

Cartography in a Mobile Internet Age

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ABSTRACT

Many now predict an era in which the display of cartographic data is not on a desktop computer, but on a mobile system located at the point of measurement or use in the field. This next cartographic revolution will be hastened by compact GPS receivers, cellular communications, portable web access, reduced size microcomputers, and next generation input and output devices for the use and display of digital maps. This research reviews field technologies for GIS and computer mapping, including those developments that will place the computer devices on the person of the user, the input devices into the hand-free use environment, and the display directly into the human vision field. A prototype ubiquitous field computing system will be demonstrated, with the intent of highlighting the extraordinary demands that will be placed upon the human-computer interface of the resultant wearable GIS. Particular concerns are communications, data bandwidth, Internet access and coverage, high-throughput Internet links, digital library database access, but above all the user interface of such a system. Some alternative designs for the mobile ubiquitous GIS user interface are presented, that include capabilities for in-view augmented cartographic reality. View options include feature frames, three dimensional glyphs, text feature annotation, monochrome feature filters, feature location identification and selection, Internet linkage, haloing, and pointer and navigation aids and mechanisms. Of particular concern in such ubiquitous systems will be data screening or access limitations, and the techniques of pixel blocking as a solution to security and privacy. Speculations on the future of cartography, assuming the existence of such devices and user interfaces, will be made including the negative consequences of the use of the systems. Clearly, liberation from the constraints of the desktop will have much to offer the future of mapping, above all a reorientation toward exploration and field data collection for mapping. If the negative consequences can be anticipated and controlled, then mobile GIS will constitute the next generation of geographic information technologies.

INTRODUCTION

The era of the computer's influence on cartography can be divided into three phases. At first, large mainframe computers were used as analytical engines for problem solving using the algorithmic approach. In the second phase, smaller desktop computers and workstations became capable of a dedicated replacement of mainframe systems, allowing personal interaction with computer-based processes. The third phase involved hooking these systems into a network, the Internet, to permit distributed computing and the client/server interaction model. In this environment, the primary interaction tool has become the browser, and human computer

interaction, though far more freeform, has remained largely based on the graphical user interface. Even the advent of laptop and palmtop computing has retained this interaction model, especially as far as computer mapping is concerned.

A fourth era is now evident, that of mobile computing. As computers become more embedded, incorporated into appliances, vehicles, and system sensors, and as networks have migrated toward wireless connections, the computer has finally removed itself from the user interface paradigm of prior eras and created a completely new model. This model might be called *ubiquitous computing*. This paper discusses the impact that high mobility computing will have on cartography, focusing on the design, construction and testing of a mobile wearable computing system for personal map use at the University of California as part of our field computing project Battuta (<http://www.statlab.iastate.edu/dg/>). In the wearable computer paradigm, the computer is contained in the user's clothing, and the input and output devices interact with the normal motions and senses of the human body, including normal vision. As such, wearable computers offer two great cartographic advantages. First, the system can present the map user with cartographic information in real time during map use. When this information is placed into the vision field, it is a cartographic form of augmented reality. Secondly, the system can take advantage of distributed systems to retrieve map and image data for display based on the position of the user. This location-basis for information selection and retrieval is the most basic, and maybe the most powerful form of context awareness for ubiquitous computing.

Literature on wearable and mobile computing dates back less than a decade (Gold, 1993). Several technology surveys have considered the field, and a series of conferences has been held to assist progress in the area, including *the International Symposium on Wearable Computers* (<http://iswc.gatech.edu/>). A comprehensive bibliography covering the early meetings, and a host of workshops and seminars is available at the University of Lancaster in the UK (Lancaster University, 1996), and the history is summarized as a timeline at the Massachusetts Institute of Technology (MIT, 1999). Much research on ubiquitous computers is available, with a literature guide at http://www.hitl.washington.edu/projects/knowledge_base/wearable.html. Most work examines the perception and measurement of context awareness, that is what a wearable user can detect within the real and virtual environment. Azuma (1997) surveyed augmented reality applications. Billingshurst (1998) and Beadle et al. (1997) have surveyed locational applications. Clark (1996) has considered user interface design issues. Most wearable applications are found in the realms of industrial process control and in medical support. A search for wearable systems that integrate virtual map (or world) data using GIS produced no papers. We hope to fill this research void.

