Augmented Reality

Exploring MARS: developing indoor and outdoor user interfaces to a mobile augmented reality system

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Abstract

We describe an experimental mobile augmented reality system (MARS) testbed that employs different user interfaces to allow outdoor and indoor users to access and manage information that is spatially registered with the real world. Outdoor users can experience spatialized multimedia presentations that are presented on a head-tracked, see-through, head-worn display used in conjunction with a hand-held pen-based computer. Indoor users can get an overview of the outdoor scene and communicate with outdoor users through a desktop user interface or a head- and hand-tracked immersive augmented reality user interface. © 1999 Elsevier Science Limited. All rights reserved.

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1. Introduction

As computers increase in power and decrease in size, new mobile and wearable computing applications are rapidly becoming feasible, promising users access to on-line resources always and everywhere. This new flexibility makes possible a new kind of application — one that exploits the user's surrounding context.

Location-aware computing [1] allows us to link electronic data to actual physical locations, thereby augmenting the real world with a layer of virtual information. Augmented reality [2] is particularly well suited as a user interface (UI) for location-aware applications. Equipped with location and orientation sensors and with a model of the user's environment, the computer can annotate the user's view of the physical world [3]. Through optical or video-mixed see-through displays, the user views the electronic information in situ, attached to the physical world, and can interact with this virtual layer or even modify it. Thus, the world *becomes* the UI.

A wearable UI alone will not be enough to fully capture the potential of a worldwide layer of spatialized information. For various tasks, a stationary computer system will be more adequate, especially for those applications whose UIs work best with physically large displays. Among these applications are tools, especially collaborative ones, for authoring the information layer, for obtaining a broad-scale overview of relevant information, and for playing back logs of user interactions with the augmented world.

In this paper we present a mobile augmented reality system (MARS) testbed that employs four different UIs:

(1) Outdoors, a mobile user, tracked by a centimeter-level real-time-kinematic global positioning system (GPS) and an inertial/magnetometer orientation sensor, and equipped with our prototype backpack computer system, experiences the world augmented by multimedia material displayed on a see-through and hear-through head-worn display (cf. Figs. 1 and 2).
(2) A hand-held display offers a map-based UI to some of the virtual information (Fig. 3), either in conjunction with the backpack or standalone.
(3) Indoors, a desktop or projection-display UI (Fig. 4a), based on a 3D environment model, lets users create virtual objects and highlight and annotate real

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Fig. 1. A view through the mobile user's see-through head-worn display. (This and all other augmented reality images in this paper were captured by a video camera aimed through the see-through head-worn display.)

Fig. 2. A user wearing our prototype MARS backpack.

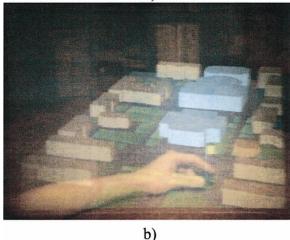Fig. 3. The hand-held computer with the map UI.

Fig. 4. Indoor UIs. (a) Desktop UI, showing (clockwise from lower right) main model window, map window, information window. (b) Immersive augmented reality UI. The user positions a virtual flag by moving its position-tracked physical base.

objects for outdoor users to see, and maintain histories of outdoor users' activities; in turn, outdoor users point out interesting objects and events for indoor users to view.

(4) An immersive version of the indoor UI (Fig. 4b) relies on see-through head-worn displays, in conjunction with 6DOF head and hand trackers, and 3DOF object trackers, to overlay and manipulate virtual information on and over a physical desk.

1.1. Related work

Many researchers have addressed the development of outdoor location-aware mobile and wearable systems. Some have relied on modifying the environment being

explored; for example, Smailagic and Martin [4] label campus information signs with bar codes to provide location-specific information on a hand-held computer equipped with a bar code scanner. Others have combined GPS and orientation trackers to produce map-based contextual displays [5], to provide audio navigation assistance to blind users [6], or to annotate the world with overlaid textual labels [7–9] or multimedia information [10]. These projects presage the goal articulated in Spohrer's proposal for a "WorldBoard" [11]: a world-wide spatial hypertext of information anchored to physical locations and objects.

