Assessing the Usability of a Wearable Computer System For Outdoor Pedestrian Navigation

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Abstract:
The paper outlines a pilot test on the UCSB Wearable Computer developed in conjunction with Project Battuta. The UCSB Wearable incorporates geographic context information (location and orientation) to display an electronic digital map to a user via a Heads-Up Display (HUD). Features of the custom designed Geographic Referenced Graphic Environment (GEORGE) software allow the user to switch between types of maps, and automatically center and rotate the map. The pilot study used pre and post-experiment questionnaires, performance records and interaction logs to evaluate which aspects of the system were most useful both in terms of user attitudes and objective performance on a navigation task. Zoom, pan and auto-rotate features were shown to be well used, while subjects showed indifference to map type and perspective view options. Performance on the wayfinding task generally improved over each segment of the trial, with subjects approaching normal walking speeds at the end of the trial.

1. Introduction

The purpose of this study is to evaluate the effectiveness of the wearable computing system developed in conjunction with Project Battuta at University of California Santa Barbara (UCSB) on human pedestrian navigation (Clarke 2001). The system (described in detail below) was intended to provide a flexible computing platform in a variety of contexts outside of the office. The system was developed with navigation to novel destinations specifically in mind, and as a result a small Global Positioning System (GPS) unit and digital compass were incorporated into the hardware array to provide geographic context information. In addition, new software (the Geographic Referenced Graphic Environment or GEORGE) was specifically written to incorporate this context information and act as a navigation aid and scaled-down Geographic Information System (GIS).

The UCSB Wearable system combines several features that make it different from other mobile digital map displays. Since the system is worn, interaction with it is somewhat unusual, both in terms of hardware and software. This is by design, since many of the devices and interfaces usually used when interacting with a normal palmtop computer do not apply. This paper presents the result of a pilot study to test the hardware and software system in the context of a navigation task.

We tested three methods to assess whether our system was useful as a navigation assistant to pedestrians. First, we asked subjects to provide quantitative and qualitative feedback to determine what user *attitudes* about the system were. Second, we used objective measures of *performance* to determine how system/user interaction changed over the course of the trial. Finally, we examined logs of system interaction to determine *revealed user preferences* about the system, based on which features users interacted with.

In order to provide context for the experiment, technical information about the system is presented first. Next, we discuss some of the relevant issues in designing electronic map displays for heads-up navigation aids. Finally, we describe the experiment and the results, and discuss the possible implications for further development of navigation-based wearable computers.

2. The UCSB Wearable System

2.1 Hardware

The computer itself is a wearable computer built by Charmit Technologies. It is roughly 6”x5”x2” and weighs about 1.75 pounds. It is a low power consuming PC compatible 800 MHz processor computer with 256 megabytes of random access memory (RAM) and a twenty-gigabyte hard disk. It is powered by lithium-ion batteries, each of which lasts approximately one to three hours, depending on usage. There are two battery connection ports, which enable the user to swap new batteries onto the unit without the need to power-down. There is one PS/2 keyboard/mouse slot, four Universal Serial Bus (USB) ports, two Firewire ports, three standard serial ports, 10/100 Ethernet port, and a Super Video Graphics Adapter (SVGA) port for connection to a display device.

There are currently two devices that provide geographic context information to the system: a GPS unit and a digital compass. Both connect to serial ports and require external power sources. In the case of the UCSB wearable unit, these are wired to the same battery connection devices used for the system as a whole, thus eliminating the need for a separate power source.

The GPS unit is a Garmin GPS 35 TracPak unit, originally designed for use in a car. It offers a maximum capability of sending data at 19200 bits per second (bps) to a serial port. The system is currently configured to provide information at a rate of one location fix every second. The unit provides position information without the aid of a differential correction signal, producing horizontal position accuracy of at least fifteen meters. Observed accuracy during tests was typically within three meters at the study site. The calculated maximum error is recorded in the data log along with position information.

The digital compass is a Honeywell HMR 3000 unit, capable of transmission of 38,400 bps. It is currently configured to send six-hundred directional messages per minute. The accuracy of the orientation information depends on a variety of factors, but is reported to be accurate to within one degree at zero degrees of pitch or roll (Honeywell 1999). Accuracy degrades as pitch and roll decrease, with about two-degree accuracy at 45 degrees of both pitch and roll.

The combination of the GPS unit and compass provides a quite accurate positioning and orientation of a user’s location. The wearable software incorporates this information to provide a digital map that is (optionally) automatically centered and rotated, thus possibly reducing the cognitive load on the person using it for navigation, and enabling enhanced performance on navigation tasks.

