Augmented Reality as a Medium for Cartography

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Abstract

Augmented Reality (AR) is a radically new user interface paradigm, which aims to amplify a user's sensory perception directly by supplementing computer generated, mostly visual information. Computer graphics elements are superimposed in the user's field of view. This approach is particularly powerful when trying to aid human users in their everyday activities, and in combination with mobile computing. This chapter explains basic technology of AR, and discusses examples of how AR can be applied as a medium for cartography.

Introduction

In contrast to Virtual Reality, which completely immerses a user in a computer-generated virtual environment, Augmented Reality (AR) aims to amplify a user's senses with additional information, letting them experience both real and virtual information at the same time. Technically, this is often achieved by superimposing computer graphics in the user's field of view through optical or electronic combination of real and virtual images. The widely accepted definition of AR according to Azuma (Azuma 1997) requires the following three characteristics:

1. Combines real and virtual
2. Interactive in real-time
3. Registered in 3D

Note that while this definition rules out non-interactive media such as film or television, it does allow for non-visual augmentation (e.g., audio AR) as well as mediated reality environments, where a part of reality is replaced rather than augmented with computer-generated information.

Fulfilling all three requirements of Azuma's definition is a challenging task, which has fuelled over ten years of intensive research and development. The combination of real and virtual requires that an AR system must include input and output devices which are capable of achieving such a combination. An output device such as a head-mounted display (HMD) can present perspectively correct three-dimensional computer generated images wherever a user is looking. It must be combined with a tracking device which can accurately measure the position and orientation of the user's head, to control the virtual camera used to render the images presented to the user. Accuracy of registration between virtual and real objects highly influences the realism of the AR experience as perceived by the user. Achieving such high registration accuracy despite problems with systematic errors and noise in the tracking devices, miscalibration of the HMD or viewing device, and latency in the processing is subject to past and ongoing research.

While registration is an important research topic for AR, the field offers many other interesting research challenges. The primary motivation to develop AR is to establish a more natural user interface by exposing abstract information properties of the real world or associating it with phenomena encountered within the real world such as space and time. An important part of any AR user interface is 3D interaction. Humans know how to interact with real objects, how to handle and manipulate them. The augmentation of the real world with artificial objects tries to leverage that knowledge and extend it to the artificial information objects.

In doing so, AR blurs the distinction between the real world and the user interface in a way similar to the ideas of ubiquitous computing as described by Weiser (Weiser 1991). While ubiquitous computing focuses on the computer becoming invisible among the objects of everyday life, AR seeks to add to the experience of reality, thereby creating new forms of interaction between humans and computers. Mobile computers running AR applications can provide such ubiquity.

AR is useful in every situation where a human operator requires additional information, such as a doctor desiring to look "inside" a patient, or a maintenance technician referring to a technical manual. Obviously, the objective of cartography is to provide humans with additional information regarding their surrounding, such as navigation or cultural information. Consequently, AR can make a useful new type of user interface for computer-mediated cartography. In particular, delivering 3D geo-information directly at a task location makes new applications of cartography possible.

In the following, we discuss basic enabling technologies for AR, and case studies of stationary as well as mobile AR applications for the visualization of geo-information.

Augmented reality technology

Most AR systems use graphics as their primary output medium. To support the presentation of visual AR content, and to combine this content with the real world, various display systems have been introduced.

Piekarski gives a useful summary of technological, perceptual and ergonomic issues of AR displays (Piekarski 2004). Technical issues are overall latency from user movement to image update, resolution and optical distortion of the image, field of view and registration quality. Perceptual issues are the number and quality of the provided depth cues such as occlusion, perspective, motion parallax or depth of field, as well as other quantitative image properties such as color, brightness, and contrast. Ergonomic issues concern such things as weight, tethering, safety concerns (when navigating potentially dangerous environs while using the display), and support for non-augmented peripheral vision.

Generally, AR displays can be split into head-mounted displays, handheld displays and projection displays, the latter being stationary but potentially able to accommodate multiple users.