Indoors, researchers have begun to explore the development of multi-user augmented reality systems. Szalavari and colleagues [12] use tethered trackers to support a collaborative augmented reality environment. Billinghurst and colleagues [13] rely on visual fiducials to position texture-mapped representations of participants in an augmented reality teleconference. Rekimoto and Saitoh [14] use a projection display to show links among material that is displayed on the optically tracked computers of a meeting's participants, while Szalavari et al. [15] and Butz and colleagues [15] present shared context on see-through head-worn displays whose customized overlays support privacy.

2. System overview

The mobile part of our MARS environment is explored by a roaming user wearing our backpack system. The user is restricted to the area around Columbia's campus that satisfies three conditions:

- Within range of the local base station for our real-time-kinematic GPS system, which sends error correction information that makes possible centimeter-level position tracking of roaming users.
- Covered by our wireless communications infrastructure: a network of spread-spectrum radio transceivers that give us access to the internet when needed.
- Represented within our 3D environment model: a coarse block representation of all Columbia buildings, pathways, and main green spaces. Our model also includes selected underground infrastructure and several buildings that have been demolished (cf. Fig. 7).

In contrast, our indoor UIs are constrained only by the third condition: the 3D environment model.

2.1. Functionality

One goal of our research is to explore the kinds of UIs that will be needed to interact with a spatialized hypertext, whose multimedia information can be linked to physical objects and tracked users. We support text,

audio, static images, video, 3D graphics, 360° surround view images, and Java applets (cf. [10]). We are especially interested in *hybrid UIs* [17] that combine different display technologies, such as the tablet computer and see-through head-worn display worn by the outdoor user of Fig. 2. Thus far, we have developed two prototype applications for outdoor users: a campus tour [7] and a journalistic storytelling system [10].

For indoor users, we have explored three areas of core functionality:

(1) Creating and editing virtual information, and associating it with real objects and locations.
(2) Obtaining an overview and keeping a log of outdoor users' activities. This could be done by the user herself, to review the history of her whereabouts and interactions with the world, or by somebody who is supervising the outdoor user.
(3) Communicating among indoor and outdoor users, including giving status reports and providing guidance.

2.2. System architecture

Fig. 5 shows an overview of the system architecture for our MARS environment. A detailed description of our backpack system's hardware design can be found in [7] and [10]. We use Sony LDI-100B and LDI-D100B 800×600 triad resolution, color, see-through, head-worn displays for indoor and outdoor augmented reality UIs. Our current hand-held computer, shown in Fig. 3, is a Mitsubishi AMiTY CP, with a Pentium MMX 166 MHz CPU, running Windows95. Our wireless communication infrastructure comprises Lucent WavePoint II base stations and Wave-LAN PC cards for our mobile computers. Our indoor immersive UI is tracked with an InterSense IS600 Mark II hybrid ultrasonic and inertial 6DOF tracker.

We use two different software development platforms for our outdoor and indoor applications: our Coterie distributed virtual environment infrastructure [18,19], based on Modula-3, for the outdoor backpack system and its indoor simulation version, and Java/Java 3D for the indoor desktop and immersive UIs, as well as for the main database interface. Our hand-held-based map UI is coded in Coterie. Alternatively, we can run a custom HTTP server (coded in Coterie) on the hand-held computer and use it with a generic web browser [7].

All applications in our testbed access a main database that contains a model of the physical environment and of the virtual information added to it. When each UI is started up, it reads the most recent state of the database. Internally, the data is organized in a relational format, currently maintained using Microsoft SQL Server.

