborative work process: A case study, in: *Proceedings of ACM CSCW '96 Conference* (1996).

[11] H. Rheingold, *Tools for Thought* (Prentice-Hall, Englewood Cliffs, 1985).

[12] N.N. Sawhney, G.D. Abowd and C.G. Atkeson, Can electronic notebooks enhance the classroom? Technical Report GIT-96-06, Graphics, Visualization and Usability Center, Georgia Institute of Technology (February 1996).

[13] W.N. Schilit, System architecture for context-aware mobile computing, Ph.D. Thesis, Columbia University (1995).

[14] R. Want, A. Hopper, V. Falcao and J. Gibbons, The active badge location system, ACM Transactions on Information Systems 10(1) (January 1992) 91–102.

[15] R. Want, B. Schilit, N. Adams, R. Gold, K. Petersen, J. Ellis, D. Goldberg and M. Weiser, The PARCTAB ubiquitous computing experiment, Technical Report CSL-95-1, Xerox Palo Alto Research Center (March 1995).

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Appendix AB02

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245 00 |**a** Wireless networks.
246 13 |**a** WN
260 __ |**a** Amsterdam : |**b** Baltzer Science Publishers, |**c** c1995-
300 __ |**a** v. : |**b** ill. ; |**c** 29 cm.
310 __ |**a** Quarterly
362 0_ |**a** Vol. 1, no. 1 (Feb. 1995)-
500 __ |**a** "The journal of mobile communication, computation and information."
530 __ |**a** Also available on the World Wide Web.
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650 _0 |**a** Wireless communication systems |**x** Periodicals.
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Other Author(s):	Association for Computing Machinery.
Publisher:	Amsterdam : Baltzer Science Publishers, c1995-
ISSN:	1022-0038
Description:	v. : ill. ; 29 cm. Quarterly Vol. 1, no. 1 (Feb. 1995)-
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Appendix AB03

Cyberguide: A mobile context-aware tour guide

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Future computing environments will free the user from the constraints of the desktop. Applications for a mobile environment should take advantage of contextual information, such as position, to offer greater services to the user. In this paper, we present the Cyberguide project, in which we are building prototypes of a mobile context-aware tour guide. Knowledge of the user's current location, as well as a history of past locations, are used to provide more of the kind of services that we come to expect from a real tour guide. We describe the architecture and features of a variety of Cyberguide prototypes developed for indoor and outdoor use on a number of different hand-held platforms. We also discuss the general research issues that have emerged in our context-aware applications development in a mobile environment.

1. Introduction

Future computing environments promise to free the user from the constraints of stationary desktop computing, yet relatively few researchers are investigating what applications maximally benefit from mobility. Current use of mobile technology shows a slow evolution from our current desktop paradigm of computing, but the history of interaction shows that the adoption of new technology usually brings about a radical revolution in the way humans use and view technology [11]. Whereas the effective use of mobile technology will give rise to an interaction paradigm shift, it is difficult to predict what that shift will be. We follow the advice of Alan Kay, therefore, and choose to predict the future by inventing it. Our approach is to think first about what activities could be best supported by mobile technology and then determine how the technology would have to work. This applications focus is important to distinguishing our work in mobile computing.

In April 1995, we formed the Future Computing Environments (FCE) Group within the College of Computing and the Graphics, Visualization and Usability (GVU Center) at Georgia Tech to promote such an applications focus. Our group is committed to the rapid prototyping of applications that benefit from the use of emerging mobile and ubiquitous computing technologies. Quick development of these futuristic applications allows us to predict and shape what our everyday lives will be like when today's novel technology becomes commonplace.

Applications for a mobile environment should take advantage of contextual information, such as position, to offer greater services to the user. In this paper, we present the Cyberguide project, a series of prototypes of a mobile, hand-held context-aware tour guide. Initially, we are concerned with only a small part of the user's context, specifically location and orientation. Knowledge of the user's current location, as well as a history of past locations, are used to provide more of the kind of services that we come to expect from a real tour guide. We describe the architecture and features of a variety of Cyberguide prototypes developed for indoor and outdoor use on a number of different hand-held platforms. We also discuss the general research issues that have emerged in our experience of developing context-aware applications in a mobile environment. Some of these research issues overlap with those that we have considered in applying other applications of ubiquitous computing technology.

The general application domain which has driven the development of Cyberguide is tourism, but we have found it necessary to be even more focused in our research. The initial prototypes of Cyberguide, therefore, were designed to assist a very specific kind of tourist – a visitor in a tour of the GVU Center Lab during our monthly open houses. Visitors to a GVU open house are typically given a map of the various labs and an information packet describing all of the projects that are being demonstrated at various sites. Moving all of the paper-based information into a hand-held, position-aware unit provided a testbed for research questions on mobile, context-aware application development.

The long-term goal is an application that knows where the tourist is, what she is looking at, can predict and answer questions she might pose, and provide the ability to interact with other people and the environment. Our short-term goal was to prototype versions of Cyberguide on commercially available PDAs and pen-based PCs in which context-awareness simply meant the current physical position and orientation of the Cyberguide unit (and since it is hand-held, this locates the user as well). Position information improves the utility of a tour guide application. As the prototypes of Cyberguide evolve, we have been able to handle more of the user's context, such as where she and others have been, and we have increased the amount in which the tourist can interact and communicate with the place and people she is visiting.

1.1. Overview

This paper is an extended version of an earlier report on Cyberguide [7], we discuss the evolution of the Cyberguide design and prototype as well as what future research areas our experience has uncovered. We begin in section 2 by describing scenarios for the use of context-aware mobile applications. In section 3, we provide context for our research within the area of applications-centered mobile computing. The generic architecture of Cyberguide is explained in section 4. We will describe in section 5 the initial realization of the generic components of the Cyberguide architecture, a series of prototypes developed for the Apple MessagePad. We will then describe in section 6 how the initial indoor prototypes were extended for use outdoors and for greater interaction with the environment. We conclude in sections 7 and 8 with a discussion of significant issues for context-aware applications development and how our past experience will influence our future development plans.

2. Scenarios for a mobile context-aware application

This section outlines some possible uses for future mobile context-aware applications. Some of these uses are currently being implemented and some are futuristic. We begin with our initial assumptions about what technology we expect Cyberguide to use. Tourists are usually quite happy to carry around a book that describes the location they are visiting, so a reasonable packaging would be in the form of a hand-held device. The ideal hand-held device will have a screen and pen/finger interface, access to substantial storage resources – possibly through an internal device such as a CD drive, or through substantial communication and networking resources (cell phone, pager, data radio interface) providing access to other storage servers (such as the Web) – an audio input and output interface with speech generation and potentially sophisticated voice recognition, and a video input and output interface. The video input (a video camera) could be pointed at the user to interpret user gestures, or pointed at the environment to interpret objects or symbols in the environment. The video output could be integrated into the main screen or be a separate video display device, such as an attached screen or heads up display on glasses worn by the user.

One major application of mobile context-aware devices are personal guides. Museums could provide these devices and allow users to take personalized tours seeing any exhibits desired in any order, in contrast to today's taped tours. In fact, many museums now provide portable devices for just such a purpose, but what we are envisioning is a device that would allow the tourist to go anywhere she pleases and be able to receive information about anywhere she is. Walking tours of cities or historical sites could be assisted by these electronic guidebooks. The hand-held devices could use position measurement systems such as indoor beacons or the Global Positioning System (GPS) to locate the user, and an electronic compass or inertial navigation system to find user orientation. Objects of interest could be marked with visual markers or active beacons or recognized using computer vision. Some objects, such as animals at a zoo or aquarium, might be difficult to mark but could be recognized with simple computer vision and some assistance from the environment (indications that this is the elephant cage, for example). The personal guide could also assist in route planning and providing directions. Some of these functions are currently being provided by automobile on-board navigation systems.

There are other ways to assist users. Consider a traveler in Japan that does not speak or read Japanese. The hand-held device could act as a pocket multilingual dictionary, actually speaking the appropriate phrase with the appropriate pronunciation to a taxi driver, for example (or even showing the appropriate Kanji and an associated map on the screen). A device that included video input or a scanner could assist in reading signs or menus. A device that could show stored images might be able to show a shopkeeper the desired object or favorite meal. Another more futuristic use is to assist the user by recognizing faces at a cocktail party and reminding the user who people are.

Real-time communication allows a personal device to act as an agent for the user. A personal guide to a theme park could make reservations at particular rides, and alert the user when the reservation was available. The device could also tell the user which rides had the shortest lines. Similar approaches are currently being used for automobile traffic management in major cities.

An important application of context-aware devices is enhanced reality. A heads up display could provide "X-ray" vision for the user. While surveying a building for renovation, the location of hidden plumbing or electrical conduits could be indicated to the user, based on information from sensors and/or building plans. At an archeological site a visitor could be provided with various overlays indicating what used to be above the current ground level as well as what is below the current ground level.

Context-aware devices can also be used as tools. Simple sonar devices are used to make room measurements today. It would not take much to have a hand-held device that both videotaped and mapped a room along with user commentary. An ecological field study or an archeological dig could be assisted by a device that automatically recorded the context of a particular find, including noting the surrounding objects. Consider an electronic field guide that assisted the user in recognizing plants or insects.

One of the most interesting applications of context-aware devices is to support group interaction on a tour or in a classroom, for example. Participants in a live demonstration of some new technology could use their personal device to help steer the demo using majority voting or consensus among the viewers. Each participant could run a personalized version of the same demo by expressing their own choices. In this case context is which demo a participant is participating in or attending to, and the personal machine may switch to another context if it detects the user is attending to that context instead.

Many tourists take records of some sort of their travelling experiences, either by taking pictures or videos or by composing a travel diary. Imagine the possibilities if the recording of these experiences could be more efficiently and accurately recorded. A drive across the country could result in a trail superimposed upon a map, and clicking on the trail would reveal an image of what you could see at that moment – an automatically-generated spatial index into your memories.

These are but a few of the possibilities we can imagine that a context-aware application can provide for the tourist. We have investigated many of these possibilities already and report on them later.

3. Related work

In thinking about and developing a location-aware application, we were greatly influenced by work such as the PARCTab at Xerox PARC [15], the InfoPad project at Berkeley [8], the Olivetti Active Badge system [14] and the Personal Shopping Assistant proposed at AT&T [3]. We wanted to build useful applications that might take advantage of the hardware developed in the PARCTab and InfoPad projects. We did not want to build our own hardware, so we have a different focus from all of these projects. There are a number of commercially available and relatively inexpensive hand-held units that would suffice for our purposes, such as the Apple MessagePad with the Newton Operating System[1], a MagicCap[2] machine or a pen-based palmtop/tablet PC. We chose to work initially with the Apple MessagePad 100 with Newton 1.3 and pen-based PCs running Windows for Pen Computing 1.0. Each platform was available for $150–500 with relatively powerful development environments. This low cost of hardware was critical to the success of Cyberguide because it made it possible to put a number of units in the hands of many students, all with different ideas that they were allowed to investigate.