Head-mounted displays are worn by the user on her head, and provide two image-generating devices, one for each eye. Since the display surface is located very close to the eye, additional optics have to be provided to move the focal point further away from the user, allowing the eyes to focus on the environment and the overlay at the same time. HMDs are suitable for stereoscopic display, delivering separate images to each eye. However, only high-end HMDs support stereo, while the low-end devices simply duplicate a single input image for each eye.

For image generation and merging with the real world, two approaches can be distinguished: Optical see-through systems, which allow the user to see through the display onto the real world, and video see-through systems, that use video cameras to capture an image of the real world and provide the user with an augmented video image of her environment.

Optical see-through systems use optical image combiners (usually half-silvered mirrors) to blend together virtual and real content. Due to their working principle, not all of the light of the environment will reach the user's eye, resulting in a slightly attenuated view of the world, comparable to wearing sunglasses. The computer-generated images shown to the user always appear semi-transparent and cannot fully replace or occlude the real world.

Video see-through systems do not allow a direct look onto the real world. Instead, one or two video cameras at the front of the device capture images of the real world, which are mixed with the virtual content and then displayed to the user's eyes through two monitors inside the device. By overlaying the video images with the rendered content before displaying both to the user, virtual objects can, in contrast to optical see-through solutions, appear fully opaque and occlude the real objects behind them. The drawback of video-based systems is that the viewpoint of the video camera does not completely match the user's viewpoint. Although the brain can adapt to the new situation, for security reasons these systems cannot be used in applications where the user has to walk around or perform complex or dangerous tasks, since judgment of distances is distorted.

Hand-held displays also use a video-see through technique. They consist of a portable display with an attached video camera, essentially the same technical configuration as in a video-see through HMD. However, hand-held AR displays can be built from consumer devices such as tablet PCs, personal digital assistants (PDAs) or even cell phones. All these devices represent combinations of CPU, display and camera at extremely competitive price/performance ratios. In addition to this advantage, they are also lightweight and discrete, and have therefore recently become popular with AR researchers.

Projection-based AR displays use video projectors for directly casting images on surfaces in the environment. There are a number of options for configuring such projection systems: They can show monoscopic or stereoscopic images (stereo through the use of LCD shutter glasses for eye separation), employ front or back projection, and use either video augmentation or physical surface augmentation. Video augmentation is essentially the stripped down version of a video see-through HMD, displaying the image of an external video camera augmented with computer graphics on the screen. Physical surface augmentation works by projecting light onto arbitrarily shaped real-world objects (Raskar et al. 1998). This technique can be used to dynamically illuminate real objects in the scene, or to simulate alternate surface texture properties. In both cases, to produce correct results, the geometry of the target object for projection has to be known in advance for perspectively correct rendering.

Well-established standard computer input devices such as the keyboard or the mouse are practically useless in AR applications – often, users are moving around freely in space, or even roaming through buildings or outdoor areas. This leads to the requirement that input devices must either be ubiquitous, being able to follow the user's input without a fixed spatial location, or wearable, so that the user can carry the input devices with her.

Finding out where the user, her hands or some artifact she is handling is located in space is called tracking, and is probably the most important type of input to be fed into an AR system. Typically, tracking devices used in AR applications deliver data about the six degrees of freedom (6DOF) of a tracked point in space: three position coordinates and three rotation components, plus optional action buttons. Furthermore, there are several properties of tracking hardware that are important to consider for AR applications:

- The range of operation. Some devices work only in a given radius from a central unit, for others the targets must be within the field of view of a camera.
- The update rate, measured in Hertz (updates per second). For the primary interaction devices, this should ideally match the frame rate of the display, but at least 10-15 Hz for interactive applications. Additional information, such as user or environmental context, can be delivered with lower update rates, depending on the application.
- The accuracy of the measurement, measured in relative (percent) or absolute average or maximum deviations from the correct result.
- The confidence whether a tracking target has correctly been identified. This applies primarily to optical trackers.
- Whether the tracked target has to be tethered (connected with a cable), or supplied with electrical power.
- Finally, also the effort to set up and calibrate the device has to be taken into account when considering different tracking technologies. Some products come pre-calibrated, others have to be calibrated after installation, some even regularly.