A database server process, written in Java using the JDBC API, provides client processes (multiple users and
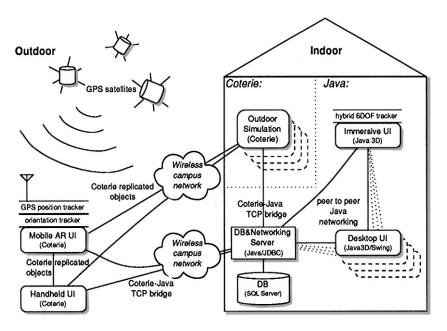
Fig. 5. MARS architecture.

UIs) with access to this data. To make this possible, we first developed a client–server database access protocol. Not surprisingly, the latency of these calls is too great for real-time graphics updates (e.g., rendering a moving outdoor user in an indoor system). To address this, we developed a simple UDP-based (in the Coterie-Java link: TCP-based) peer-to-peer communication infrastructure, emulating a distributed shared memory model for the objects that need to be updated rapidly. We are currently exploring several options to replace this with a more general distribution scheme based on object replication, similar to what is used in our Coterie system [18].

2.3. The development environment

We developed several tools and techniques to make the development and testing of new collaborative outdoor and indoor UIs easier and more efficient.

To test new outdoor UI components without actually taking the backpack system outside, we designed a Coterie application that simulates an outdoor user indoors. This program can be run in two modes: free navigation mode, which supports mouse-based navigation over the whole terrain on a conventional CRT display, using controls similar to those of first-person action games, and immersive mode, which uses the same head-worn display and orientation tracker we use outdoors. In immersive mode, we assume a fixed position in our environment and use either a 360° omnidirectional image taken from that position as a "backdrop" [10] or display the 3D environment model.

Since both real and simulated outdoor users are treated alike in their interaction with other processes, we can do tests with multiple roaming users in this fashion, although we currently have only one physical backpack system.

We developed a separate authoring tool for creating and placing new 3D models. It uses a 2D map of the area to be modeled, with its latitude–longitude coordinates. The user can trace over the 2D map with the geometrical primitives typically supported by 2D drawing programs. The tool can extrude these outlines in 3D to create simple models of buildings that are saved for use in our MARS environment.

3. UI design

3.1. Outdoor MARS UI

Building on our first MARS work on overlaying labels on campus buildings [7], our head-worn UI, shown in Figs. 1, 6–8(b)–(c), consists of a world-stabilized part and a screen-stabilized part. World-stabilized items, which are visually registered with specific locations, and displayed in the correct perspective for the user's viewpoint, include labels of buildings (Fig. 1), iconic flags representing important information that can be further examined by the user (Fig. 1), and virtual representations of physical buildings (Fig. 7).

Screen-stabilized items are fixed to the display and are always visible; they include the menu bar at the top, and

Fig. 6. An in-place menu realized with a screen stabilized menu and a leader line.
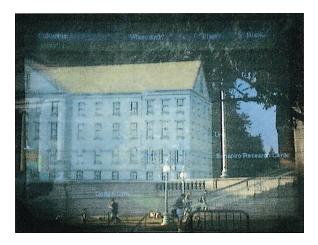

Fig. 7. 3D model of a building that once occupied Columbia's campus, overlaid on its former site.

the cone-shaped pointer at the bottom. Head-worn display menus are controlled through a trackpad mounted on the hand-held display. The cone-shaped pointer indicates the currently selected object. An object can be selected through several mechanisms, including an approximation to gaze-directed selection, and following links presented in the on-screen menu or on the pen-based hand-held computer. When enabled, our approximation to gaze-directed selection is accomplished by the user orienting her head so the desired objects's projection is closer than any other to the center of the head-worn display and within a small target area. If it remains the closest within that area for a half-second, the object's label will smoothly change color over that interval to confirm the selection.