For positioning, we considered the Active Badge system, but rejected it for reasons of cost and long-term objectives. The Active Badge system combines position detection with communication. For room-level granularity of position, this is reasonable since the communications range is on par with the position resolution. With Cyberguide, it is not clear that positioning and communication systems should always share physical resources. Certain versions of our prototype did; other prototypes did not. We provided for the separation of the wireless communications capabilities from the positioning system, so we could seek out more cost-effective solutions for both.

[1] MessagePad and the Newton Operating System are registered trademarks of Apple Computer, Inc.

[2] MagicCap is a registered trademark of General Magic, Inc.

We tried to pay attention to the higher level conceptual design of Cyberguide, but we have not been as general in our handling of context-aware mobile objects as has Schilit [13].

4. Architecture of Cyberguide

From the beginning, we have viewed Cyberguide as a family of prototypes and not just a single prototype, so it made sense to think about a conceptual design, or architecture, that captured the essence of the mobile tour guide. We have divided the system into several independent components, or building, and have found it useful to present those components both in terms of the generic function and personified in terms of the people a tourist would like to have available while exploring unfamiliar territory. The overall system serves as a tour guide, but we can think of a tour guide as playing the role of cartographer, librarian, navigator and messenger. The services provided by these components are:

- *Cartographer* (*map component*). This person has intimate knowledge of the physical surroundings, such as the location of buildings, interesting sights within a building, or pathways that the tourist can access. This component is realized in our systems by a map (or maps) of the physical environments that the tourist is visiting.
- *Librarian* (*information component*). This person provides access to all of the information about sights that a tourist might encounter during their visit. This would include descriptions of buildings or other interesting sights and the identities of people associated with the areas. The librarian can answer specific question about certain sights ("Who works in that building?" or "What artist painted that picture?" or "What other demonstrations are related to what I am looking at?"). This component is realized as a structured repository of information relating to objects and people of interest in the physical world.
- *Navigator* (*positioning component*). The interests of the tourist lie relatively close to their physical location. Therefore, it is important to know exactly where the tourist is, in order to show the immediate surroundings on the map or answer questions about those surroundings ("What am I looking at?"). The navigator is responsible for charting the location of the tourist within the physical surroundings. This component is realized by a positioning module that delivers accurate information on tourist location and orientation.
- *Messenger* (*communications component*). A tourist will want to send and receive information, and so the messenger provides a delivery service. For example, when visiting an exhibit or demonstration, the tourist might want to speak with the owner of the exhibit. If the owner is not present, the tourist can leave a message. In order to find out where other tourists are located, each

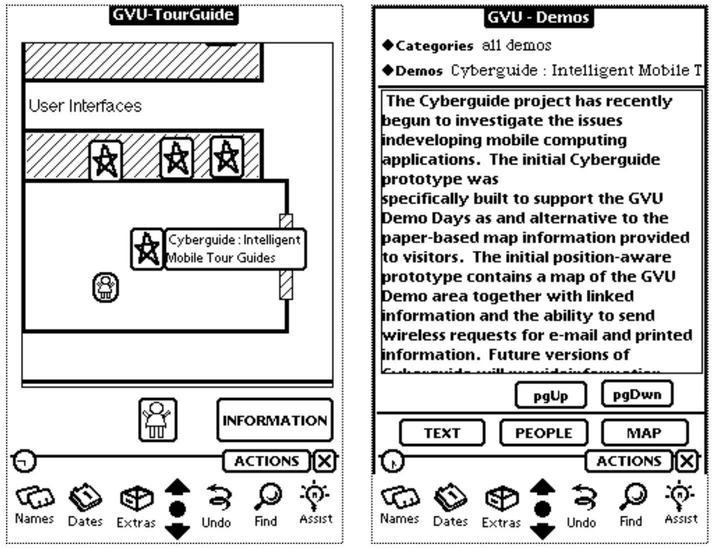

Figure 1. The map (left) and information (right) interfaces of the initial Cyberguide MessagePad prototype.

tourist can communicate her current location to some central service that others can access. It might also be desirable to broadcast information to a set of tourists ("The bus will be leaving from the departure point in 15 minutes."). This component is realized as a set of (wireless) communications services.

The utility of this architectural decomposition for Cyberguide is that it provides an extensible and modular approach to system development. It is extensible because we can always add further services. For example, we have considered adding an historian whose purpose is to document where the tourist has been and what her reactions were to the things she saw. It is modular because it has allowed us to change the implementation of one component of the system with minimal impact on the rest of the system. For example, we have implemented different versions of the navigator and the librarian without having to alter the other components. Of course, these components are related in some ways; for instance, position information ultimately has to be translated into a location on the physical map. Defining standard interfaces between the components is the means by which we achieve separation between and coordination among the various components.

5. The indoor Cyberguide

In this section, we describe how each of the separate modules in the conceptual architecture have been realized in the initial series of prototypes developed on the Apple MessagePad for use indoors during GVU open houses.

5.1. Map component

The initial map module, shown on the left side of figure 1, contains a map of the entire GVU Center. Passageways and demonstration stations (stars in figure 1) are shown. Only a limited view of the lab can be seen at any given time. The user can scroll the map around and zoom in and out to see alternative views. There is an icon to show the user's location on the map. Using information from the positioning module, we implemented automatic scrolling of the map. If desired, the user's position is updated automatically and the map is scrolled to ensure that the user's current position remains on the visible portion of the map.

5.2. Information component

The information module (shown on the right side of figure 1) contains information about each of the demos on display at the GVU open house. This includes abstracts of the project being demoed, background information on those involved with the project, as well as where to get further information. The location of each demo is marked on the map by a star. The user selects the star icon for a demo to reveal its name. Selecting the name brings up the information page for that demo. The user can also go directly into the information module and search for information for specific demo pages either by category or by project name.

One version of the information module was hard-coded, providing very fast response but requiring a recompilation every time demo information needed to be updated. Another implementation used Newton files, called soups, to store information. The use of soups avoided hard-coding data into the application and simplified demo information updates, but did not have adequate response time. Our third implementation of the information module used Newton Books, the Newton platform documentation viewer, to store the demo information. The use of Newton Books improved our access time considerably, allowing for an automated information update process without requiring data be hard-coded directly into the application. Throughout all

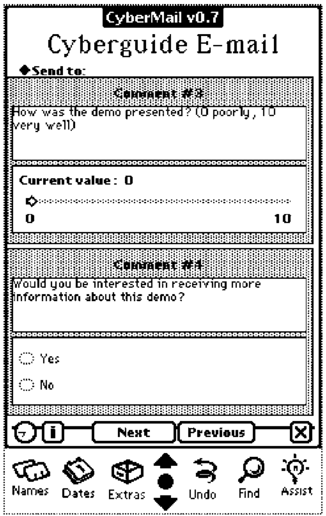

Figure 2. Questionnaire using communications module for delivery.

three versions of our information module, we were able to modify the information module independent of the development efforts of the other modules, validating the modularity of part of our design.

5.3. Communication component

Our initial implementation of a communication module consisted of a wired Internet Appletalk connection from a Apple MessagePad through a Unix Appletalk Gateway. We designed an application level protocol on top of a public domain implementation of the Appletalk protocol for Solaris [4]. This allows us to open a connection-based Appletalk stream from the Apple MessagePad to a UNIX platform. We then invoked our gateway application to repacketize Appletalk packets into TCP/IP packets for transmission over the Internet. This allowed for TCP/IP connectivity from a Apple MessagePad via an Appletalk connection. We could then fetch HTML documents as well as send and receive e-mail. We utilized this functionality within Cyberguide by providing a questionnaire for users to complete, which was sent to the developers as an e-mail message (see figure 2).

5.4. Position component

Position is the obvious starting point for a context-aware mobile device. We considered several methods for sensing the user location. Outdoors, continuous services, such as GPS, can be used. Indoors, however, GPS signals are weak or not available. We considered RF for indoor position measurement, but found off the shelf solutions too expensive.

One solution for an indoor positioning system was to use infrared (IR). Our first positioning system was based on using TV remote control units as active beacons, and using a special IR receiver tuned to the carrier frequency ($\approx$ 40kHz) of those beacons (figure 3). A microcontroller (Motorola 68332) interfaced the IR receiver to the serial port of the Apple MessagePad. We deployed an array of remote controls hanging from the ceiling (figure 3 right), each remote control acting as a position beacon by repeatedly beaming out a unique pattern. The 68332 translates the IR pattern into a unique cell identifier that is sent to the Apple MessagePad's serial port. As the tourist moves around the room and passes into the range of a new cell, the position (indicated by an arrowhead) is updated on the map. Keeping track of the last recorded cell location provides a good guess as to the location the tourist is heading, so we indicate an assumed orientation by pointing the position icon accordingly.

The remote control system is too expensive for large scale use as the cost of the 68332 microcontroller is roughly equivalent to that of the MessagePad.

6. Extending the initial prototype

The first Cyberguide prototypes were completed within 6 months. To test out the genericity of our architectural approach, we decided to develop further prototypes that altered one or more of the major components described in section 4 and increased overall functionality. We describe these extended prototypes here.

6.1. Outdoor positioning

There were several motivations for building a Cyberguide prototype for outdoor use (figure 4). First, we wanted to use Cyberguide over a wider area than the relatively small GVU Center. We also wanted to test the modularity of our design by having to change critical features. The two features that were changed on this prototype were the underlying map and the physical positioning system. We obtained a different map and inserted that into the map module without any problems. For positioning, we replaced the IR positioning module with a Trimble GPS unit attached to the Apple MessagePad serial port. (see right side of figure 4). The GPS unit sends a position in latitude and longitude which was then translated into a pixel coordinate representing the user's current position on the map.

The outdoor positioning system has been tested by two prototypes. We first built a proof of concept tour of the Georgia Tech campus (shown in figure 4). We also developed a more functional outdoor prototype that covered three surrounding neighborhoods of the campus, described later.

6.2. Alternate platforms

In order to verify the platform independence of our conceptual design, we initiated two separate efforts building pen-based PC versions of Cyberguide. These limited functionality PC versions were written using Borland's Delphi environment and Microsoft's Visual Basic. Both were initially installed on Dauphin DTR-1 palmtops running Pen for Windows Computing 1.0.