Interaction with a wearable computer is somewhat different than interaction with other computers, and hardware input devices must be adjusted to allow for successful and efficient communication from human to machine. Early implementations of the UCSB wearable system used a combination keyboard-mouse called the Twiddler2, but the chorded-keying system proved difficult to learn. An effort was made to keep the input mechanisms as easy to learn as possible, so devices more similar to standard input devices were used in its place.

In place of a typical mouse, a small finger-held trackball-style mouse was used (Figure 1). A trackball controlled by the thumb moves the pointer on the screen, a button located in the "trigger" position acts as one button, and two buttons located by the thumb act as the second button. The symmetrical configuration affords use by either left or right-handed users without mechanical bias for either group. This is particularly useful, not only because any given user may be right or left-handed, but also because depending on the task, users of the system may find it desirable to use the mouse in different hands at different times.

Figure 1: Finger Held Trackball Mouse

In place of a normal keyboard, a condensed, wrist-sized keyboard measuring five by two inches was used. All of the keys found on a normal keyboard are available to the user, although access to some keys requires a combination key to be pressed. This is similar to how the "control," "alt", and "shift" keys work on a normal keyboard. However, given the condensed size, key generation is generally more difficult. For instance, accessing the asterisk (*) character on a normal keyboard can either be done by hitting one key (located on the side numeric keypad attached to most desktop keyboards) or a simple combination (e.g., the "Shift-8" combination on more condensed keyboards like those found on laptops). Although generally intuitive for alpha-numeric entries, the system may become confusing for special characters.

Auditory interaction has also been tested, although not with the software package used in navigation. Initial tests indicate there may be problems with distinguishing user commands from background noise. Development of this method of interaction is ongoing.

The primary output device for the computer is a MicroOptical mono-vision device mounted on a pair of glasses. The display has a 16 degree horizontal field of view, and has a 640x480 pixel resolution at 24-bit (16 million colors) color depth. It is powered by its own battery, which connects to a box measuring 4x3x1.5 inches. The display can be configured to display on the right or left eye of the user, depending on preference. A counterweight roughly equal to that of the display (~40 grams) is also attached to the glasses for the sake of balance and comfort.

Building the system not only included technical challenges associated with hardware and software development, but also concerns of making the system sufficiently streamlined and comfortable to wear, while maintaining its functionality. The current design is built into a fisherman-type utility vest. The computer and batteries fit into a large pocket located in the small of the back. The cable of the mouse is threaded through the vest and out one of the sleeves, depending on the preference of the user. The keyboard is connected in the same way, and is attached to the wrist indicated by the preference of the user. The GPS and digital compass are mounted on the left and right shoulder of the vest, respectively. The display is threaded through the vest and stored in a front breast pocket when not in use. Figure 2 shows a version of the system as configured for the experiment.

Figure 2: The UCSB Wearable System

2.2 Software

The UCSB wearable system is equipped with a dual boot Debian Linux/Windows 2000 Professional Operating System. Windows is the default boot mode, and the only option enabled to the subjects of the study.

The primary software interaction is done via a custom built interface called the Geographic Referenced Graphic Environment (GEORGE). GEORGE is written entirely in Java to allow for platform mobility. It was designed to function both as a navigation aid and a scaled down GIS.

As originally conceived, the system implemented a standard Windows Icons Menus and Pointers (WIMP) interface. Initial testing on the system showed substantial difficulty because the small text usually found on menu bars was nearly impossible to read with the MicroOptical display and fine pointer movement required for control of the system proved difficult.

As a result, the interface was completely redesigned with these difficulties in mind. The chosen model was that of Nakamura et al. (2001), who had experimented with interfaces dominated by a central ellipse that acted as a display and a periphery containing menu choices. Nakamura's model used icons placed around the edge of the ellipse as menu selections, but the GEORGE system was modified such that there are eight basic zones of interaction. These are highlighted by Figure 3, which shows the GEORGE screen in full menu-mode, where no map display is visible and the entire screen is devoted to displaying menu options.

The mouse can be used to interact with each zone by dragging the pointer to it and pressing the "trigger" button on the mouse. The keyboard can also be used, since each zone can be assigned a key to allow for more rapid menu traversal.