The desire to fulfill as many of these requirements as possible has lead to a number of technical approaches for tracking technologies. To date, no solution without significant restrictions exists; therefore it is important for practical applications to consider the trade-offs.

Optical tracking is the most accepted technique for AR, since it allows leveraging ongoing developments in computer vision and substitute computational intelligence for sensor performance. Optical tracking systems use one or more cameras and advanced computer vision software to detect targets (often called markers) in the camera image and calculate their position and orientation information from that camera images.

An infrastructure of cameras permanently mounted in the environment can observe humans or physical artifacts instrumented with inexpensive passive fiducial markers. Multiple cameras with overlapping field of view can not only provide superior pose estimation through multi-view geometric analysis of the observed scene, but also provide better robustness against marker occlusion. Alternatively to stationary cameras, a mobile computer can be equipped with a single miniature camera, which is used to deliver images for both video-see through augmentation and optical tracking.

The range of available solutions for marker-based optical tracking ranges from highly professional systems provided by commercial companies such as Advanced Real-time Tracking or Vicon to inexpensive open source solutions working with a single consumer camera such as ARToolKit (Kato and Billinghurst 1999). Finally markerless tracking relies on natural features detected in the environment, and does not require any physical infrastructure. However, 3D tracking from natural features is currently not robust and fast enough for widespread commercial use.

One of the older methods is tracking by electromagnetic sensing. An emitter generates an electro-magnetic field, which is detected by the electronics in the tracking targets and results in accurate 6DOF tracking information. The main drawbacks with magnetic tracking are that the targets are tethered, and the whole system is very sensible to metal in the environment.

Acoustic tracking uses time of flight of an ultrasonic signal, to calculate the distance between emitter and receiver. For three-dimensional tracking information, three emitters in the environment and one microphone at the target are required. If 6DOF information is needed, three microphones on the target must supply independent measurements. Although ultrasonic devices need not be tethered, the targets have to be equipped with active electronics and require batteries and radio transmission facilities. This makes the targets bulky and expensive, which, besides the low update rate, limits the number of targets that can be used simultaneously.

Inertial trackers measure linear acceleration or angular velocity. The obtained rate information is integrated per time step, resulting in the measurement of the current position and orientation of the device. While inertial trackers tend to suffer from drift resulting from integration errors, they are an excellent complement to other types of trackers such as optical or acoustic technologies.

Finally for outdoor applications, the global positioning system (GPS) can deliver rough positional data. For accurate positioning, GPS systems have to be accompanied by electronic compasses and inertial trackers, which allow for efficient dead reckoning between successive GPS measurements. While GPS is primarily designed for coarse location information used in ubiquitous computing applications, careful setup of a GPS system allows using it for AR as well.

Augmented reality visualization

Visualization for augmented reality focuses on two aspects: the realistic merging of artificial objects and effects with reality and the appropriate presentation of abstract information. The first aspect typically involves techniques from computer graphics such as correct illumination, image based rendering and advanced transparency and shadow creation. The second has more in common with visualization in general and is of more interest to us here, as cartography also deals with visualization of abstractions.

Augmented reality user interfaces typically employ simple rendering styles such as uniformly lit lines and surfaces, strong primary colors, transparency and regular textures to distinguish abstract information from the real world. Proximity, call-out lines and correct depth interaction using occlusions establish relationships between real objects and augmented information. Note, that while real objects can easily occlude virtual information by not rendering the virtual part, occluding real objects is much harder and relies on special hardware (Kiyokawa et al. 2003) or illumination control over the environment (Bimber and Fröhlich 2002).