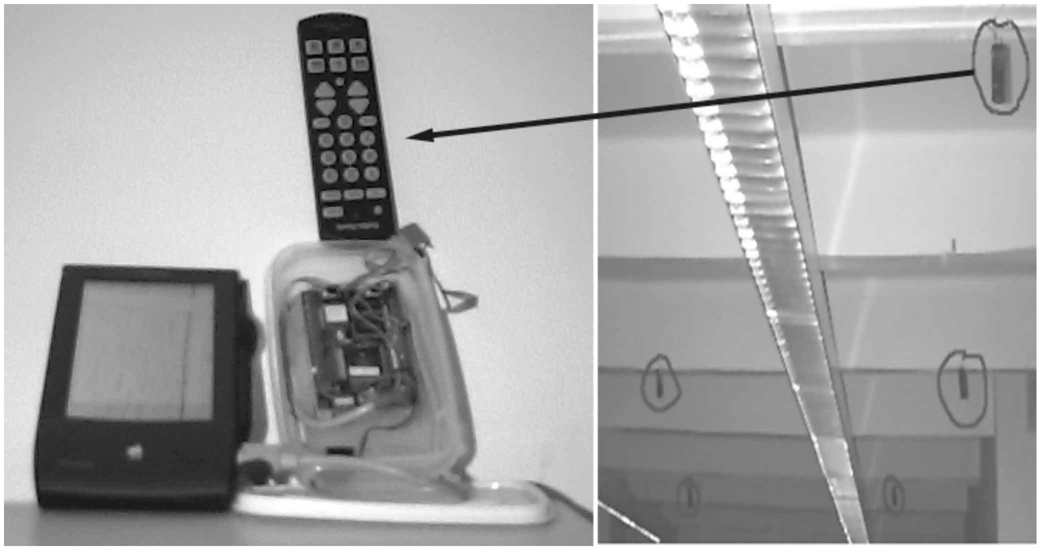

Figure 3. IR positioning prototype (left) and the array of positioning beacons in the GVU Lab (right).

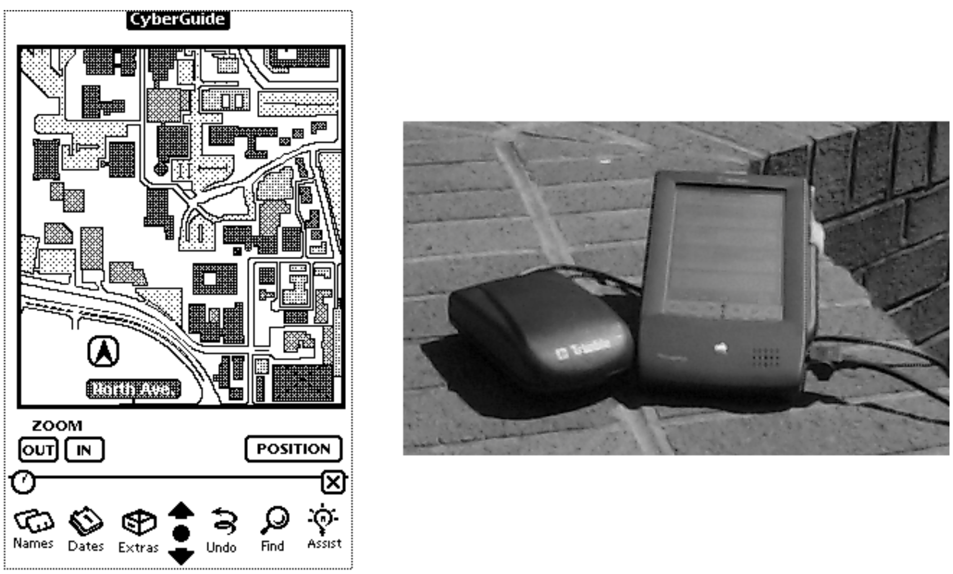

Figure 4. The outdoor Cyberguide (left) with GPS unit (right).

The Delphi version implements the map and information module. Web pages containing demo information are stored locally as database objects using a stand-alone Borland database engine. The information base is extracted from the collection of existing Web pages for GVU projects but stored locally. This information is viewed using a public domain Delphi HTML viewer. Though this provided a very fast response for information queries, it is a long-term disadvantage to have the information base stored locally. Too much in our environment is subject to change. A local and static database is only slightly more useful than a book. This approach to static information storage is used currently for on-board navigation systems on certain rental cars.

The Delphi prototype uses vector-based maps, allowing for arbitrary scaling and rotation of the map and well as path generation. While there are several sources for obtaining vector maps for outdoor regions, it is not so easy for indoors. Consequently, there is a trade-off between the easily generated but limited functionality of bitmap images and the highly functional but hard to generate vector maps for indoor use.

The Visual Basic prototype, shown in figures 5–9 realizes all four components of Cyberguide, including two-way communications, which is discussed next. We implemented historical context by predicting when a user had visited a demo, based on time spent in the area of the demo and interaction with the map. In figure 5, a visited demo is in-

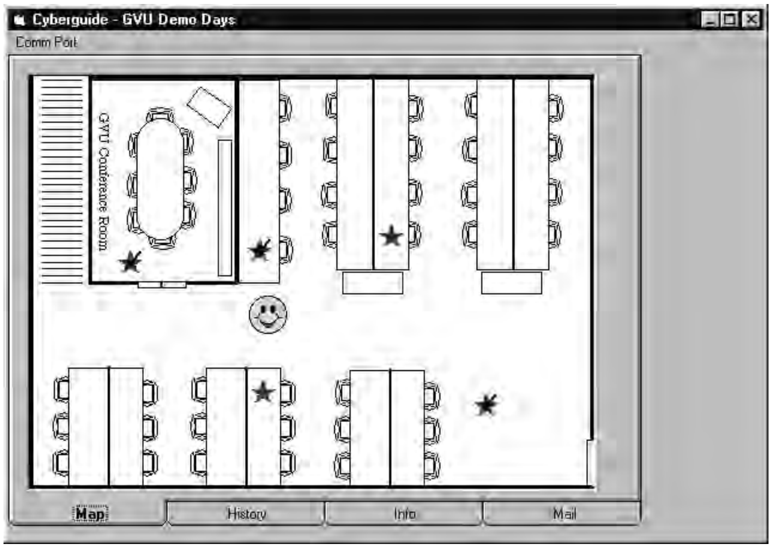

Figure 5. The main map interface of the PC Cyberguide. Checks on demo sites indicate the user has been to visit that demo already, indicating history-sensitive interface.

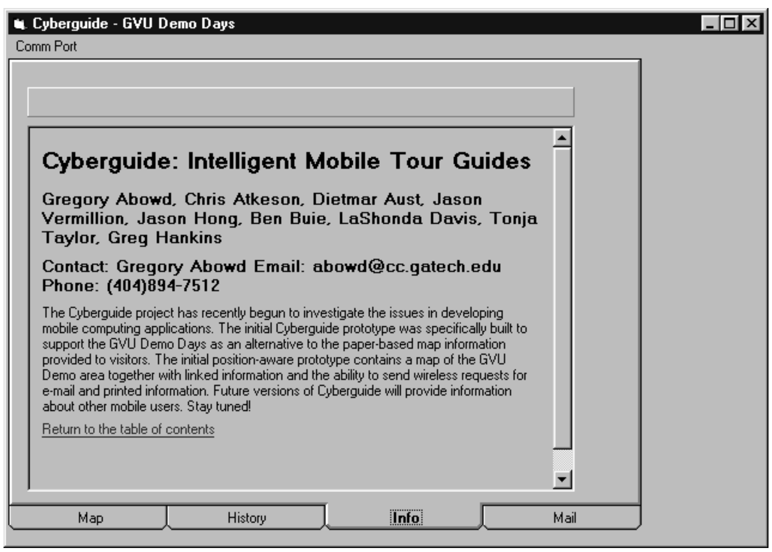

Figure 6. The information browser interface of the PC Cyberguide.

dicated on the map by a checkmark. There is also a separate panel that lists the demos visited. This information could be used, for example, to generate a summary of the day's visit to GVU open house and then mailed off to the visitor. We again made use of a publicly available HTML rendering component to display the project descriptions, still stored locally.

6.3. Increased communication

A number of interesting possibilities are enabled for the tourist in a wireless communication mode. We have spent a good deal of effort building an indoor, low-cost wireless communications infrastructure for Cyberguide. We have built a serial IR network using inexpensive modules from Sharp (the same modules used in the MessagePad). We have written UNIX server software and client software for both the MessagePad and PC. Figure 7 shows how our homemade network connects mobile units to the departmental network. We have defined a simple protocol to support three different kinds of messages: mailing out from a mobile unit to the network (as shown in figure 8); broadcasting from the network to all mobile units (figure 9); and updating positioning information. We implemented this protocol over serial IR instead of some other standard so that we could immediately use all platforms (UNIX, Newton and Windows). Given the appropriate hardware and protocol support (perhaps IRDA), we sencould provide the same functionality more robustly.

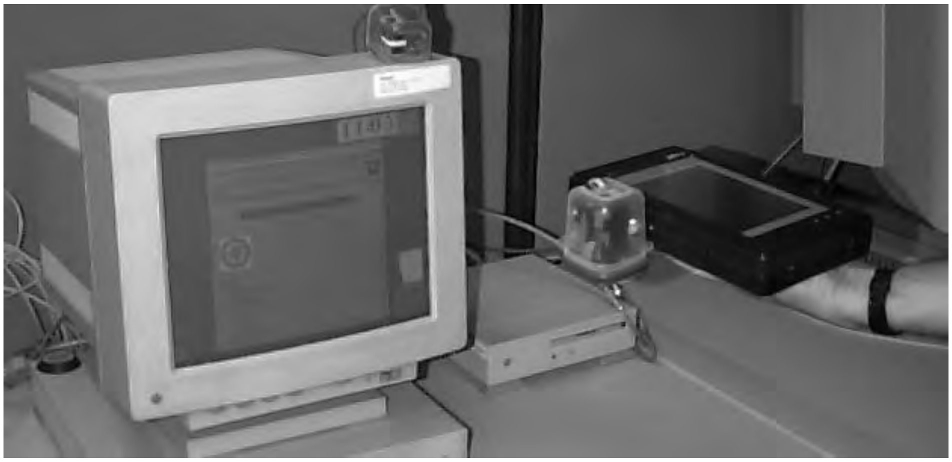

Figure 7. Home-made IR units allow cross-platform communication.

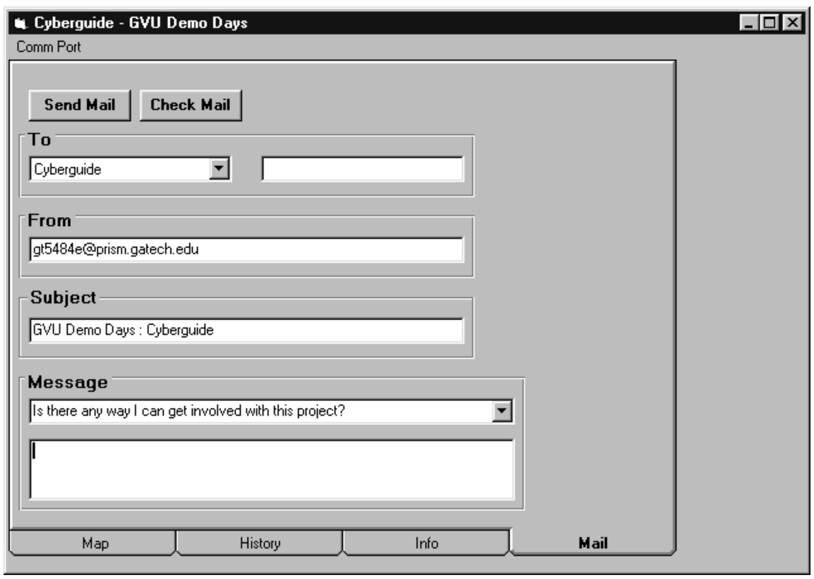

Figure 8. The mail interface of the PC Cyberguide. Addresses are automatically filled in and message templates are supplied upon request.

