A Mobile Augmented Reality User Interface for Terrestrial Navigation

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Abstract. To date augmented realities are typically operated in only a small defined area, in the order of a large room. This paper reports on our investigation into expanding augmented realities to the outdoor environment. The project entails providing visual navigation aids to users. A wearable computer system with a see-through display, digital compass, and a differential GPS are used to provide visual cues while performing a standard orienteering task. This paper reports the outcomes of a set of trials using an off the shelf wearable computer, equipped with a custom built navigation software package, "map-in-the-hat."
Keywords: Wearable computers, augmented reality, and GPS

1 Introduction

A new physical form of a portable computer has emerged in the form of a *wearable computer* [Bass, 1995; Bass et al., 1997; Mann, 1996]. Instead of the computer being hand-held, it is attached to the user on a backpack or belt, as illustrated in Figure 1. This is an alternative to traditional pen based computing [MacKenzie et al., 1994; Selker, 1996], leaving the hands free when the computer is in use,

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and also allowing the user to view data in the privacy of a head mounted display (HMD) [Starner et al., 1995]. The application areas for this form of computer range from factory monitoring, stock taking, field data collection, to soldiers in the field.

Fig. 1. See-through display

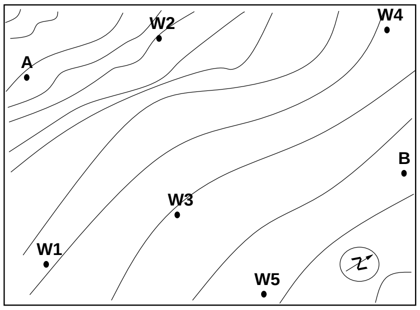


Fig. 2. Example of a paper map

In common with other recent research [S. Feiner, B. MacIntyre, T. Höllerer and A. Webster, 1991], we are investigating the use of a wearable computer with augmented realities in an outdoor environment (WCAROE). We have been working with the Australian Defence Science and Technology Organisation (DSTO) and the Australian Army investigating ways of improving the effectiveness of the dismounted combat soldier. Navigation is a significant task for soldiers. The application we are investigating is the use of such a WCAROE system to support navigational tasks, or as we like to call it, "map-in-the-hat." We are proposing to extend the use of GPS with an augmented reality user interface. A key objective of our work is extending augmented reality systems from room size areas to outdoor environments [Azuma, 1997].

This paper begins with a description of related work and the navigation task, and highlights some problems we wish to overcome. The second section describes the wearable computer system used in the trials. This is followed with a description of the trials we performed with the system and observations obtained from using the system. Finally, we conclude with some observations about our experiences.

2 Related Work

Wearable computers have been used to supply online manuals for maintenance workers [Esposito, 1997], to allow hands free viewing of manuals in awkward locations. Augment reality has been used for Heads Up Displays for aviation, assistance for surgery [State et al., 1996], architecture visualisation [Webster et al., 1996], and maintenance work [Karez et al., 1997]. This augmented reality work can be characterised as requiring precise tracking in small operating regions.

The work presented in this paper breaks from the requirement of precise tracking in small operating regions. A few researchers are investigating large area augmented reality. Most notable is the work of Steven Feiner *et.al.* with *Touring Machine* project. The Touring Machine allows users to walk around the Columbia campus and access information via a tracked see-through display and a hand-held display. The three main themes of the their work are as follows: 1) presenting University contextual information visually connected to the physical world, 2) supporting a relatively large area in which the user is able to walk around in, and 3) combining multiple display and interaction technologies. The work presented in this paper extends this concept to a new application, *terrestrial navigation.*

3 Navigation Task

Navigation is the process which guides movement between two points, and enables the navigator to know exactly where they are at any given time. Navigation involves position finding, direction finding and measuring distance.

A typical navigation task is to navigate from point A to point B through a set of waypoints W1..Wn. Figure 2 shows an example of a topographical map plotting this task with five waypoints (W1..W5). The user starts at position A and initially navigates to position W1. Once the user reaches waypoint W1, the user then navigates to position W2. This process continues until the waypoint W5 is reached. From there, the user navigates to the final position B.