The potential of GIS to move from the desktop into the field (Benison, 1999) to create what could be termed *ubiquitous GIS* (not necessarily always wearable), depends on three factors. These are (1) the solution to the thin/fat client issue for GIS; (2) the compression and integration of computer hardware and GIS software; and, of interest here, (3) the design of effective user interfaces for these systems. The first issue, that of choosing between mobility based on self contained GIS capability versus using telecommunications to access the data base, obviously hinges upon how much memory can be stored on mobile devices. While the amounts can be significant, the disadvantages of this solution are heavier mobile systems, limited query capability, lack of timeliness, and susceptibility of the hardware to failure and damage. The alternative is to build relatively little data base strength into the mobile client, but to build a high bandwidth mobile cellular or other communications link with a network, such as the Internet, and to download data on demand in real time. Software solutions to this problems are now

imminent (Nusser et al., 1999) and are likely to be based on multidatabase and mediator-based systems, on data warehousing, and on discovery and retrieval with multi-agent systems. Similarly, the band-width communications problem will likely be solved in hardware within the near future. Thus a cellular communications-based, web-linked mobile ubiquitous system seems likely to be very much on the near horizon.

This leaves to be solved the two problems most closely related to geospatial data. First, how can GIS software be used in the new ubiquitous environment? Some speculations about likely uses are given in Clarke (1999a), Grossman (1998) and in Cartwright (1997). Central to the newer approach to visualization is the concept of *augmented reality*, in which computer-generated views are placed into or over the natural human viewfield. This can be accomplished with a new generation of wearable head-mounted displays, often small enough to be integrated into glasses (Spitzer et al., 1997). Augmented reality will be of increased importance in the future, falling into the category of both “smart” interactive display and machine decision-making, since the information it provides can be used directly in the decision-making process and in real time.

Some of the GIS challenges are purely practical. While many wearables, for example, run Windows CE as their operating system, an increasing number use Linux, which shows a remarkable degree of flexibility and interoperability. While the first generation wearables had severe RAM, disk and I/O constraints, the latest versions have capabilities very similar to desktop PCs, and so can run standard GIS software. Similarly, the number of buses and ports for the different I/O devices can mean that the connectivity hardware exceeds in size the computer and its peripherals.

The third critical problem is: what sorts of user interfaces work best with ubiquitous geospatial information systems? Obviously, the normal set of input and output devices have to be rethought for ubiquitous systems (Clarke, 1999a). A proposed approach is the VISIO interface standing for Voice-In, Sound and Images Out (Clarke, 1999b). Most ubiquitous systems have either small keyboards or none at all, relying heavily on voice and positioning input. Also forming input devices are head trackers, GPS devices and range finders (Clarke, 1999a). Sound as output has been exploited most heavily by the Personal Guidance System (Golledge et al., 1998), where stereo sound is used to indicate direction. No major GIS yet fully incorporates sound input or output, although research has started on this topic outside of the field (Barrass and Kramer, 1999; Krygier, 1994). Coupling with in-vision displays, particularly the augmented reality displays, with the new range of inputs offers some significant user interface design challenges. To approach these problems, the Battuta project has built and is testing a wearable computer for mapping.

DESCRIPTION OF THE UCSB WEARABLE MAPPING SYSTEM

The design of a wearable computer is a work in progress. Many commercially available wearable computer applications have been developed for industrial process control and medical support. Wearable devices for blood pressure and pulse control are commonly used already, and augmented reality in operating rooms is developing quickly. The U.S. Army’s Land Warrior wearable system has driven civilian technology, but even this system assembled mostly off-the-shelf hardware. The unit provides the dismounted soldier with technology for wireless communication, navigation, and data sharing. The communications-navigation unit contains a GPS receiver and dead reckoning positioning module, and a wireless LAN PC card. It

automatically generates and transmits regular GPS-based position update messages and geo-referenced graphics.

A set of design goals for wearable computing systems includes that they should be lightweight, as small as possible, unobtrusive and discreet, ergonomically sound and comfortable, power-efficient, robust, and inexpensive. Several off-the-shelf wearable computers are now available, and they are a good choice for people who want to avoid the expense, effort, and time involved in building their own, but they have made trade-offs between application and cost. An example is the Xybernaut Mobile Assistant, employed for plant and equipment. This system uses an Intel Pentium MMX processor, Windows 95, 98, NT, or 2000, up to 160 mb RAM, 512 kb of L2 Cache, a 2.1 to 8.0 gb hard drive, two CardBus slots (2 Type I or II and one Type III), a hot-swappable, lithium-ion battery pack, and contains connecting peripherals (USB, display, audio, video) and power cables as well as PCMCIA slots. The unit weighs 795g (1.75 lbs), clips onto a vest or belt, has either a touch screen flat panel color display or a head mounted color display with hands-free voice recognition and activation. Another commercially available ready-to-use computer is the ViA II wearable PC. The Base unit configuration consists of a 166 MHz Cyrix MediaGX processor, 64 mb DRAM, a 3.2 gb 2.5 inch rotating hard disk drive, two expansion sockets for two Type II or one Type III PC card, full duplex audio for speech recognition, SVGA video for CRTs and LCDs, digital display interface, RS-232 serial communication interface, one USB interfaces, mouse and keyboard interfaces, and Microsoft Windows 98. PCMCIA Card Options including GPS receiver, hard drive, video capture, and Wireless LAN. A sunlight readable or indoor readable color handheld display with stylus, power devices, and other accessories can be added accordingly.