Abstract information displayed in AR user interfaces still registers in 3D with the real environment. However, the same visualization properties labeling information as abstract contradict the natural depth cues of human perception. As a result, simple computer graphics often appear to be situated on a virtual screen between the user and the environment rather than merge with it. Several projects have investigated appropriate visualization techniques to overcome this problem. Furmanski et al. conducted a study comparing three visualization methods for representations of occluded objects (Furmanski et al. 2002). Livingston et al. expanded this work by comparing a number of different factors such as color, brightness and rendering style on the depth perception of occluded virtual objects (Livingston et al. 2003).

A common approach to deploy augmented reality is to create interactive workspaces. Using head-mounted or projection displays, a system overlays dynamic information on static real world objects such as plain pieces of paper, maps and models of cities and buildings. An early example is the metaDESK that annotates a plain paper worksheet on a tabletop with projected information (Ullmer and Ishii 1997). A camera captures user input such as numbers written down for summation or copy and paste gestures on parts of the worksheet. The system reacts to such inputs and computes sums or projects copied parts back on the sheet. A more extensive system for urban planning applications is Urb which annotates a small scale city model with output from wind simulations and shadow and reflections computations (Ishii et al. 2002). Users can move physical building models and perceive the updated results of the simulations.

Similarly, head-mounted display based systems allow to present 3D information in the context of plain 2D artifacts. Hedley et al. present an interesting system for visualization of geographical data in an AR environment (Hedley et al. 2001). This research group developed a system called AR PRISM that presents the user geographic information on top of real maps, viewed with a head-tracked HMD. The system allows collaborative work of multiple users (via multiple HMDs) and gesture-based interaction.

Case study: Augmented map system

The augmented map system developed at Cambridge University (Reitmayr et al. 2005) is a direct combination of cartographic maps as basic artifacts and augmented reality as user interface. Paper-based cartographic maps provide highly detailed information visualization with unrivaled fidelity and information density. However, printed maps are static displays and while computer-based map displays can support dynamic information, they lack the nice properties of real maps identified above. The restrictions are overcome by projecting digital graphical information and user interface components directly onto the physical map. User interaction with the both the original map and displayed information is mediated through a set of tangible tools.

The overall system centers on a tabletop environment where users work with maps. One or more maps are spread out on a table or any other planar surface. A camera mounted above the table tracks the maps' locations on the surface and registers interaction devices placed on them. A projector augments the maps with projected information from overhead. A computer vision based localization system tracks both the maps and interaction devices on the table surface. An image browser interaction device lets the user quickly view images that are associated with locations on the map. A rectangular prop consisting of a white piece of cardboard with a black border is placed on the map. The pointer in the middle of one side of the rectangle is used to denote a specific location and orientation on the map. The white area on the prop itself is used to project the retrieved image. Both location and direction of the pointer influence the displayed image. The direct display of the images enables seamless operation because both the query and the result are visible to the user within the same area.

Abb. 1. (Left) a user interacting with an augmented map, (right) overview of the individual tools and example augmentation of the expanded river

A second interaction device provides control over entities referenced to map locations. A Windows CE based PDA device is located using the screen rectangle which appears almost black in the video image. Again a pointer is present on the top of the device to accurately determine a location. An active entity referenced to a location presents a dedicated user interface on the PDA. Typically the user interface is persistent on the PDA until a new one replaces it. Therefore users can pick up the PDA from the table surface again and operate it in a more comfortable hand-held manner.

The system was demonstrated with a flood control application for the City of Cambridge (UK) to demonstrate possible features of augmented maps. The River Cam running close to the town center of Cambridge regularly floods the surrounding areas, which are lower than the water level of the river in a number of cases. In the event of real flood, the water line needs to be monitored, threatened areas identified and response units managed. Information provided by local personnel helps to assess the situation. An augmented map provides the ideal frame for presenting and controlling all the relevant information in one place.