3.1 Position Finding

Position finding is typically done by reference to a map – a scaled plan of a portion of the earth's surface. Since the earth's surface is curved, there is always some distortion on a map, due to the type of projection used. The amount of distortion is usually not significant to a map user. However, if a number of maps are used to travel over a significant distance, issues of the type of projection used and coordinate standard can be important. Position finding is vital for orientation. Maps can be used to locate significant features, from which location can be determined. This can be difficult in close country (such as jungle), featureless country (such as desert), or at night.

3.2 Direction Finding

When planning a route or navigation leg, the distance and direction to the next waypoint must be determined. The direction is usually assessed by use of a magnetic compass. Typically the navigator picks a prominent object (such as a tree) which lies on the magnetic bearing, and walks towards it. Once it is reached, another object which is on the same bearing is selected, and the process is repeated. A feature of this type of navigation is that the bearing path must be followed, even if there are obstacles, since orientation is lost if a different bearing path is taken. This is particularly a problem in close country or at night, when it is difficult to orientate on distant objects. This may result in difficult travelling as obstacles like thick bushes must be walked through rather than avoided.

3.3 Distance

When planning a route, the distances to be travelled between waypoints are determined in case position finding is prevented due to poor feature visibility. When actually navigating, measuring distance can be performed by pacing or time calculations. Pacing is a practical distance measuring technique for people on foot. Each individual has to determine the average number of paces taken to cover 100 metres over varying types of ground. A method of recording paces is also needed, and one method is to tie a knot in a piece of string every one hundred paces. This must then be converted to metres. The number of paces must also be adjusted for the type and slope of terrain. Time can be used to check distance travelled when movement is continuous and does not involve the crossing of many obstacles. This is sometimes referred to as “dead reckoning”; the calculation of distance of travel from the time and average velocity of travel.

3.4 Problems in Traditional Navigation

Navigation using the above means can be quite difficult and requires considerable training and concentration. Time and attention spent on navigation means less attention is paid to the task environment. There are many environments where manual navigation is difficult and error prone. The military attempt to cope with this by sharing the navigation task amongst the team and by training and practice. A novel use of Virtual Reality is for terrain familiarisation in natural environments [Darken and Banker, 1998]; where the user can be train for a particular set of waypoints.

3.5 Global Positioning System

With GPS, the user applies a similar technique to to those traditionally used, except for the addition of accurate positioning information. The user no longer has to decipher their current position from the landmarks plotted against the topographical map or through the use of dead reckoning. The user knows within the accuracy of the GPS their current location, thereby greatly enhancing their ability to plot their current position on a map.

3.6 Automatic Navigation Aids

Automatic navigation aids such as described in this paper can considerably aid the navigator. A significant portion of military field activities involve position situational awareness. As described above, the difficulties encountered with navigation means that navigators are constantly checking position. On a foot patrol this may mean frequent stops, which reduces task performance. Time spent looking at a map and compass is time not spent looking at the environment (e.g. to detect the enemy). Soldiers usually have their hands full carrying a weapon, and so they must pause to check a map or compass. A “head-up” configuration for navigation, provided it does not obscure normal vision, would considerably improve task performance.

There are two current technologies employed to assist in this navigation task; the traditional “map and compass” and the use of GPS. We are proposing to use augmented reality as means of providing a “head-up” user interface to supply navigation information.

4 The Wearable Computer System

The core of the wearable computer system used in our experiments is the Phoenix 2 wearable computer [Phoenix Group,]. This system has been used in previous experiments described in [Thomas et al., 1997; Tyerman and Thomas, 1998], involving comparisons between various types of input devices for wearable computers. Previously, the Phoenix 2 has been used in its belt mounted configuration, which is the computer, and a secondary module containing both a battery and pointing device.