6.4. Increased interaction with environment

All of our applications of Cyberguide so far have restricted the role of the tourist to browsing, but it is likely that as she visits some place, the tourist will want to keep a record of her experience as advice for herself or others later on. With this idea of increased interaction with the environment and recording in mind, we created another Cyberguide prototype, called CyBARguide, to assist a tourist in pursuit of refreshment at neighborhood establishments in Atlanta. This prototype covers approximately 12 square miles of midtown Atlanta, using multiple maps at varying levels of detail.

Figure 10 shows the map interface on the left and a view of a user-modifiable database for interesting establishments on the right. The tourist can indicate a desired destination and as she moves around, CyBARguide automatically chooses the map of the highest detail that contains both the traveler (indicated by a triangle in figure 10), and the destination (the beer mug with the emboldened border in figure 10). Along the way, if the tourist eyes another interesting establishment that is not currently highlighted on the map, it could be added. Each establishment has a user-modifiable database entry associated with it that reflects both objective (e.g., availability of parking, average price of drinks) and subjective (e.g., ambiance or other comments) information that can be used in the future to plan an evening's excursion. querying of a large amount of information and some minimal routing facilities. We also plan to make the data within the information module modifiable so the user can add personalized information including personal impressions that may be useful for future reference, a type of virtual graffiti. We envision the use of CyBARguide in a mode in which both tourist and proprietors are able to modify the information base. A simple searching

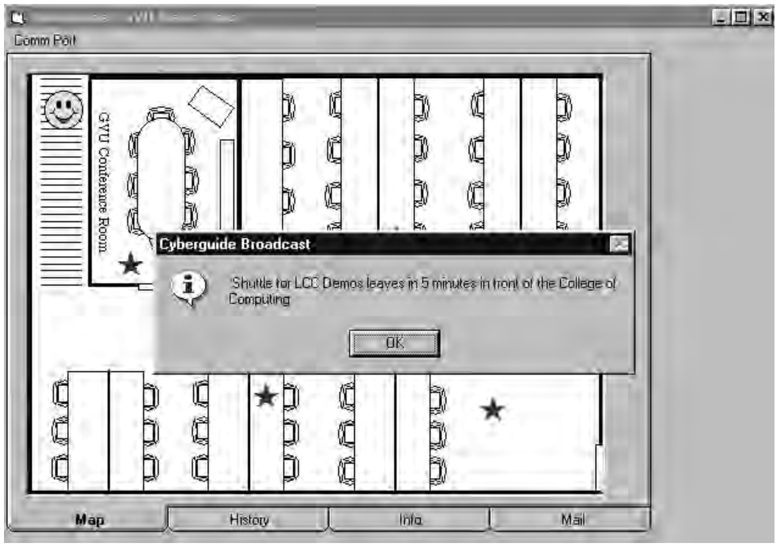

Figure 9. A demonstration of receiving a broadcast message from the Network to an individual Cyberguide unit.

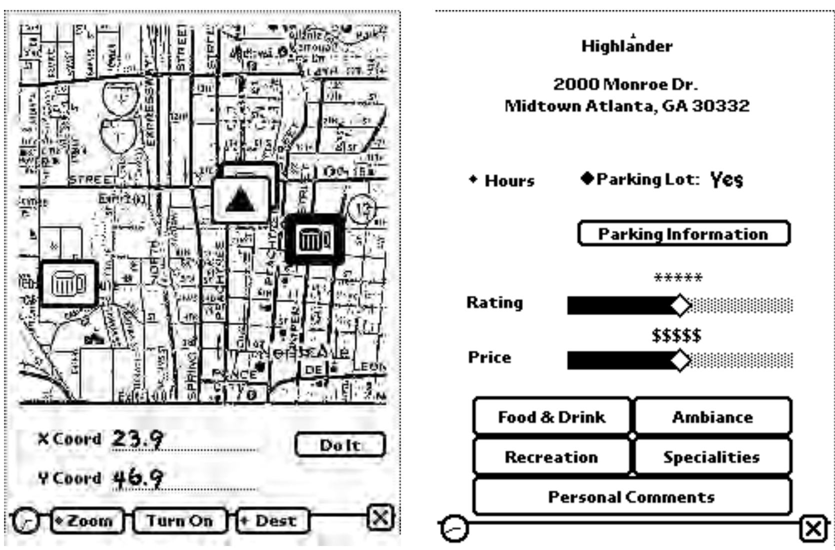

Figure 10. The CyBARguide interface. The left shows the interactive map indicating the user's location (the triangle) and the location of establishments previously visited (the beer mugs). The user modifiable database shown on the right supports the long-term development of touring information for a location.

capability can assist revellers in search of a certain kind of entertainment experience, and additional contextual information, such as the knowledge of where the traveller has been already, the time of day, and what special events (information provided by the proprietors) are currently scheduled, can be used to deliver suggestions for where to go.

7. Issues

Our experience over the last year developing versions of Cyberguide with different features on different platforms has given us a certain amount of insight into the important issues in developing mobile, context-aware applications. In this section, we summarize some of those issues.

Our prototyping efforts were iterative, modifying both hardware and software to improve functionality. Our primary focus, to assess the impact of mobile technology for a specific task, necessitated rapid and inexpensive prototyping. This motivated the use of inexpensive commercially available hardware. When choosing our hardware platform, we considered several mobile hand-held devices before deciding on the Apple MessagePad and various palmtop PCs. One of the driving considerations in purchasing hardware was cost, because we wanted to provide as many units to individuals and groups to maximize the number of ideas investigated. The downside of this decision was a collection of applications that were not very robust, but that negative has been outweighed by the sheer number of options we have been able to investigate and prototype in little over a year.

Over the last year we have used Cyberguide for many GVU open houses. We gathered informal feedback through informal surveys, formal questionnaires and informal user comments. We also observed visitors as they tried to use Cyberguide to maneuver around the lab. During each iteration we incorporated the user feedback and our own reactions to what was good and what was bad into the next iteration on the design. While our major focus was to prototype a context-aware mobile application rapidly, we realize that little can be determined concerning the impact of such technology unless the technology is put in the hands of real users.

7.1. Coupling of positioning and communication

There is an interesting relationship between the positioning and communication systems. Systems such as PARCTab and the Active Badge rely on a close coupling of positioning and communication. This is because the location of any mobile entity is determined by the beacon which receives a communication from the entity. In Cyberguide, the indoor and outdoor positioning system worked by having the beacon inform the mobile entity where it was located. The disadvantage of this latter approach for Cyberguide is that only the mobile entity knows its location. For applications in which you want objects to know about the position of other objects, there must be some sort of communication. However, it can be impossible or undesirable to couple positioning and communication together. For example, if position is coming from GPS, then a separate means of communication must be used. In our current version of indoor IR positioning using the Sharp IR units, we can couple positioning and communication, but the range of the IR link is so limited (3 feet) that communication will be cumbersome. It makes sense to use a short range IR positioning system because position information can be localized to objects of interest. Communication, on the other hand, needs to be uniform throughout some space.

7.2. Communication medium

We have been trying to implement communications services on commercial hand-held units. While communication is important to Cyberguide, there is no obvious appropriate choice for a wireless communication medium to suit our needs. It clearly is not a priority among the manufacturers of these units to provide high bandwidth, cost-effective wireless communications. There are many potential solutions for communications (IR, spread-spectrum RF, cellular packet, cellular modem), but the variety and quality of these services changes so much that manufacturers tend not to build communications devices into the units, for fear of premature obsolescence. Instead, they rely on third party communications solutions with standard interfaces (e.g., PCMCIA). In our experience, there is a need to have high bandwidth communication to the mobile unit and low bandwidth connection back to the network. We do not assume that the hand-held unit will always carry around with it the entire information base or map associated with the area the tourist is visiting. Rather, that information should be provided on demand and relative to the position/orientation of the tourist.

7.3. Map representation

We have experimented with bitmap and vector-based maps. The bitmap representation is easy to obtain (scanning) for any area and is relatively inexpensive to store and display. Scaling and rotation, however, are cumbersome with that representation. Since we were decorating the map to highlight places of interest that were not on the original bitmap, it was difficult to control the display of the decorations after scaling for a zoom in or out. Another problem with the bitmap representation is accuracy with respect to the real-world. In the outdoor version of Cyberguide, we noticed a drift on the positioning system for a certain region of the map attributed to the map itself being out of scale. Also, a bitmap representation is not suited to doing higher level map services, such as generating a path to direct the tourist to a location of interest.

A vector-based representation, on the other hand, is easier to handle in terms of manipulation and additional services such as way-finding, but was not a feasible solution on the interpreted platforms (Visual Basic and Apple MessagePad 100 with Newton 1.3 using the Newton Toolkit 1.5) because it was computationally overwhelming to manage the display (this may be solved with compiling capabilities of later versions of the Newton Toolkit). It is also more difficult to obtain a vector-based map for a large and detailed area. For example, when we built the Delphi prototype, it was not difficult to build a map tool to construct the vector-based map, but it would take a very long time to create a map of the GVU Lab with the detail we already had in the bitmap version. For outdoor use, there are already commercially available structured map databases for large areas, and these are being used in navigational systems in rental cars. However, the size of the map database prohibits local storage on hand-held units, so there is an even stronger argument for high bandwidth downstream wireless connectivity.

7.4. Cross-platform issues

We developed prototypes on multiple platforms to validate our claim of platform independence for the architecture. It was encouraging to see the same indoor positioning system work for both the Apple MessagePad and Visual Basic prototypes. Outdoor positioning is similarly cross-platform, relying on either a serial or PCMCIA interface.

For communication, we also see the need to standardize the interface and protocol. For information services, it is natural to want support for wireless TCP/IP to enable full

Internet capability. The information browsing can then be treated as a Web browsing task, for example. There are efforts already to support TCP/IP for platforms such as the Newton platform, but the bandwidth does not yet support delivery of complex graphics, as we would need for map delivery. Without cross-platform wireless Internet support, we were forced to approximate the connectivity using simple wireless serial connections. These do not provide the reliability nor range that would be necessary for a commercial strength application, but they provided enough of the infrastructure to investigate functional capabilities for the user.