Some items are partially world-stabilized and partially screen-stabilized. For example, the vertical menu at the left of Fig. 6 displays a set of multimedia items associated with the flag at the center of the display. The menu is screen-stabilized and the flag is world-stabilized; however, the leader line connecting them has a screen-stabilized vertex attached to the menu and a world-stabilized vertex attached to the flag. The leader line helps establish the relationship between the menu and flag, even when the flag is not visible because the user is turned away from it. (A detailed discussion of the UIs for our two outdoor MARS applications can be found in [7] and [10].)

3.2. Hand-held map UI

The map UI, running on our hand-held computer, can be used in conjunction with our outdoor MARS UI or standalone. The "map" is a projection of our 3D environment model, which can be chosen to emulate a conventional 2D map (Fig. 3). The user can review her current position and select objects; when used in conjunction with the outdoor MARS UI, an object selected on the map will be selected on the head-worn display (and vice versa), so the user can be directed toward it.

3.3. Indoor UIs

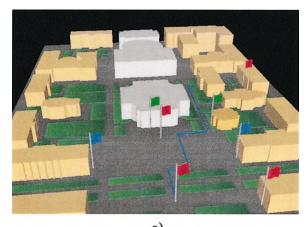We have two indoor UIs: a desktop UI and an immersive augmented reality UI.

The desktop UI presents information in multiple windows, as shown in Fig. 4(a). The main window shows a navigable 3D model of the campus environment in which the user can select objects to extract information and create new objects. A 2D map window, shown at the left, can be used to aid in navigating the 3D view.

The main window's pop-up menu allows users to create new objects, such as flags and paths through the environment, to delete objects, and to bring up an information window for any given object. An information window, shown at the top right of Fig. 4(a) makes it possible to view and modify all information associated with its object for display to MARS users.
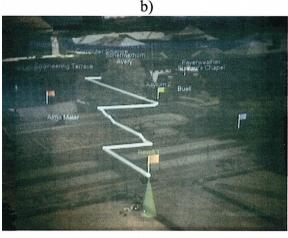
Users of the immersive augmented reality UI wear see-through head-worn displays tracked by an Inter-Sense IS600 Mark II 6DOF tracker. The 3D environment's ground plane is coplanar with a physical desk. Our main input devices are Logitech wireless trackballs, tracked by wireless InterSense position sensors. We also use the position sensors as physical props. For example, Fig. 4(b) shows a user placing a virtual flag by moving a position sensor that acts as the physical base for the flag.

3.4. Indoor/outdoor interaction

Our four UIs offer many opportunities for indoor/outdoor communication and collaboration. New

a)

b)

c)

Fig. 8. Outdoor paths. (a) Creating a path in the desktop UI. (b) Same path, seen outdoors from ground level. (c) Same path, seen from above.

virtual objects can be introduced by any UI and, when moved around, their position is updated in all participating UIs. This can be used, for example, to highlight points of interest. Fig. 8 shows an example of indoor/outdoor interaction: an indoor user giving guidance to a roaming user by drawing a path on the virtual model (part (a)). Parts (b) and (c) shows outdoor views of that path as seen from two different perspectives.

4. Conclusions and future work

We have described our experimental MARS testbed, presenting four different UIs for indoor and outdoor users, enabling users to annotate the real world with virtual information and to explore the merged environment. Indoor users can provide guidance to outdoor users by sketching paths or pointing out objects of interest. An outdoor user's position and head orientation can be tracked in the indoor system and logged in the main database for later review.

There are many directions in which we would like to extend this work. Because the indoor augmented reality UI lends itself well to collaborative work, we are integrating it with our EMMIE multi-user augmented reality system [16]. This will allow us to further explore EMMIE's support for customized views for displaying private information; for example, to allow different indoor users to direct and track their own separate crews of outdoor users. Over the past few months, we have started to collaborate with researchers at the Naval Research Lab, with the goal of linking our systems with ones that they are building, to support a collaborative MARS environment that is distributed across both our campuses.

Acknowledgements

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