With our current research, the computer system has become a lot more complex, with extra peripherals and more batteries, making it impractical to mount everything comfortably on a belt. Therefore, a backpack was used to allow us to carry all the needed components, see Figure 1. The central computer is Phoenix 2 Wearable Computer (with a Cyrix 486DX2/66 Processor, 32 MB RAM, and a 850 MB 2.5” hard disk drive. The operating system is Slackware Linux v3.3 running kernel version 2.0.30. The GPS system is a Trimble SVeeSix-CM3 GPS Core Module (NMEA-0183 output and RTCM-104 input), a Aztec RDS3000 Differential GPS Receiver Module (RTCM-104 output.) The electronic compass is Precision Navigation TCM2. The Sony PLM-100 dual colour personal LCD monitor is the see-through device. A VGA to NTSC converter board is used due to the Sony display requiring a NTSC signal. The remainder of the section will describe the following components: the GPS module, the differential GPS module, compass module, the video system, and the power supply.

GPS Module The GPS module is a receiver which uses the 24 NAVSTAR satellites installed by the US Department of Defence, allowing units to accurately determine their position on the Earth. The module contains an onboard microprocessor which computes position using the carrier waves transmitted by each of the satellites. The coordinates are output to other devices via the RS-232 interface, using the standard NMEA-0183 sentence format.

Unfortunately, the GPS system used by civilian systems has been crippled by the US government (called Selective Availability) to deliver approximately 100 metre accuracy [Dana, 1997]. A much greater accuracy may be achieved using a differential GPS (DGSP) unit. DGPS corrects the purposely inaccurate GPS data to ensure that the position information output by the GPS is accurate to a more acceptable error. To do this, a ground station is accurately surveyed and a GPS receiver is placed at this point. The receiver monitors the GPS satellites and calculates its position using this information. The calculated position does not match the true position due to Selective Availability (SA) and so correction information is calculated which when combined with the GPS data enables the true position to be determined. This correction information is then transmitted via radio (encoded using the standard RTCM-104 format) to interested DGPS units which use this to correct the GPS information they are receiving. Using this method, it is possible to achieve position fixes of around one metre accuracy, but the service used in our research was purchased for five metre accuracy.

Compass Module TCM2 Electronic Compass, which uses a magneto-inductive magnetometer, involves no moving parts. The compass can compute heading, pitch, and roll information. With the compass mounted on the user's head, our navigation system can measure accurate direction information. The compass contains a microprocessor which smoothes the output values, and detects when the values are being distorted by other magnetic fields. The unit outputs data in text format over an RS-232 serial connection. The data contains orientation and magnetic field distortion information. The unit can be controlled using the serial connection to adjust the rate the updates are delivered, and the calibration of the magnetometer.

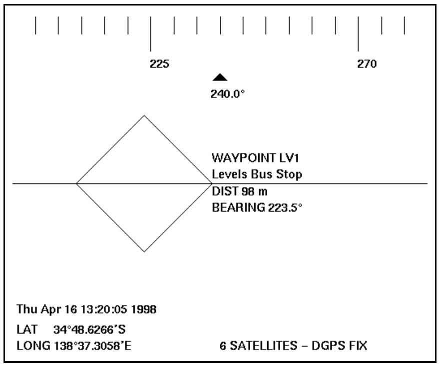
Video System The video output system is based around the Sony PLM-100 display unit, which contains two colour LCD displays mounted on a head brace which holds the display unit in front of the user's eyes, see Figure 1. The unit contains numerous controls which enable the user to adjust the contrast of the screen and the transparency of the background. By adjusting the screen settings, it is possible to see-through the display, and have information projected over the top of the physical world.

The display unit uses an NTSC input, and so a converter is employed to convert the VGA signal from the computer to an NTSC signal. The VGA 640x480 pixel resolution signal is also cropped and scaled to fit on a smaller resolution NTSC display. The actual size of the image used for drawing the head up display is 512x420, as this produced the best image when displayed on the screen; other sizes produced lines with artifacts from the scaling process.

Power Supply The system was powered by a total of three batteries - one 12V for the computer, which lasts approximately three hours, one 7.5V for the Sony display, which lasts about two and a half hours, and a large one kilogram 12V battery to power all the external peripherals. Although the third battery is quite large, it is not very heavy, fits well into the backpack, and runs for long periods (over ten hours of operation) due to its size. One advantage of the backpack is that it allows heavier items to be carried, where normally in a laptop or belt mounted computer the batteries must be very light.