The software incorporated several features thought likely to improve navigation performance. These include pan, zoom, map rotation, perspective view (depth rotation of images), egocentric map cropping, destination marking, and toggles between maps within the same area. Map display currently is done via georeferenced raster image files of any of the common formats (e.g., gif, jpg, tif). Figure 4 shows the display as it might appear during use. The map has been automatically track-up aligned, panned to the right, and depth rotated (perspective view). The user's position is marked with a red dot on a generalized map.

Part of the GEORGE program includes a logging function that records position and orientation information each second, and menu selections as they occur. This logging function is consistent with many of the criteria described for wearable field testing by Lyons and Starner (2001). As a result, it is possible to reconstruct the GEORGE screen for any point during its past use. These logs were used to evaluate subject performance and use of the system after subject testing.

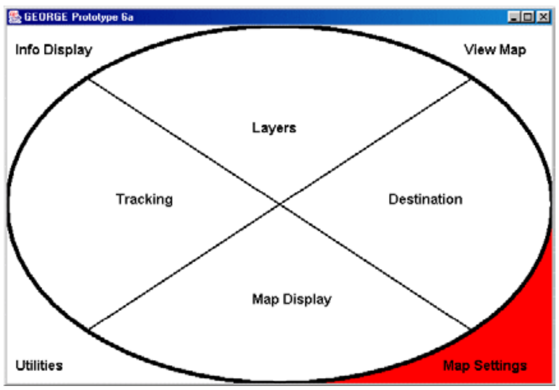

Figure 3: GEORGE menu structure

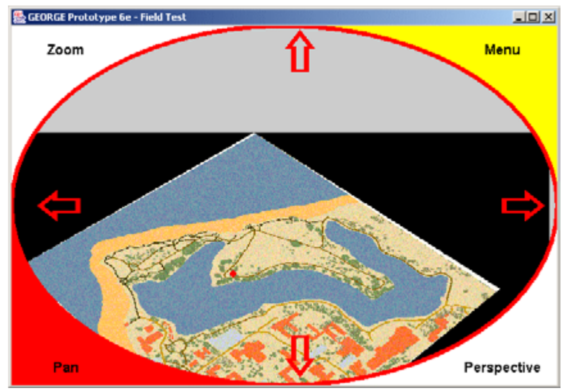

Figure 4: GEORGE map display

3. Navigation With Wearable Computers and Electronic Maps

The UCSB Wearable System was developed (and continues to be developed) with an eye towards understanding the role of cognition in navigation and human computer interaction (Clarke et al. 2003). In this case, there are two broad categories of cognitive processes at work. The first include the general cognitive demands of navigation. The second include the cognitive demands of interacting with a computer. Although the system was intended in part to reduce the cognitive demands of humans during navigation, it is fully realized that the additional demands of interacting with a computer while moving may result in a net increase of cognitive load, actually slowing down the user and reducing navigation performance. Design principles that tend to make interaction with the computer as easy and intuitive as possible should help reduce the cognitive load on the user and increase the effectiveness of the system as a whole. A look at some of the lessons learned from past research and their applicability to the design of the UCSB wearable system is important before proceeding to the experimental design.

The task of navigation combines the cognitive functions associated with locomotion with those of wayfinding (Montello 2005). Wayfinding is usually associated with purposeful movement to a distal site (Allen 1999). Although humans are able to move purposefully towards a goal without external aids, they do so much more efficiently by using landmarks and by building cognitive maps. Physical maps reduce cognitive load in part by obviating the need for detailed memory and recall functions. In doing so, however, they can introduce new cognitive demands. Maps are useful to the extent that they reduce more cognitive load than they introduce. Maps are arguably most useful when they express knowledge that is beyond the experience of the map-reader by illustrating things about a known area that they cannot perceive directly (in the case of variable band remotely sensed images) or by providing information on an area that has never been directly experienced by the map-reader.

Geographic Information Systems (GIS) (and to a limited extent their analog predecessors) allow maps to be dynamic – allowing for the first time a user to add and subtract features of interest within an area. The electronic nature of the maps and displays added new complications. Zoom and panning functions, for instance, are crucial to any GIS software because (with most maps) only a small amount of the map can be displayed on the screen at any one time. Electronic maps specifically for navigation add a further wrinkle – when orienting a paper map, users must rotate the map to align it. Misalignment of physical maps (e.g., "You Are Here" maps) has been shown to significantly increase the difficulty of the navigation task and increase cognitive load (Levine 1982; Shepard and Hurwitz 1984).