8. Future work

We have worked for a year on Cyberguide. We have always tried to keep in mind the very long term goals of this kind of application, and many of those ideas have been expressed by others and by us in section 2. The following is a list of features that we feel are most important for near-term future versions of mobile, context-aware applications such as Cyberguide.

8.1. Modifiable information base

As a tourist visits a place, she may read about prepared information, but she may also have her own thoughts and reactions to what she sees or may overhear someone else interpret an exhibit in an interesting way that she would like to record. Capturing relevant information along the way and adding that to the information base would be useful. We have been focusing on applications of Cyberguide that emphasize functionality based on knowledge of the user's physical context. Another major theme the FCE group has worked on involves automated capture of user experience to facilitate later access to a rich record of that experience. Most of our work in that area has involved the application of ubiquitous computing technology in the stationary environment of the university classroom [1,2,12] and others have applied it in the meeting room environment [9,10]. We can see a hint of this capture/access problem appearing in CyBARguide as the traveller records impressions of an establishment that may influence their plans later on. It is a natural extension to add this kind of capture facility for the tourist.

We have experimented with capturing contextual information from a traveller to support the automatic authoring of a travel diary.[3] As a user journeys around, a log of time and place is recorded. In addition, the traveller carries a digital camera or video and comments about a day's journey into a microphone. All of these streams of activity can be associated either by time or place, resulting in a rich multimedia record of a vacation. This record is also searchable, which supports queries such as, "What was the name of that charming gift shop we visited shortly after lunch in Albequerque yesterday?" With a suitable combination of positioning system, digital camera and wireless communication, we can create dynamic Web pages that catalog our travel experience for others to enjoy.

8.2. Increased communications

Cyberguides wireless communications is unreliable and short-range, and that has prevented us from moving the information sources off of the hand-held unit. This is a high priority in our future work and we will most likely investigate third party wireless modems with TCP/IP support on the hand-held units. Since we are currently limited to what is in place from commercial vendors, we might now take the time to investigate research platforms such as the InfoPad.

8.3. Improved context awareness

One way to view the capturing activity above is as a way to augment the system's understanding of the tourist's context by remembering what was interesting. We currently have a very limited notion of context in Cyberguide – physical location and crude orientation. We have experimented with capturing historical context (what sights have been visited already), but there are a number of other aspects of the tourist's context that can be useful. For instance, knowing where everyone else is located might suggest places of potential interest. Knowing the tourist's reaction to some exhibits would help in suggesting other related places of interest. Being aware of time of day or day of week may aid in more intelligent user queries of interesting attractions or activities. We feel that the secret to context-awareness is in doing it behind the scenes. The more that can be automatically captured and turned into context, the better. If the user has to explicitly inform the system about context information ("I am currently located here." or "This exhibit is boring to me." or "The museum is currently closed.") then the context is unlikely to be fully utilized.

8.4. Leveraging the Web

In the touring example, we found that much of the information we wanted to display was already available on the Web. Web browsing is now a natural information browsing metaphor. It makes sense to leverage this available information resource and mode of interaction for all of the information needs. The map module then provides hooks or links to the information on the Web, and it is delivered on demand, similar to when a user selects a URL on a browser. There have already been some research [3] and commercial attempts at providing mobile Web browsers.

8.5. Use of vision

In the extreme case, we can think of a communion between the physical and electronic worlds, as suggested by

[3] Take a look at http://www.gatech.edu/chow/roadtrip for a sample of what we have already done.

work in augmented reality. Replace the hand-held unit with a pair of goggles and as the user wanders around, information about certain exhibits can be summoned up and overlaid on top of the actual image. Vision techniques can be used to augment the positioning system to inform the system and tourist what the tourist is looking at. We have experimented with vision systems as an extension to Cyberguide. Ultimately, we want to move toward personalized vision systems.

8.6. Ubiquitous positioning system

Our current prototypes are exclusively indoor or outdoor, not both. This is mainly because we had no one positioning system that worked in both conditions. GPS is unreliable indoors and the IR-based beacon system is impractical for us to implement outdoors. We intend to integrate both positioning systems into one application, to allow a tourist to wander in and out of buildings and have Cyberguide automatically switch the positioning system.

8.7. Increased multimedia support

In the context of the GVU open houses, visitors often gather around a demo and stretch to watch the activity on a desktop machine as the researcher describes the related research. We would like to have Cyberguide units in the vicinity of the demonstration be able to pick up a live feed from the demonstration for display on their own unit. Initially, this could be achieved by a simple mirroring of the demonstration machine's display onto the hand-held unit. Ultimately, we envision the visitor "plugging in" to the demonstration and being able to control it from their hand-held unit.

9. Conclusions

We have described research we have been conducting over the past year prototyping mobile, context-aware applications. The main focus of our development effort has been to take an applications focus, tourism in this case, and determine what commercially available hardware can be used to deliver relevant information to the mobile user that is tuned to knowledge of their physical context. We described several iterations on the Cyberguide application, built to support tours through various venues. Our experience prototyping several variations of Cyberguide has clarified our own thoughts on how context-aware computing provides value to the emerging technology promising to release the user from the desktop paradigm of interaction. The experience also has helped to clarify some significant research issues in the continued development of mobile, context-aware applications for future computing environments.

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References

[1] G.D. Abowd, C.G. Atkeson, A. Feinstein, Y. Goolamabbas, C. Hmelo, S. Register, N.N. Sawhney and M. Tan, Classroom 2000 enhancing classroom interaction and review, Technical Report GIT-96-21, Graphics, Visualization and Usability Center, Georgia Institute of Technology (September 1996).

[2] G.D. Abowd, C.G. Atkeson, A. Feinstein, C. Hmelo, R. Kooper, S. Long, N.N. Sawhney and M. Tan, Teaching and learning as multimedia authoring: The classroom 2000 project, in: *Proceedings of the ACM Conference on Multimedia* (*Multimedia '96*) (1996).

[3] A. Asthana, M. Cravatts and P. Krzyzanouski, An indoor wireless system for personalized shopping assistance, in: eds. L.-F. Cabrera and M. Sattyanarayanan, *Workshop on Mobile Computing Systems and Applications* (IEEE Computer Society Press, December 1994) pp. 69–74.

[4] J.F. Bartlett, W4 – the wireless World Wide Web, in: eds. L.-F. Cabrera and M. Sattyanarayanan, *Workshop on Mobile Computing Systems and Applications* (IEEE Computer Society Press, December 1994) pp. 176–178.

[5] B. Krupczak, M. Ammar and K. Calvert, Multi-subsystem protocol architectures: Motivation and experience with an adaptor-based approach, in: *Proceedings of IEEE INFOCOM '96* (1996).

[6] S. Long, D. Aust, G.D. Abowd and C.G. Atkeson, Rapid prototyping of mobile context-aware applications: The cyberguide case study, in: *Proceedings of Conference on Human Factors in Computing Systems – CHI '96* (1996). Short paper.

[7] S. Long, R. Kooper, G.D. Abowd and C.G. Atkeson, Rapid prototyping of mobile context-aware applications: The cyberguide case study, in: *Proceedings of 2nd Annual International Conference on Mobile Computing and Networking* (November 1996).

[8] A.C. Long Jr, S. Narayanaswamy, A. Burstein, R. Han, K. Lutz, B. Richards, S. Sheng, R.W. Brodersen and J. Rabaey, A prototype user interface for a mobile multimedia terminal, in: *Proceedings of Conference on Human Factors in Computing Systems – CHI '95* (1995). Interactive experience demonstration.

[9] S. Minneman, S. Harrison, B. Janseen, G. Kurtenbach, T. Moran, I. Smith and B. van Melle, A confederation of tools for capturing and accessing collaborative activity, in: *Proceedings of the ACM Conference on Multimedia – Multimedia '95* (November 1995).

[10] T. Moran, P. Chiu, S. Harrison, G. Kurtenbach, S. Minneman and W. van Melle, Evolutionary engagement in an ongoing collaborative work process: A case study, in: *Proceedings of ACM CSCW '96 Conference* (1996).

[11] H. Rheingold, *Tools for Thought* (Prentice-Hall, Englewood Cliffs, 1985).

[12] N.N. Sawhney, G.D. Abowd and C.G. Atkeson, Can electronic notebooks enhance the classroom? Technical Report GIT-96-06, Graphics, Visualization and Usability Center, Georgia Institute of Technology (February 1996).

[13] W.N. Schilit, System architecture for context-aware mobile computing, Ph.D. Thesis, Columbia University (1995).

[14] R. Want, A. Hopper, V. Falcao and J. Gibbons, The active badge location system, ACM Transactions on Information Systems 10(1) (January 1992) 91–102.

[15] R. Want, B. Schilit, N. Adams, R. Gold, K. Petersen, J. Ellis, D. Goldberg and M. Weiser, The PARCTAB ubiquitous computing experiment, Technical Report CSL-95-1, Xerox Palo Alto Research Center (March 1995).