A map of the area of interest is augmented with an overlaid area representing the flooded land at a certain water level. The overlay changes dynamically with the water level. Certain endangered compounds are highlighted in red with an animated texture when the water level reaches a critical level. Other information sources include images provided by ground personnel at various locations. Dedicated icons represent the locations and directions of these images. Using the image-browsing prop an operator can see the image and assess the local situation immediately. An emergency unit represented as a helicopter is visible on the map as well. By placing the PDA next to it, a corresponding graphical user interface appears on it to present more status information and give orders to the unit. Here its direction and speed can be controlled.Mobile augmented reality

While AR in a stationary environment allows the construction of interesting new user interfaces, the ultimate goal of AR is to provide a computer-augmented environment anytime and everywhere, without restrictions. In particular, making mobile outdoor AR work outdoors pushes the envelope of what is currently possible with AR technology.

The first example of a mobile AR operating in an outdoor environment is the Touring machine (Feiner et al. 1997) developed at Columbia University. The Touring Machine consists of a backpack assembly with a mobile computer and various sensors and peripherals. Images are delivered through an HMD that includes its own tracking technology for orientation. The positioning system is delivered by a GPS with a correction system that allows an accuracy of about 1m. This work has been inspiring for many research groups, and several of them have started developing their own backpack systems.

The follow-up developments, Mobile Augmented Reality System MARS (Höllerer et al. 1999) and Situated Documentaries (Höllerer and Pavlik 1999), further explored the user interface aspects of such systems for interactive presentations and campus tours. Tour guide applications and navigation aids are a recurring theme for mobile AR applications, for example BARS (Julier et al. 2000a), Archeoguide (Vlahakis et al. 2002), GEIST (Kretschmer et al. 2001) or TOWNWEAR (Satoh et al. 2001). Also related is a prototype for visualization of subsurface features (Roberts et al. 2002) developed at Nottingham University.

The BAT system developed at AT&T research lab in Cambridge (Newman et al. 2001) is unique in its coverage of a very large indoor area (a whole office building) with a custom high quality ultrasonic tracking system. This technology enabled the researchers to develop an infrastructure for “sentient computing”, providing a permanent suite of tools to mobile AR users: The system knows the whereabouts of its inhabitants, and can for example provide visual aids to locate a person or route telephone calls to the nearest phone.

Another popular mobile AR system is Tinmith, developed at the University of South Australia (Piekarski and Thomas 2001). Tinmith supports indoor and outdoor tracking of the user via GPS and fiducial markers. Interaction with the system is brought by the use of custom tracked gloves. The display of overlays is delivered by a video see-through HMD. The main application area of Tinmith is outdoor geometric reconstruction. Through the mobile AR system, its user is enabled to interactively create and inspect digital live-size reconstructions of natural and architectural features. The position of the user in the world as well as geometric operations such as constructive solid geometry provide input to a computer aided design application operating on a full-size model of the real environment. Distance interaction techniques allow the user to cover far away or out of reach regions. This application is noteworthy since it represents the rare attempt at creating content for AR systems on-line rather than merely browsing existing content from an immutable data repository.

Mobile AR user interfaces pose a number of challenges on the interface designer. The area covered by an outdoor AR system is potentially very large, and may contain an overwhelming number of information items that can be potentially displayed. Constrained viewing and operating conditions require a simple user interface with a high degree of autonomy and context-sensitive behavior, and prohibits complex user interactions. Therefore, several research projects have investigated algorithms that determine appropriate content and style for augmented views automatically. For example, an interactive filtering algorithm selects objects to be shown based on user defined priorities and proximity (Julier et al. 2000b). Label placement techniques are responsible for avoiding display clutter and unwanted occlusion of real objects by augmented labels and annotations (Bell et al. 2001).

Case Study: Signpost

The needs and requirements of a tourist are a suitable starting point for testing location-based applications. Consequently, a number of mobile AR demonstrators focus on the needs of a tourist as discussed before. Here we will discuss the design of a particular example in greater detail. The Signpost system is a prototypical tourist guide application for the City of Vienna covering both support for large-scale environments and collaboration (Reitmayr and Schmalstieg 2004).