Integrated context devices like GPS units and electronic compasses may be of tremendous aid in helping users navigate by automatically performing the sometimes-difficult tasks of locating a position on the map by automatically aligning it to a user's current course or heading. So long as the direction the user is looking (the heading) is the same as the direction the user is going (the course) the map will be aligned correctly (i.e., to the user's view) by the GPS alone. The addition of the digital compass allows the heading and course to be different, and software can adjust the alignment of the map based on the users preference. In some cases, however, an auto-alignment feature of a digital map has been shown to actually make some navigation-related tasks more difficult (Aretz 1991).

A feature currently being tested on a number of different wearable navigation systems is that of perspective viewing (Piekarski and Hepworth 1999; Suomela, Roimela, and Lehikoinen 2003). Perspective viewing allows the digital map to appear as if it being held horizontally in front of the user rather than vertically. This placement reduces the dependence on the Up-as-Forward mapping often used when reader-aligned "You-Are-Here" maps are displayed on walls and when auto-rotated maps are displayed on a vertical computer screen. How, exactly, the apparent alignment of a digital map in the axis of depth might impact map cognition and navigation is still undetermined. The perspective implementation of Suomela et al. (*ibid.*) did not outperform the standard (2D) display implementation for navigational trials in limited user testing. Much work remains in determining optimal perspective views that are at suitable simulated viewpoint height and angles.

Interaction with computer software also places cognitive demands on the user. Although most people in the United States have interacted with computers at some level (given their ubiquity) systems still present challenges to novice users. Software based on previous experience can help to decrease learning time. An example of this approach is the development of the Windows, Icons, Menus, and Pointers (WIMP) interface. Shared visual objects (e.g., the menu bar at the top of most software) quickly cue users as to how they should interact with the system. Further standards for software interfaces similarly ease interaction and reduce cognitive demands by reinforcing experience with consistent outcomes.

In addition to standardization, cognitive demands on the user can be reduced by using intelligent design principles. A prime example of this approach is the employment of metaphor in interface design. The "desktop" metaphor, for example, that employs familiar items like "folders" and "files" helped to aid the adoption of computers into the workplace. Rather than learn how the things called "files" and "folders" work, users simply think of them *as if they were* files and folders, and ignore the differences. Another example of an attempt to reduce the cognitive load on the user is the incorporation of graphics into interface design (Bertin 1983). Graphics can encode a great deal of information within a small space – a valuable asset when space in the visual field is as limited as it is on a computer screen.

It is unclear what metaphor, if any, is as adequate for mobile computing as the desktop metaphor was for office computing. This is partly due to the wide variety of input and output devices, but mostly due to the varied ways in which mobile computers can be used. One attempt to develop a metaphor for wearable is that of using the computer-as-clothing by Lehikoinen (2001; 2002). Physical locations on the body (possibly real pockets, but potentially any location) can be touched, activating the corresponding "Virtual Pocket" and its contents. This system of metaphor taps in to the individual's current storage scheme for physical objects and turns it into a mental scheme for remembering where digital information is stored on the computer.

The menu structure of GEORGE does not attempt to invent or apply any unique metaphor that governs its use. The structure was developed after initial testing showed limitations in interaction unique to our system (Clarke, et al. 2002; Nuernberger 2003). In response to the small visual field, we increased font sizes on menus. We also decreased the number of interaction zones to eight as a result of limitations of fine pointer movement. In order to accommodate a number of different user requests, the menu structure was flattened so that all options are placed no deeper than four interactions from any point. We also attempted to use intelligent color-coding in the menu design to provide strong visual cues to the user.

One very important aspect of the use of digital maps for navigation arises when Heads Up Displays (HUDs) are used as part of the wearable navigation system. Wearable systems differ strongly from other mobile map displays because most wearable systems are developed to work with computer displays that appear right before the user's eye. These HUDs (sometimes appearing under the name Head Mounted Displays or HMDs) allow for the overlay of computer provided information right over (or augmenting) what the user sees in the real world (Wickens and Long 1995). When such a system is also equipped with geographic context sensing devices (e.g., a GPS and digital compass) the system can display pertinent information about what the user is looking at without the user having to specifically request it. Ideally, geographic-context-aware and HUD-equipped wearable computers allow a user to perform navigation tasks better than if he or she would have to continually look down at a display held in the hand and then mentally complete the overlay. In practice, the use of HUDs imparts its own costs, including cognitive tunneling and the problem of visual clutter (Wickens and Long 1995; Yeh and Wickens 2001; Yeh et al. 2003).