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Appendix AB04

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Appendix BA01

WEARABLE COMPUTERS

02

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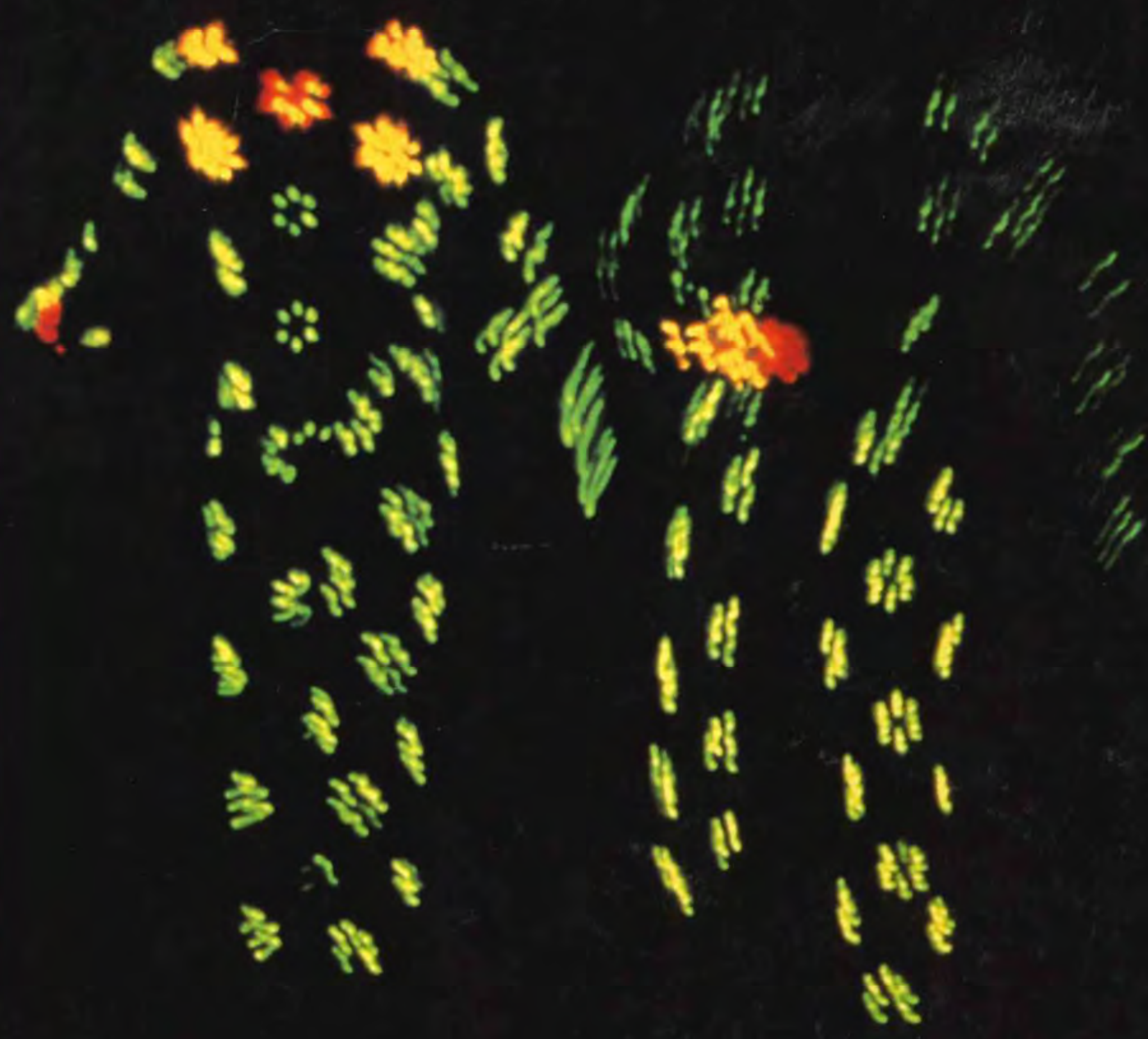

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A Collaborative Wearable System with Remote Sensing

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Abstract

This paper presents a collaborative wearable system based on the notion of remote sensing. Remote sensing lets users of wearable or stationary computers perceive a remote environment through the sensors of a remote wearable computer. We describe a concrete system with remote sensing capability that is designed to enhance the communication and cooperation of highly mobile computer technicians.

1: Introduction

There is an obvious need for effective communication and collaboration in typical wearable domains such as maintenance, repair, construction and manufacturing. As noted by Siegel et al [20], having wearable computer systems that allow field workers to access information and contact experts can be valuable in many settings, from airline maintenance, to health care, emergency response and on-the-job training.

In this paper we report on the design and implementation of a collaborative wearable computer system that supports computer technicians in their task of maintaining a campus-wide computer network. The wearable computer is a Personal Computer-like device with a head-mounted display that integrates video camera, microphone and speaker. The computer is worn by a technician in the pouch of a specially designed vest (see Figure 1).

The wearable system, which we call NETMAN, enables technicians in the field and office-based experts to collaborate in real-time using audio and video. A camera, that is attached to the wearable computer and points away from the user at the task area, enables a remote expert to see what the technician in the field sees and direct his or her attention using a remote pointer.

While similar collaborative wearable systems have been proposed before or are currently under development [5;6;15;17], the NETMAN system uses an innovative approach to enhance and enrich the collaboration between remote users, based on the concept of *remote sensing*. Remote sensing means that a remote user, the expert sitting at a desk in an office or another wearable user, has direct, unmediated access to output of sensors attached to another user's wearable computer. This concept is visualized in Figure 2.

The term 'remote sensing' originally describes the process of measuring and analyzing electromagnetic radiation for the purpose of understanding and managing the Earth's resources and environment [18]. It has also been used in the context of telepresence and telerobotics systems (e.g., [12;19]). For our purpose we define remote sensing more broadly as the collection of information about an object without being in physical contact with the object.

Remote sensing requires sensors such as cameras, microphones, laser scanners, and receivers for radio or infrared radiation. Such sensors have long been used in wearable computing to provide users of a wearable device with an enhanced view of the immediate environment. The NETMAN system allows two or more users to share this enhanced view by transmitting sensory data to remote computers over a wireless network. Depending on the number and type of sensors, this approach enables remote

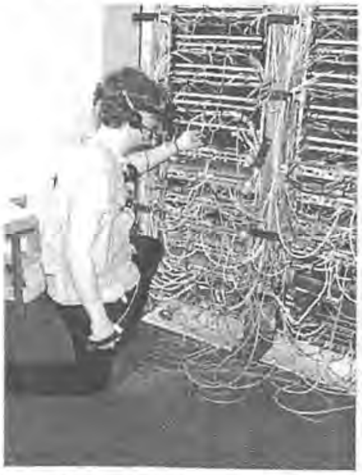

Figure 1: NETMAN Wearable Computer

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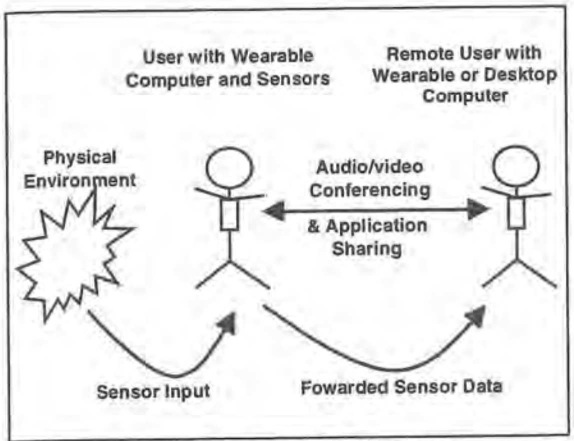


Figure 2: Remote Sensing

users to perceive a remote environment almost as if they were physically present.

The idea of using remote sensing as a way to enhance collaboration was motivated by our experience with earlier prototypes of NETMAN [14]. We soon realized that the quality of the video image that can be achieved in a wearable setting tends to be rather poor. Limitations of the wireless network in terms of bandwidth and delay characteristics restrict the usable image resolution and frame rate. Small screen size and poor quality of current head-mounted displays directly effects the perceived image quality. This together with poor lighting conditions can make it impossible for a remote user to identify any significant details in the transmitted picture.

Remote sensing is a natural generalization of shared audio/video capabilities found in 'traditional' collaborative wearable systems. It is an attempt to overcome limitations of such systems by providing a remote expert with additional (besides video and audio) and more accurate information about the state of the environment and what exactly the technician is doing.

The remainder of this paper is structured as follows. In the next section we discuss related research and introduce the application scenario that underlies the design of NETMAN. In Section 3, we discuss general design considerations for collaborative wearable systems. Section 4 outlines the NETMAN prototype, while Section 5 describes remote sensing applications and the underlying software infrastructure. In Section 6, we discuss early experiences with the prototype. Section 7, finally, summarizes.

2: Collaborative Wearable Systems

Most wearable computers today are designed as stand-alone systems that provide users with automatic, context-sensitive access to information, but do not support inter-personal communication and collaboration. In a similar vein, previous work on collaborative systems has almost exclusively focused on white-collar workers in office settings. Communication needs of mobile field workers, whose work includes a high amount of manual activities, such as technicians and repair personnel, were mostly ignored.

Recent research suggests that for certain domains collaborative wearable systems with shared audio/video capabilities can have a positive effect on workers' collaboration and coordination:

In [15;20] the authors report the results of two CMU studies on mobile collaborative systems for the support of maintenance task of bicycles and aircrafts. They describe a wearable system for collaboration with a remote expert using shared video and hypertext: "Preliminary results suggest that doing the tasks with a more experienced helper with shared video to support coordination of work is the most effective treatment. Sharing a view of the work area helped the team to coordinate their conversation".

Similar research was performed at the University of Washington [5;6]. The authors describe two pilot studies, which imply that wearables may be able to support three-dimensional collaboration and that users will perform better with these interfaces than with immersive collaborative environments.

Finally, Boeing is currently investigating the use of wearable video conferencing systems for fast and accurate communication of airplane mechanics at remote locations and/or mechanics working on different parts of the same airplane [17].

None of these systems, however, makes advanced use of sensors. They are mainly mobile videoconference systems that solely rely on audio and video signals to support collaboration. Yet one of the most interesting and most novel aspects of wearable computing is the combination of sensors and contextual awareness. Using sensors such as proximity sensors, location sensors, and electronic tags for identification of nearby objects, a wearable computer can actively gather knowledge and information about its environment and use it for advanced automatic and context-sensitive support of users. Examples include: context-sensitive user interfaces, context-based reminder systems, and context-based retrieval systems [1;2;3;4;10]. We believe that in collaborative settings remote participants can benefit in similar ways from having direct and unmediated access to another user's sensory data.

We decided to test our ideas about remote sensing and collaborative wearable systems using a real-world application with hard requirements. In the following section we will introduce the application scenario that underlies the development of NETMAN.

2.1: Application Scenario

Our goal for the NETMAN project was to design and develop a wearable system that helps technicians in their daily task of troubleshooting and repairing faults in computer network equipment. For collecting requirements we are working closely with the University of Oregon Computing Center which is responsible for maintaining the computer and network installations throughout campus. Typical tasks of technicians include: installation of new network equipment such as routers; performing regularly scheduled maintenance work; troubleshooting of network faults; repair and replacement of faulty equipment.

The technicians who are sent out to locate and, if possible, resolve network problems are equipped with an array of communication devices like cellular phone, walkie-talkie, pager, and - in some cases - a notebook computer. Skills and experiences of field technicians vary and can range from inexperienced student volunteers to highly trained experts. In most cases, however, technical knowledge of technicians is limited, but sufficient to perform routine repairs. As part of their work, technicians often have to perform manual activities like opening computers, moving furniture and equipment, dragging wires, crawling under desks, suggesting a wearable computer design with hands-free operation.

In addition to field technicians, the Computing Center employs a limited number of full-time employees who are knowledgeable experts in their domain. For the most part, they rarely leave their office and do not perform routine repairs.

Figure 3: Remote Video Image

Field technicians often have to visit a particular site several times before they are able to resolve a problem, because they need to look up information, get additional equipment, or ask a more experienced technician for advice. For example, they might call into the office to ask questions like *"How do I do...?"*. Depending on the expertise of the technician, extensive communication between field technicians and experts at the office can be required to solve a particular problem. A wearable audio/video conferencing solution clearly could be helpful in this context: the expert is able to answer questions more quickly or more accurately if he or she is able to see the remote work area and what the technician is working on.

To our surprise we found that the most frequent cause for network problems is not related to hardware faults or software configuration issues, but misconnected wires. This type of problem can very efficiently be resolved by two closely cooperating technicians: the expert can perform tests and analyze the status of the network from the office, while the technician in the field rewires cables at a network closet or other computer devices.