A more creative and customized solution for a wearable computer is to use a commercially available developer kit. The UCSB wearable computer uses the CharmIT™ kit, built on the PC/104 specification, an industry standard for embedded computing for nearly ten years. The PC/104+ configuration evolved as an extension and includes a second 32 bit PCI-based bus. The boards tend to be around 3.6" x 3.8" x 0.9" with connectors that allow stacking up or across. Many companies manufacture a wide variety of PC/104 add-ons including cards for CPU, Ethernet, PCMCIA, Flash Disk, and GPS. Our CharmIT™ consisted of a Jumptec Pentium 266 Mhz core board, an on-board 10/100 Ethernet, USB and SVGA, PCMCIA cards, power conversion/distribution board, two Sony NP-F960 batteries with approximately 5.5 hours runtime each, a customizable, lightweight aluminum case, and cables and connectors.

Input and output devices were added to the core system. For text input, we use the Twiddler2, a one-handed keyer. With only 18 keys, the Twiddler2 keyboard is designed to perform all functions of a full, 101-key keyboard by "chording". Just like playing a musical instrument, this requires the user to press multiple keys to produce specific letters and numbers. It takes some time to become proficient, but with practice the user can reach 35 words-per-minute. Despite the learning curve, the Twiddler2 has the unique advantage of leaving one hand free while typing, and it does not require a device driver. A thumb-driven mouse is included.

The primary output device is a miniature visual display. As display products became smaller and the increased information content was compressed, the demands on the display size and resolution increased dramatically. On a handheld display with a typical width of 5-10 mm, the pixels for SVGA (Super Video Graphics Array) resolution cannot be resolved by the human eye. This means that additional pixels, the power involved in processing and presenting the information, and the additional cost for the device are wasted. The UCSB wearable system therefore chose a MicroOptical display. The company offers two color monocular (320x240)

displays, a clip-on display and an integrated eyeglass display that magnifies the image displayed and, therefore, provides for a range of resolutions. The eyepiece of the clip-on display is suspended from a clear support and provides minimum occlusion by allowing a vision around all four sides of the virtual image. The display clips onto the user's eyewear frame and allows the user to wear prescription or other preferred eyewear, whereas the integrated system, being a complete eyewear system, may require a custom fit. The integrated system is the least obtrusive, but because the clip-on version is more flexible, we decided to exploit a clip-on version in our prototype system and leave the integrated approach for future consideration.

While we chose a monocular display, a promising new technology for a wearable augmented reality is the retinal scanning technique distributed by MicroVision. A very low power light source creates and conveys a single pixel at a time through the pupil to the retina. With color images, red, green, and blue light sources are modulated and then merged to produce a pixel of the appropriate color. Horizontal and vertical scanners "paint" an image on the eye by rapidly moving the light source across and down the retina, in a raster pattern. Refractive and reflective optical elements project the scanning beam of light into the viewer's eye through the viewer's pupil and onto the retina to create a large virtual image. The display does not block the user's view but instead superimposes a high-contrast image on top of the "real world" view. Because the user can see through the image, the display quality is pleasant for the eye. However, at this point the device is heavy and bulky and does not meet the expectations of an unobtrusive HMD. Once the size, the weight and the color range (wearable display at this time is monochrome red) can be improved, the retinal display has a great potential for the development of augmented reality for mapping applications.

Power management is a one of the most crucial considerations when designing a wearable system. The power consumption of a system depends on many factors, including system capacity, the operating system employed, board and modules used, and the physical environment that the unit is exposed to. There is a trade-off between the size, weight and power capacity of a battery. Rechargeable lithium iron batteries have been the standard for wearable systems. Environmental energy sources may replace batteries in wearable subsystems and some innovative alternative sources are envisioned. Storage devices for wearable systems are magnetic hard drives, PCMCIA hard drives, flash memory, and external storage such as a USB hard drive. Many wearable computers make connections vulnerable. The clothing industry has accepted the goal to integrate computers into washable vests, coats, jewelry, and accessories. Fabrics used for clothing can mix conductive fibers and regular fabric and can be fashioned to suite wearable systems. When positional devices are considered, ubiquitous mobile networking offers many new possibilities for GPS technology. Because of the future requirement for cell phone companies to be able to physically locate callers to 911, and because of GPS receiver miniaturization, GPS receivers are expected in mainstream cell phones in the very near future. This development suits wearable design and this tendency is reflected in several GPS receivers and embedded GPS modules. Integrated GPS units make it unnecessary to carry an external antenna. Since selective availability has been disabled, the accuracy of civilian-class GPS is adequate for most sea and land navigation, and a differential receiver might be needed only for special applications. To provide better orientation in space, the UCSB system uses a fluxgate compass with three-dimensional amplified sensing capability, and measures the users view roll, pitch and yaw continuously.