Other navigation-enabled wearable systems using HUDs are being developed. The U.S. Army is developing one such system for use on the battlefield. The Land Warrior System is designed to provide a variety of support, including voice communication, vision/targeting enchancement, and other tactical intelligence features (National Research Council 1997). This system has a variety of unique development issues. Soldiers, for instance, have a wide variety of other stressors that are unlikely to be experienced by other navigators. A primary objective of the Land Warrior System is to enhance battlefield situational awareness (*ibid.*). The information delivered via the HUD needs to be balanced by other potentially very important contextual events taking place in the real world.

Various features of the wearable system developed by Suomela, Lehikoinen and colleagues (Suomela and Lehikoinen, 2000; Suomela, Roimela and Lehikoinen 2003) have already been discussed. As a whole, their system provides a number of unique hardware and software interface options. One important difference between the system presented here and that of Suomela and Lehikoinen, is that they chose to build their navigation system around vector instead of raster based maps. Vector map based systems often have improved map redrawing rates as opposed to raster-based system. They also, in general, provide less detail as compared to high-resolution georeferenced raster images. The question of which characteristics are optimal for mobile digital maps remains open, and there is likely a great deal of individual and task-specific variation so that no single type of map is better overall. Wearable navigation systems should take this into account and provide flexibility in supported map formats without overwhelming the user with choices.

3. Methods

The evaluation of the system described below was intended to address how the UCSB Wearable System, as a whole, affected and enabled completion of an outdoor navigation task to novel destinations. We specifically wanted to 1) gather information about users perceptions of and experiences with the system, including perceived usefulness, comfort, and ease of use; 2) test how subjects' interaction with the system changed over the course of the trial; and 3) determine what recorded logs of interaction with the system would reveal about preferences for map display. This information was gathered with the ultimate goal of further refinement of both the testing conditions and the wearable system and software in mind.

3.1 Subjects

Six volunteer subjects participated in this pilot study. Subjects were between the ages of 23 and 32. Four were men, two were women.

3.2 Task

In order to determine how well the system provides support for outdoor navigation, a task was devised in which subjects would use the system to locate four waypoints marked on the visual display of the wearable system with blue dots with a width of eight pixels. Subjects were given a tutorial on the system (roughly twenty minutes) during which they were exposed to the locations of the waypoints, allowed to navigation the GEORGE menu structure and given a chance to try each function of the system. These functions included panning, zooming, changing the apparent perspective of the image, automatic, manual, and north-up alignment of the map, and switching between orthographic photograph (orthophoto) and generalized map views. Each function (with the exception of the north-up orientation which was only accessible via the keyboard) had an option for selection within the menu structure and via a "hotkey" on the keyboard that would activate that feature. Eight keys on the keyboard were exclusively devoted to activating one of the corresponding eight sections of the user interface, allowing the menu to be navigated exclusively with the mouse or the keyboard, depending on the preference of the user.

Subjects were free to navigate to each of the four waypoints in any order they wished, and then to return to the start site. Waypoints were physically marked with a short (.5m) wooden stake topped with orange flagging tape to facilitate visual acquisition of the target. Waypoints were spaced at varying distances over the study site, with an average distance of 170m between markers. No marker was visible from any other.

3.3 Data Collected

Immediately prior to the task, subjects took the fifteen-question Santa Barbara Sense Of Direction (SBSOD) scale test developed by Hegarty et al. (2002). This questionnaire was shown to act as a reliable metric in the assessment of general environmental spatial ability. It was administered prior to the test to account for possible impacts on performance of the navigation task.

The GEORGE software was programmed with a logging function that enables capture of location, orientation, and program interactions. The position and orientation of each subject was recorded once per second throughout the instruction phase and the trial, along with calculated Dilution of Precision (DOP) values for the GPS. Interactions with the program were also logged, as was the mode of interaction (i.e., mouse or keyboard).

Following the completion of the trial, each subject read thirty statements relating to their experience with the wearable unit during the trial. Each participant then indicated his or her level of agreement with the statement by circling a number between one and seven, drawn on a scale, and corresponding to "Strongly Agree" (1), "Neither Agree Nor Disagree" (4) and "Strongly Disagree" (7) respectively[1]. This questionnaire also included eight open answer questions in order to solicit recommendations about development of features, reasons for stopping, experience at the study site, and general evaluation of the system.

4. Results and Analysis

The results of the pilot study are presented below. First, several important user responses about the perceived usefulness of the wearable computer as a navigation aid are presented. Second, we present the evolution of usage patterns over the course of the trial and highlight some significant trends. Finally, we show the aggregate "revealed preferences" of the subjects for various system features.