Through experiments with earlier prototypes of NETMAN we made the observation that the quality of the video image can severely effect collaboration. For example, Figure 3. shows the video image as seen on the remote expert's computer. The video quality in terms of resolution, frame rate, and delay characteristics is good enough to allow the remote expert to determine where a wearable user is, in which direction he or she is looking in, and what objects are in the environment. Yet, it is impossible to clearly identify details like shape and type of connectors or read printed labels. This information is necessary for the expert to determine if cables are connected properly.

This observation lead us to the idea to use additional sensors, most notably sensors for object identity and location, in order to provide the remote expert with an enhanced view of the technician's work area.

3: Design Considerations

During the design phase of NETMAN we studied a number of possible design alternatives. We finally came up with a list of six possible *collaboration functions* from which a collaborative system can be assembled. These collaboration functions define a design space for (synchronous) collaborative wearable systems:

1) *Remote awareness*: It has been shown in the CSCW literature that users of collaborative systems feel more comfortable when they know who else participates in a conversation [8;9;11]. Awareness of remote communication partners can be achieved in many ways, for example, by presenting icons or pictures of each participant. For wearable applications, one can also think of audio-only representations.

1) *Remote presence*: Going one step beyond remote awareness, remote presence provides a richer and more natural conversation by using live representations of participants. This can be in the form of a live-feed from a camera showing a user's face or in form of an avatar, a 3-dimensional representation of a user's face or body controlled by a remote user. In both cases, remote presence gives users the ability to convey non-verbal clues using gestures and facial expressions, resulting in an improved intimacy between communication partners and a feeling of co-presence.

2) *Remote presentation*: By remote presentation we mean a user's ability to superimpose images over a wearable user's (real-world) view. By using shared computer screens it is possible for a participant to put a wiring diagram in the field of view of another wearable user. Remote presentation is thus an effective means for sharing information and focusing verbal communication.

3) *Remote pointing*: The ability to control a remote cursor enables users to point at objects in other users' view. Such objects can either be virtual objects (a wire in a wiring diagram) or real-world objects captured by the camera of a wearable computer. Like remote presentation, remote pointing can increase the effectiveness of verbal communications by directing the participants' attention.

4) *Remote sensing*: Remote sensing means that a remote user has direct, unmediated access to output of sensors attached to another user's wearable computer. Remote Sensing has the potential of streamlining the conversation among several collaboration partners by helping them to establish a shared conversational context and by creating a heightened sense of copresence. For example, participants do not have to talk explicitly about which computer one of them is standing in front of, because this information is available automatically to each participant. Remote sensing allows users to perceive a remote environment almost as if they were physically present.

5) *Remote manipulation*: Remote manipulation, finally, goes beyond remote sensing and refers to a user's ability to manipulate objects in another user's physical environment.

Collaborative wearable systems discussed in the literature ([5;6;15;20]) focus almost exclusively on remote presentation and remote pointing. NETMAN goes beyond these systems by adding remote sensing as a third component. In this paper we focus on the remote sensing aspect of NETMAN, while remote presentation and remote pointing are addressed in [14].

4: The NETMAN Prototype

The NETMAN system is a distributed groupware system that consists of several hardware and software components (Figure 4):

- One or more wearable computers worn by field technicians during repair and maintenance tasks;
- various sensors attached to wearable computers;
- one or more desk bound workstations used by expert technicians in offices at the Computing Center;
- application and system software running on both the wearable computer and the workstations;
- a central database server that stores information about computer and network equipment found throughout campus.

We will now describe each of these components in detail.

4.1: Wearable Computer

The wearable computer we use in NETMAN is based upon a Pentium motherboard from Texas Instrument and runs Windows95 as operating system. The computer is housed in a specially designed vest that accommodates the various batteries and input devices (Figure 1). The central processing unit is fitted into a pouch on the back, and cables are run from the CPU out to the front pockets in the vest. These cables feed the batteries and input devices positioned in the front of the vest. The weight of the batteries and accessories counters the weight of the CPU pouch on the back, providing a comfortable fit. A head-mounted display is used for output. The primary form of user input is keyboard input using a Twiddler keyboard. More details on the design of the wearable computer can be found in [10;13;14].

We are also experimenting with a commercial wearable computer, the FlexiPC by VIA Corporation. This computer combines a lightweight design with easy

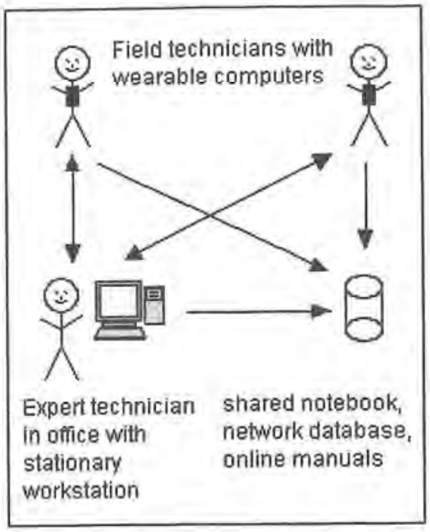


Figure 4: NETMAN Overview

extensibility and features a hand-held display and pen-input. While this combination is not a wearable computer in the strict sense, because it doesn't provide hands-free operation, we use it as our primary development and test platform.

All wearable computers and stationary workstations are directly connected to the Internet. We are using a Metricom wireless local-area, which covers the entire University of Oregon campus.

4.2: Sensors

Each wearable device is equipped with the following sensors for location, object identity, and analyzing network traffic:

Location: The first sensor is an infrared receiver for determining the wearable's location inside buildings. The IR sensor receives signals sent out by IR transmitters that are attached to the ceiling of various rooms in our lab. Each transmitter broadcasts a unique signal allowing the wearable to look up its location in a centralized database. The IR receivers and transmitters are based on a proprietary design and are described in more detail in [13;14].

Object Identity: The second sensor is a scanner for electronic equipment tags. We use iButtons from Dallas Semiconductor [7] as electronic tags for equipment, and iButton scanners (so-called 'Blue Dot Receptor') as sensors. An iButton is a 16mm computer chip housed in a stainless steel case. Each iButton has a unique, unalterable, 64-bit unique registration number stored on the silicon chip that we use to uniquely identify computer equipment.[1] By attaching iButtons to computers, routers, network outlets, and even individual wires we are able to uniquely identify objects that are important to network technicians. In order to read the registration number of an iButton, the user touches the button with the iButton scanner, which is connected to the parallel port of the wearable computer. A daemon process, written in Java using the iButton development kit, runs on the wearable device and listens to signals coming from the iButton scanner.

A centralized database stores information about iButton-enhanced objects. Currently, the only information stored about objects is their location and type, that is, whether an object is a computer, a router or something else. At a later time we plan on storing this information directly in the memory of iButtons (iButtons with up to 4K memory are available), which would eliminate the need for a centralized database.

Network Traffic: The third sensor is a packet sniffer, a devices that plugs into network outlets and allows technicians to analyze network packets.[2]

4.3: Software Applications

Several applications make use of the information delivered by these sensors. Among them are:

- a context sensitive *document browser* that uses the input of the iButton scanner to automatically search a database for documents about the equipment the technician is working on;
- an *interactive map* that displays a building floor plan showing the location of various types of computer and network equipment, such as routers and network outlets (Figure 5). This application is used by technician and expert to identify which piece of equipment they are talking about, and to access information about network equipment by location (see below);
- a *network analyzer*, a software packet that analyzes and visualizes the information about the network traffic delivered by the packet sniffer.

Because of the characteristics and limitations of the input devices of the wearable computer we have abandoned some features typical of current GUI interfaces, most notably the desktop-metaphor and the concept of movable

[1] We use DS1990A iButtons with 64-Bit ROM.

[2] The packet sniffer is not implemented in the current prototype.

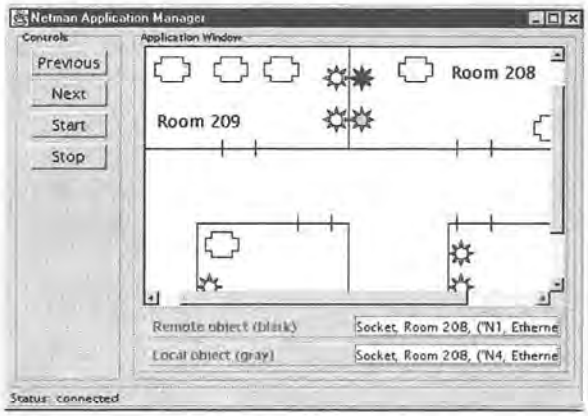


Figure 5: Interactive Map Application

and resizable windows. Both concepts have proven very successful for desktop computers, but seem inappropriate for wearable computers with limited screen space and restricted input device options.

The desktop has been replaced by the so-called *Application Manager*, which allows the user to toggle between application modules. The application manager provides a streamlined user-interface for switching among several application modules. Using the *Previous* and *Next* buttons visible in Figures 3 and 5, the user can switch from application to application by simply pressing one button. While several applications can be running at the same time, only one applications is visible in the main window of the application manager.

Each application module is an independent software entity that plugs into the *Application Manager*. The *Application Manager* provides a simple API that makes it easy for software developers to write new application modules.

5: Remote Sensing

All three applications mentioned above make use of remote sensing. This means that, while copies of each application are running on the wearable computer as well as on the workstation of the remote expert, sensor input is simultaneously sent to the applications on both computers (the exact mechanism is explained below).

To explain how remote sensing works let's assume that both users have decided to work together to resolve a particular network problem. Let's further assume that they have decided to check the wiring in a building.

Through the camera of the wearable computer the expert can see the remote work area, albeit in low quality. As they talk about how equipment is connected or how it should be connected, they use the map application to indicate what device or network outlet they are referring to (Figure 5).

The map application is a shared-window application, so that both users see identical screens. The symbols in the map represent various types of network equipment. For example, network wall sockets are indicated by stars. Both users can select symbols to indicate which particular piece of equipment they are referring to. Objects can be selected by either scanning the iButton tag attached to a device in the real world, or by clicking on the symbol on the screen. The selections of the local and remote user are indicated by colors: the object that was selected or scanned by the local user is indicated by the color gray, whereas the selection of the remote user is displayed in black. Additional information about the selected devices is displayed in the text fields at the bottom of the screen.