4.1 Software Operation

As described in the introduction, the main purpose of the software is to use the output from the hardware devices, such as the GPS and compass, to produce navigation information which is displayed to the user, see Figure 3.

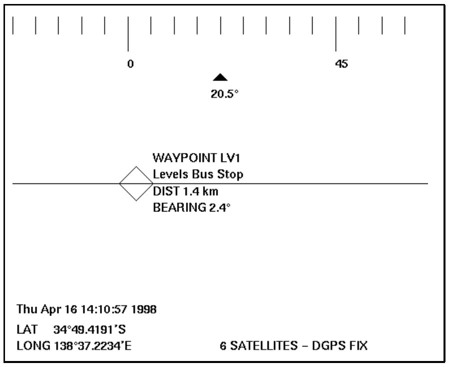


240.0°

WAYPOINT LV1
Levels Bus Stop
DIST 98 m
BEARING 223.5°

Thu Apr 16 13:20:05 1998
LAT 34°48.6266'S
LONG 138°37.3058'E
6 SATELLITES – DGPS FIX

Fig. 3. User's screen view



20.5°

WAYPOINT LV1
Levels Bus Stop
DIST 1.4 km
BEARING 2.4°

Thu Apr 16 14:10:57 1998
LAT 34°49.4191'S
LONG 138°37.2234'E
6 SATELLITES – DGPS FIX

Fig. 4. View of cursor when 1400 meters from the waypoint

To use our system, the user must first enter a list of waypoints in the form of WGS84 latitude and longitude coordinate points. These coordinate points are stored in a data file and are read into the navigation software when it starts up. Once the waypoints have been entered, the user starts the map-in-the-hat program. Keypresses of the characters '>' and '<' change the current waypoint displayed on the screen.

The display shows information such as where the user is located, how many satellites are currently being tracked (at least three are required, but this gives poor accuracy, the GPS unit used will track up to six, which gives the best accuracy), the status of the differential information, and steering instructions to the target.

The compass at the top of the screen shows where the viewer's head is currently pointed, the small triangle underneath with the value indicates the exact direction in degrees true [1]. The diamond on the display represents the waypoint

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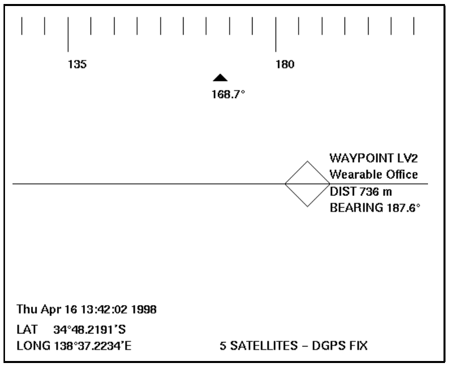
[1] True North is the direction of the shortest global arc that intersects with the axis of the earth's rotation, and Magnetic North points in the direction of the horizontal

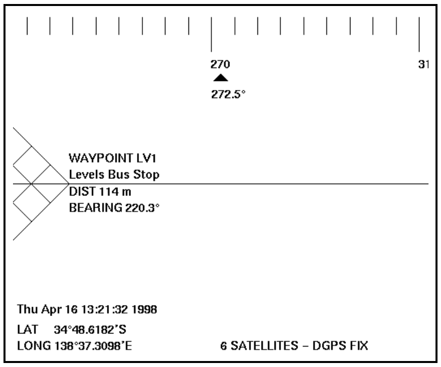
the user is heading towards, and is positioned relative to the compass at the top of the screen; it is meant to approximate where the object would be positioned in the physical world if the user was looking through the display. However, perspective corrections have not been implemented yet and so the diamond will only overlay the target exactly when the user is looking straight at it. To the right of the diamond is information showing the name of the waypoint, a short label for it, and the distance and bearing. When the user is within 1000 meters of the next waypoint, the size of the diamond cursor increases as the user approaches the waypoint. The above figures show diamond cursor size when the user is at the following distances from the waypoint: Figure 4 – 1400 meters, Figure 5 – 700 meters, and Figure 3 – 100 meters.