4.1 User Response

We examined average scores of the users' responses to see if there were general trends in agreement or disagreement with the statements (strong feelings one way or the other showing up as mean scores closer to 1 or 7) and to see how broad the consensus about the issue was (represented by the standard deviation of the mean score).

To begin broadly, there was strong agreement with two statements asking about the usefulness of the system as a whole ($\bar{x}$ =2.08, SD=1.51). Various methods of interacting with the map were specifically asked about. Zooming was rated quite highly ($\bar{x}$ =1.50, SD=1.22) as useful, but other map interactions were not. Panning was rated slightly better than neutral ($\bar{x}$ =2.67, SD=1.86), but the Perspective View feature tended to be regarded as not useful ($\bar{x}$ =5.50, SD=1.64). The automatic rotation feature was rated more useful than not but there was not great agreement on the issue ($\bar{x}$ =2.5, SD=2.07). Similarly the manual rotate feature was rated not very useful ($\bar{x}$ =5.00, SD=1.55), but with slightly more agreement.

Several questions attempted to gather information about users' perception of how easy or difficult it was to interact with the system. When asked whether the system was difficult to use, most people indicated that it was not ($\bar{x}$ =6.55, SD=0.55), although questions about particular features showed some particular problems. Users responded with ambiguity about whether the

[1] One subject received a five-point rather than a seven-point scale. Values "2" and "4" of this scale (between "Strongly Dis/Agree" and "Neither Agree Nor Disagree") were recoded "2.5" and "5.5" on the seven point scale for analysis.

display strained their eyes ($\bar{x}$ =3.67, SD=1.63). Most did not find the menu structure confusing ($\bar{x}$ =5.83, SD=1.83) and most did not report difficulty in finding the features that they wanted to use ($\bar{x}$ =6.50, SD=0.84). Many noted difficulty with the colors on the map display, both in their quantitative response ($\bar{x}$ =5.83, SD=1.94) and well as the open answer questions.

Subjects indicated that both the keyboard and mouse were useful for them during the navigation task, with the mouse ($\bar{x}$ =2.00, SD=1.67) rated slightly more useful than the keyboard ($\bar{x}$ =2.25, SD=1.60). Subjects indicated that they usually used the mouse rather than the keyboard ($\bar{x}$ =1.67, SD=1.21).

4.2 Objective Performance and Evolution of Usage Patterns

Since each subject was instructed to locate four waypoints and then return to the point of origin, the experiment included five segments in each individual's trial. Due to hardware malfunctions early in the trial, three datasets were incomplete. Even so, we were able to get indications about how usage of the system varied throughout the test.

Figures 5 through 7 are scatterplots and linear regression fits for average walking speed and number of interactions (i.e., key presses or mouse clicks) over each segment. Figure 8 shows the number of stops made by the subject over the number of interactions with the system.

Analysis of speed over segment (Figure 5) showed a positive, statistically significant relationship ($r=.60$, $t(22)=3.54$, $p=.002$). Stops were not well associated with progression along segments ($r=-.19$, $t(21)=.89$, $p=.38$). This finding was supported by the open-answer portion of the post-test questionnaire: many individuals, when asked why they stopped during the trial, reported stopping to reorient themselves, but also to adjust clothing, adjust for weather conditions, and a variety of other reasons not well-connected with either the task or the wearable system.

Interactions tended to decrease over the course of the experiment, although the relationship was slightly complex than the others. Figure 6 shows data for all participants. The relationship is negative and approached significance ($r=-.37$, $t(21)=1.87$, $p=.08$), but the fit is weak ($R^2=.14$, $F(1,21)=3.48$, $p=.08$). Part of this, we believe, is due to the technical difficulties with the system noted above. When observations from subjects that experienced these difficulties are removed, the relationship between number of interactions and segment number is much stronger ($r=-.61$, $t(13)=2.79$, $p=.02$). Figure 7 shows the scatterplot and linear regression fit for these data.

Two of the objective measures of performance were highly correlated with reported environmental spatial ability. SBSOD score and average walking speed had a good correlation that approached significance ($r=.70$, $t(4)=1.94$, $p=.12$). SBSOD score and average interactions per segment were even more highly correlated and did reach significance ($r=.84$, $t(4)=3.11$, $p=.04$). Some of this is likely accounted for by gender effects (sex and average walking speed were correlated $r=.88$, $t(4)=3.77$, $p=.02$), but the small sample size and composition preclude assessment of this issue.