In summary, the UCSB wearable computer supports both text and GPS input, and augmented reality visual output. Other communications for both data input and forms output are

driven using mobile cellular connections to the world wide web via cellular telephonic connections. Thus the user can know exactly where they are in geographic space, and can interact with and report spatial and attribute information in real time.

A USER INTERFACE FOR A WEARABLE MAPPING SYSTEM

Most desktop computer applications have an explicit user interface that expects the user to specify exactly what the computer is supposed to do. Wearable computers can run standard desktop applications, but this ignores the immense potential for wearables to be more than simply highly portable computers. An augmented reality system generates a composite view that is a combination of the real scene viewed by the user and a virtual scene generated by the computer augmented with additional information. A virtual environment (VE) is defined as a computer generated, interactive, three-dimensional environment in which a person is immersed and it requires high performance computer graphics to provide an adequate level of realism, is interactive, and a user requires real-time response from the system to be able to interact with it in an effective manner. VE can be immersive and non-immersive, yet in wearing a standard HMD the user is immersed in a virtual environment, and the display blocks out the external world and presents to the wearer a view that is under the complete control of the computer. The user is completely immersed in an artificial world and becomes divorced from the real environment. Ubiquitous computing is the opposite of virtual reality. Where virtual reality puts people inside a computer-generated world, ubiquitous computing forces the computer to live and interact with the real world.

The most recent advances in VR technology have offered great potential for map displays. Controllable graphic variables and animations can be used to control the complexity of a map and therefore maximize its efficiency. The map user can dictate the perspective from which the map is viewed and can choose the mode with which to move through the map. Billingham et al. (1998) investigated the usefulness of spatialized information display and categorized augmented reality interfaces on wearable computers into three groups: head-stabilized (no tracking), body-stabilized (orientation tracking, one degree of freedom), and world stabilized (position and orientation tracking) interfaces. In their study, subjects were asked to perform a search task while using these three different interfaces, and the results showed that even simple specialized displays provide benefit over traditional head-stabilized interfaces. There was no significant difference between specialized display with or without head tracking, suggesting that the differences in search performance comes from the spatialization of the information itself.

Most GIS applications have been designed for desktop use and do not meet the needs for wearable use. The desktop Graphical User Interface (GUI) is based on the WIMP (Window Icon Menu Pointer) metaphor and assumes that interaction with the computer is the primary task. In contrast, the user of wearable computer applications is most likely distracted by the environment, and the operation of the computer is not necessarily the primary task because the user is doing something else besides interacting with the computer. Some designs for the mobile ubiquitous GIS user interface are feature frames, three dimensional glyphs, text feature annotation, monochrome feature filters, feature location identification and selection, Internet linkage, haloing, and pointer and navigation aids and mechanisms. Of particular concern in such ubiquitous systems will be data screening or access limitations, and the techniques of pixel blocking as a solution to security and privacy.

A feature frame is the wire-frame equivalent of a three dimensional object. In augmented reality, a realistic depiction is unnecessary, so simplified, stylistic object representations are necessary to outline and draw attention to objects. Three dimensional glyphs are solid objects that depict or carry attribute information about the objects that they symbolize. For example, an extruded polygon can be colored, enlarged and annotated with data about a feature. Text annotation is text that is placed into the augmented reality view that labels or otherwise communicates information about the feature, its name, or its attributes. Feature filters allow augmented reality views to be changed depending on the attributes. For example, features can be shown in black and white on a color image (monochrome feature filter), highlighted with image enhancement such as circles and halos, or pointed to with color or animation.

Navigation can also be significantly enhanced through augmented reality. Users can be pointed to locations, or navigational indicators such as magic carpets and floating arrows can be used as aids. Even a disoriented user can be simply pointed towards the correct target. Similarly, locations can be linked directly to web-based information via web hotlinks.

The nature of wearable systems may place a premium on security, in which case images placed into augmented reality can be changed to enhance reality. Private features can be blacked out, or access to augmented reality can be blocked at the server side. Such systems may become necessary in the future, or in special environments,

CONCLUSION

High mobility and wearable computing constitute a new paradigm for cartography. User interface design is critical, yet current research has little to guide this new field of research. When map creation and use are synonymous, many tried and trusted principles of cartographic design fail. Project Batutta hopes to provide the first advances in the new field of wearable computer mapping, and to demonstrate the utility with the project prototype wearable system.

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