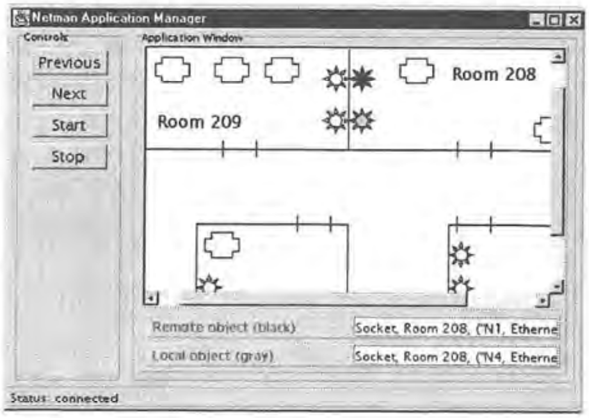
When asked how a particular router is connected to the network, the technician scans the electronic tag of the respective outlet saying: "It is connected to *this* outlet." This action highlights the outlet in the map application so that both users see what outlet the technician is referring to. Conversely, when asking "And what is connected to *this* socket?" the expert selects an outlet on the map. Seeing which object the expert selected, the technician then scans several sockets till he finds the one indicated by the expert. On the map the technician can observe which piece of equipment the expert has selected and which he himself scanned last. As response the technician then scans the tag of the connected device. This way the expert not only knows what type of device is connected to this outlet, but using the *document browser* has immediate access to all the relevant information without having to manually look for it.

The network analyzer software could be used in a similar vein. Asking the technician to plug the network sensor into a specific outlet (again indicating it on the map) the expert could then analyze the network traffic at this particular outlet from his workstation.

This description shows how remote sensing can facilitate collaboration by helping to disambiguate the meaning of pronouns or verbal descriptions like "the router over there". Again, the quality of the video image makes it impossible to use a shared view for a similar purpose.

5.1: Sensor Forwarding

Remote sensing is implemented using a set of specially designed system services. The overall software organization of the wearable device follows a layered architecture as shown in Figure 6.



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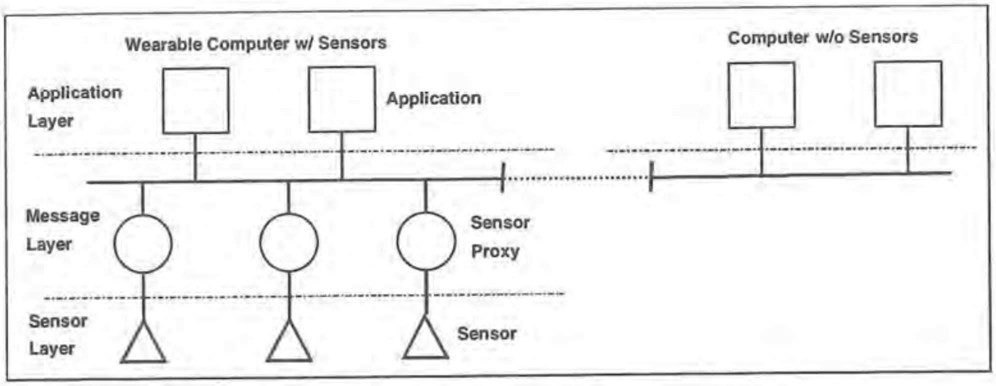

Figure 6: Software Infrastructure for Sensor Forwarding

The top layer consists of several software applications as described above. Application modules receive input from one or more sensors using an event-based communication mechanism. An event-bus connects application modules with so-called *sensor proxies*[3]. Sensor proxies are background applications (daemons) that provide a unified, event-based API to heterogeneous sensors and make it easy for applications to talk to a wide variety of sensors. This approach enables us to easily integrate new types of sensors, or to replace one sensor with another one of the same type. In order to receive sensor data from a particular sensor, applications register with the event bus:

```
int register(<host-name>, <sensor-type>)
```

Upon registration applications receive notification events through the event-bus whenever a new sensor reading is available. For example, the call

```
register( "localhost", "iButton")
```

causes the calling application to be notified whenever the iButton reader scans a new iButton.

In general, each application can register with several sensors and each sensor can have several applications it sends input to. The event mechanism is implemented using Sun's InfoBus architecture [21].

In our prototype, the workstation of the office-based expert runs essentially the same software as the wearable computer[4]. However, since (in our scenario) there are no sensors attached to the stationary workstation, the bottom two layers are missing. Application modules on the workstation can register with sensor proxies on the wearable computer just like local applications by specifying the host name of the wearable computer.

The distributed event-bus connects wearable and stationary computer (or two or more wearable computer) seamlessly, and ensures that sensor data are transparently forwarded to applications on the remote machine.

5.2: Application Sharing

In addition to the application modules described above, we realized a number of shared applications, which simultaneously run on both participants' machines. These applications realize more traditional forms of synchronous collaboration (remote presentation and remote pointing).

These modules are: (1) a shared *web browser* for accessing online manuals, help files, configuration files etc. which are stored on a central LAN server; (2) a shared *video viewer* which displays the current image of the wearable camera (Figure 3).

6: Discussion

The current NETMAN system is an early prototype, which has not yet seen formal evaluation or deployment in the real world. Preliminary observation point to the validity of some of the technical solutions employed in NETMAN. In particular the sensor-proxy approach has proved to provide a useful level of abstraction. It facilitates the construction of remote-sensing applications in two ways: (1) applications do not need to be concerned about characteristics of individual sensor types. Sensor proxies provide applications with a unified view of sensory input, whether the input comes from a GPS, an IR sensor or an iButton scanner. This fact makes the design of applications much simpler. We anticipate that this concept will also be useful for the design of traditional wearable systems without remote sensing. (2) Sensor-proxies allow us to switch the implementation of a particular sensor type

[3] The term 'sensor proxy' was introduced by Ullmer and Ishii in [22].

[4] In a more sophisticated prototype the client software running on the stationary workstation could use a more traditional user-interface with multiple independent windows.

without effecting the application. For example, in the future we could easily switch from using iButtons for object identification to wireless electronic tags.

The user-Interface of the current prototype is traditional compared to other approaches. For example, MacIntyre [16] describes an audio-based augmented-reality interface to intelligent environments. However, we believe that even simple interfaces in connection with remote-sensing can provide a significant advantage over systems without remote sensing.

7: Conclusion

The combination of wearable computing and remote sensing introduces new and interesting ways of interacting with the real world. By creating a rich shared conversational context, remote sensing has the potential of significantly enhancing the collaboration of remote users. Wearable computers provide a sole remote-sensing platform, because of their unique combination of mobility, perception, and context-awareness.

In this paper we have described a concrete system with remote sensing capability. In particular we have shown an architecture for forwarding sensory data between wearable computers and how this architecture can be used to implement remote sensing applications. Furthermore, we have shown a real-world usage scenario for wearable remote sensing. The described applications are simple, yet we believe provide a glimpse of the future potential of wearable remote sensing systems. More sophisticated systems will include different and advanced types of sensors and more sophisticated user-interfaces. In future work we hope to apply remote sensing to other domains and integrate additional types of sensors.

8: Reference List

1. Abowd, G. D.; Atkeson, Ch. G.; Hong, J.; Long, S.; Kooper, R., and Pinkerton, M. Cyberguide: A Mobile Context-Aware Tour Guide. Baltzer/ACM Wireless Networks. 1997; 3.

2. Abowd, G. D.; Dey, A. K.; Orr, R., and Brotherton, J. Context-awareness in Wearable and Ubiquitous Computing. First International Symposium on Wearable Computing; 1997.

3. Beadle, H. W. P.; Harper, B.; Maguire Jr., G. Q., and Judge, J. Location Aware Mobile Computing. IEEE/IEE International Conference on Telecommunications, (ICT'97); 1997 Apr; Melbourne.

4. Beadle, H. W. P.; Maguire Jr., G. Q., and Smith, M. T. Using Location and Environment Awareness in Mobile Communications. EEE/IEEE ICICS'97; 1997 Sep; Singapore.

5. Billinghurst, M.; Bowskill, J.; Dyer, N., and Morphett, J. An Evaluation of Wearable Information Spaces. VRAIS '98.

6. Billinghurst, M.; Weghorst, S., and Furness, T. A. Wearable Computers for Three-Dimensional CSCW. First International Symposium on Wearable Computing; 1997; Boston, MA.

7. Dallas Semiconductor. http://www.ibutton.com.

8. Dourish, P. and Bellotti, V. Awareness and Coordination in Shared Workspaces. Proceedings CSCW'92; 1992.

9. Dourish, P. and Bly, S. Portholes: Supporting Awareness in Distributed Worksgroup. Proceedings CHI'92;

10. Fickas, S.; Kortuem, G., and Segall, Z., Software Organization for Dynamic and Adaptable Wearable Systems. First International Symposium on Wearable Computing; 1997; Boston, MA.

11. Gutwin, C.; Stark, G., and Greenberg, S. Supporting Workspace Awareness in Educational Groupware. Proceedings CSCL'95; 1995; Bloomington.

12. Kontarinis, D. A. and Howe, R. D., Tactile Display of Vibratory Information in Teleoperation and Virtual Environments. Presence: Teleoperators and Virtual Environments. 1995 Fall; 4(4):387-402 .

13. Kortuem, G.; Segall, Z., and Bauer, M., Context-Aware, Adaptive Wearable Computers as Remote Interfaces to 'Intelligent' Environments. Second International Symposium on Wearable Computing; 1998; Pittsburgh, PA.

14. Kortuem, G.; Segall, Z.; Bauer, M., and Heiber, T. NETMAN: The Design of a Collaborative Wearable Computer System. MONET: Mobile Networks and Applications. to appear.

15. Kraut, R. E.; Miller, M. D., and Siegel, J. Collaboration in Performance of Physical Tasks: Effects on Outcome and Communication. Computer Supported Cooperative Work; 1996; Boston, Massachusetts, USA.

16. MacIntyre, B. and Mynatt E. D. Augmenting Intelligent Environments: Augmented Reality as an Interface to Intelligent Environments. AAAI 1998 Spring Symposium Series, Intelligent Environments Symposium; Stanford University, CA.

17. Mizell, D. Presentation given at VRAIS'98 Workshop on User-Interfaces for Wearable Computers.

18. Sabins, F. F. Jr. Remote Sensing Principles and Interpretation. San Francisco: W.H. Freeman and Company; 1978.

19. Sayers, C. P. and Paul, R. P. An Operator Interface for Teleprogramming Employing Synthetic Fixtures. Presence: Teleoperators and Virtual Environments. 1994 Fall; 3(4)

20. Siegel, J.; Kraut, R. E.; John, B. E., and Carley, K. M. An Empirical Study of Collaborative Wearable Computer Systems. Conference on Human factors in computing systems, CHI'95.

21. Sun Microsystems. http://java.sun.com/beans/infobus/.

22. Ullmer, B. and Ishii, H. The metaDESK: Models and Prototypes for Tangible User Interfaces. Proceedings of the 10th Annual ACM Symposium on User Interface Software and Technology (UIST'97), Oct. 14-17, 1997, Banff, Alta., CA.

Appendix BA02

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020     ##$a0818690747
020     ##$a0818690771 (microfiche)
020     ##$a9780818690747
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035     ##$a(OCoLC)1317101 $9ExL
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246     14$aWearable computers
260     ##$aLos Alamitos, Calif. : $bIEEE Computer Society Press, $cc1998.
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596     ##$a9
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