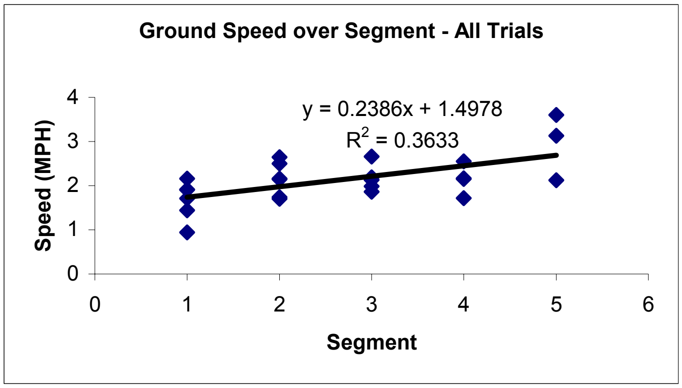

Figure 5

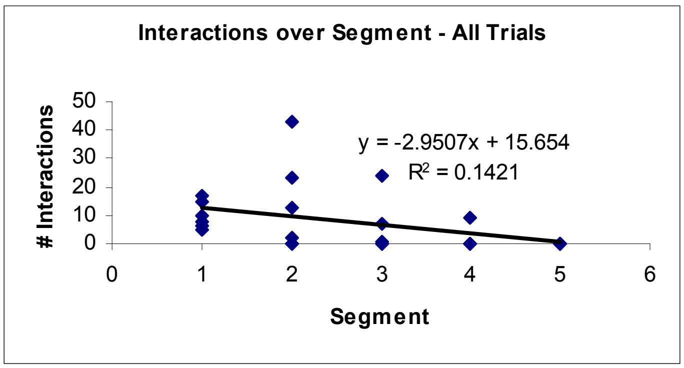

Figure 6

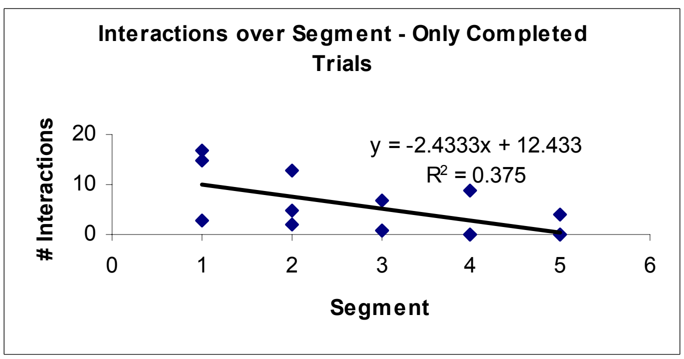

Figure 7

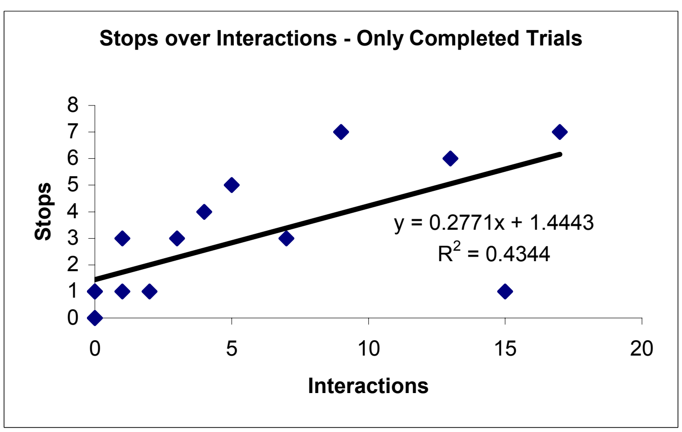

Figure 8

Figure 8 shows a scatterplot of number of stops over number of interactions. Although the stops were negatively (but not statistically significantly) correlated with segment number, there was a strong relationship between stops and interactions ($r=.66$, $t(13)=3.16$, $p=.008$) for the three trials that reached completion. This provides evidence that interaction with the system was significantly taxing enough that users, at times, felt the need to stop in order to concentrate. These results are not conclusive, but rather point to the need for further research, and establish the necessity of analyzing stops *and* interactions in determining the efficacy and usefulness of a wearable navigation unit.

4.3 Revealed Preferences

While there was some variation in the way individuals used the system, some patterns were very distinct. The zoom feature was the most used (50.8% of 183 total interactions), followed by panning (23.5%) and then menu interaction (23.5%). All other interactions totaled 4.4%. Two of the subjects interacted with the system exclusively via the zoom. These results were consistent with the subjects' own responses about how useful they found the zoom, panning, and menu aspects of the system.