Signpost covers both outdoor city areas as well as indoor areas of buildings. The system uses different tracking technologies in each individual type of environment and switches transparently between them. Outdoors a combination of differential GPS and inertial tracking is used, while a computer vision based localization system employing fiducial markers was developed for indoor environments (Reitmayr and Schmalstieg 2003). Different levels of accuracy can be achieved by varying the density of fiducial markers.

The basic function of the system provides a navigational aid that directs the user to a target location. An information browser displays location-referenced information icons that can be selected to present more detailed information in a variety of formats. Both functions support collaboration between multiple mobile users.

In navigation mode the user selects a specific target address or a desired target location of a certain type such as a supermarket or a pharmacy. If the user is within a building a destination room is selected. The system then computes the shortest path in a known network of possible routes. It is interactive and reacts to the user's movements. It re-computes the shortest path to the target if the user goes astray or decides to take another route.

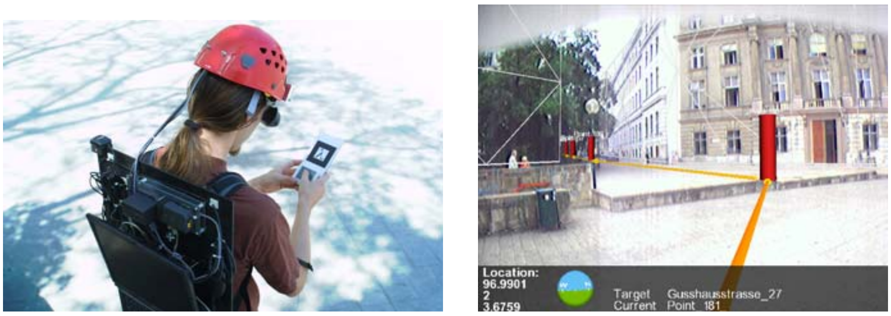

Abb. 2. (Left) User interacting with a mobile AR system, (Right) Outdoor navigation display leading a user down a street

Outdoors, the information is displayed as a series of waypoints that are visualized as cylinders standing in the environment. Arrows indicating the direction the user should take between waypoints connect these cylinders. Together they become a visible line through the environment that is easy to follow. Buildings clip the displayed geometry to enable additional depth perception cues between the virtual information and the real world. Finally, the system displays simple directional information, if the user is not looking into the direction of the next waypoint.

Indoors, the system continuously provides the user with two modes of visual feedback: a heads-up display with directional arrows and a world in miniature model of the environment. The heads-up display shows a wire frame model of the current room superimposed on top of the real view and an arrow shows the direction to the next door. The application also presents a world-in-miniature model of the building to the user in the lower area of the heads-up display. The model shows an overview of the user’s current environment including the complete path.

In information browsing mode the system presents the user with location-based information. Location-referenced information icons appear in view and are selected by looking at them. Once activated, they present additional information associated with that location. The application conveys historical and cultural information about sights in the City of Vienna.

Conclusion

Augmented reality promises to merge the interactive nature of computer generated user interfaces with real objects and environments that create the every-day experience of users. New forms of cartography already build on the flexible access to online data and adaptive presentation of geographic information. These recent innovations combine well with interactive augmentations enabled by AR

Stationary workplace systems can improve the users' performance because of the natural interactions they afford. The shared space between users is reused as output channel for digital and dynamic information, thereby naturally enhancing collaboration by providing the relevant information in place rather than in the confining context of traditional monitors.

With the advent of powerful handheld devices, applications of AR are becoming mobile and ubiquitous. Contrary to stationary systems the workplace now becomes a large-scale environment. Moreover, information need not be abstracted completely from its location anymore, because users can perceive and manipulate it directly within its original setting.

We believe that these features of AR closely match potential future applications of cartography and therefore invite researches to take it into consideration. While the past research focused on the technological underpinnings of AR, future directions must come to a better understanding of efficient and practical methods to displaying spatial information. Therefore AR could draw as well from the knowledge and experience of cartographers.

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