All subjects used the autorotation feature of the map either exclusively or nearly exclusively. Greater than 99.9% of all time during the trial was spent with the autorotation on. Only one subject tried the manual rotate feature, and that subject quickly turned the automatic rotation back on almost immediately. Again, this result tended to correspond to the answers given by the participants in the questionnaire.

Subjects did not generally change between the orthophoto and the generalized map. Only one subject changed to the vector map during the trial, and that subject reselected the orthophoto after twenty-five seconds. No subjects interacted with the perspective view feature.

Subject overwhelmingly used the mouse for interaction rather than the keyboard. Despite the fact that the keyboard took less physical effort than the mouse to use, the mouse was for 97.8% of all (183) interactions. The aggregate pattern was generally true of all individuals as well. Four users used the mouse exclusively, one used it 97% of the time, and one used it 67% of the time (4 out of 6 total interactions).

5. Discussion

These results have several implications. First, there is strong evidence that the system introduces a significant amount of cognitive load on the user, despite the fact that it simplifies in many ways the task of navigation. Average walking speed ranges from 2.8 to 3.4 miles per hour (Boles 1981). Only during the last segment, where subjects were returning to a known point over recently traveled ground, did the average speed fall into this range ($\bar{x}$ =2.95 MPH). The increase in speed over the course of the trial represents the learning curve for the system. When judging whether the system is an effective aid to navigation, we assert that the most effective navigation assistant would allow the user to walk at the same speed to an unfamiliar destination as to a familiar one. From this perspective, the UCSB Wearable System is likely still short of that goal.

Several features that were included in the software that were posited to be potential aids to navigation went unused. It may be that these features were considered not useful, or it may be that users felt the other features were good enough for the task at hand. It may also be that users forgot about those features (which is unlikely, since the perspective feature controls, for instance, were on the same menu as those for the zoom and pan features), or that users were overwhelmed with the choices that they had. Even with the varied methods employed in this experiment, it is difficult to say definitively the reason for their disuse. This issue taps in to the larger issue of optimizing versus satisficing behavior. The subjects were not instructed to be efficient; indeed even if they were, there are a variety of factors on which subjects could try to optimize – speed, distance traveled, minimum use of the system, and so on. These results indicate that one can more effectively gauge usefulness of a feature (based on questionnaires and menu interaction logs) than one can gauge how unsuitable a given feature is.

Display-related difficulties appear to be a large reason for difficulty in using the system. Some of the research being done on other mobile electronic map displays (e.g., Dillemuth 2005) will likely carry over and apply to wearable computers with HUDs. The results of this study raise issues about how important color maps are to various navigation tasks. Since many subjects complained of problems locating the waypoint markers on the electronic displays, one possible option is to simply change the colors. However the shifting color patterns on the map (as the map rotates) mean that no single color or pattern is likely to stand out all of the time. Adaptive cartographic representations that are tuned to the background may be one option, but the cognitive load involved in tracking changing symbols may actually add to the net difficulty in locating features on a map.

In choosing three different methods of evaluation for usefulness, we were able to provide a better picture than any one method would have shown alone. For instance, while users overwhelmingly *used* the mouse rather than the keyboard, they also indicated that both were *useful* in completing the navigation task. This essentially means that features that are not perceived to be useful will probably not be used (as was the case with the perspective view) but features that are useful may or may not be used.

6. Conclusions and Future Work

Given the wide variety of hardware and software options combined with the range of user preferences and spatial abilities, no one feature, display, or component is likely to be definitively optimal. Nevertheless, research on wearable navigation aids using digital maps may provide general trends in the usefulness of elements that can result in better automation of tasks, better human understanding of information, and ultimately provide humans with better navigation support. This research shows that users prefer zooming, panning, and auto-rotation options, and raises questions about what methodologies can provide information about features that go unused.

Future work with UCSB Wearable will include continued development of the hardware and software. We plan to increase the processing and memory capacity of the unit to allow for faster image processing times, and to continue to investigate interaction modality options, especially voice and audio interaction. The software will be revised and rewritten to take advantage of new java image processing functions to allow for faster redrawing of the map.

One important area in the development of such systems is in identifying deficiencies of the system that contribute to lowered navigation performance. Much harder is in developing and testing entirely new mobile dynamic design principles for map display. Even so, the outlook is good; human computer interaction, human factors design, and navigation and cartographic cognition fields are vibrant. The community benefits both from in-depth studies that look at particular features, and studies like the one presented here which investigate whole systems in realistic navigation environments.

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