WAYPOINT LV2
Wearable Office
DIST 736 m
BEARING 187.6°

Thu Apr 16 13:42:02 1998
LAT 34°48.2191'S
LONG 138°37.2234'E
5 SATELLITES – DGPS FIX

Fig. 5. View of cursor when 700 meters from the waypoint



WAYPOINT LV1
Levels Bus Stop
DIST 114 m
BEARING 220.3°

Thu Apr 16 13:21:32 1998
LAT 34°48.6182'S
LONG 138°37.3098'E
6 SATELLITES – DGPS FIX

Fig. 6. View of cursor when bearing is out of view

The bearing information is used to draw the diamond on the screen, and so does not need to be used by the user if they are not comfortable with it. One important feature of the software is that all the information items on the screen may be turned on and off under user control as the program is running, so information which is not required can be removed to unclutter the display.

To walk to the target, the user looks through the display and looks at where the diamond is located. If the diamond is to the left of the display centre, then the user rotates their head to the left until the diamond is centred on the screen. If the direction to the next waypoint is outside the field of view, the diamond cursor is placed on the side of the screen and filled with hash marks, see Figure 6. The side of the screen the cursor is placed on indicates the direction for the user to turn. The display works in a similar way to the head up display used on military aircraft, where a box is placed around the target on the display, and the pilot can fly the plane toward the target by keeping it in the centre of the glass.

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component of the earth's magnetic field at its current location, and not actually to True North.

The bottom left portion of the display shows the current date and time. Under this information is the user's position as a WGS84 latitude and longitude coordinate. The bottom right portion of the display shows the number of GPS satellites in contact with the receiver, and if any differential GPS data is being used.

5 Trials

We performed three field trials of our navigation system to test the system in a realistic outdoor setting. The trials tested three different conditions: waypoints a large distance apart, a large set of waypoints, and waypoints in an urban setting. The waypoints were derived from a series of South Australian Department of Lands survey markers with accurate coordinate information. These survey markers are 20cm square blocks placed in the ground with 1 metre tall poles set next to them. The limitations of the SONY display power consumption forced us to limit the trials to no longer than 2.5 hours each.

5.1 Trial 1 – Long Distances

The first trial was between waypoints a large distance apart with obstacles between them, such as buildings to force us to deviate from the prescribed bearing. This trial included waypoints in Technology Park (a local research industrial park adjacent to our campus), roughly a distance of 1.7 kilometres maximum from the starting position. Because the display has a battery life of only 2.5 hours, this trial only tested a start, middle and end waypoint.

The navigation system provided accurate bearing and distance information to the first waypoint. Deviations while walking were needed to be undertaken to avoid construction works, and the navigation system behaving accordingly. The DGPS signal was lost upon reaching the destination waypoint, thus accuracy was 40 metres. The DGPS signal returned after a few minutes, and the accuracy increased to 15 metres. Two to three minutes of hovering about the target area, increased the accuracy to 2 meters. It was noticed the waypoint diamond cursor jumped around considerably and did not remain fixed in the desired direction when within 20 metres of the target, as we were too close to the target.

The final waypoint for the trial was at a distance of 400 metres and in a westerly direction. There were no obstacles to the waypoint, and as such we did not deviate until 20 metres from location. Once again, accuracy obtained was to 5 metres, within the accuracy of our current GPS.

A second problem we noted was that sometimes the GPS signal would completely disappear in open terrain with no discernible features blocking the signal, but after a moment or two the signal was reacquired.

5.2 Trial 2 – Large Data Set

The second trail was with a more numerous set of waypoints for a navigation task; six waypoints were selected. They were all derived from survey markers and were within a kilometre of each other.

The first three waypoints were within a 30 metre radius of each other. This was to test the system's accuracy. Unfortunately, only 20 metre accuracy was achieved, for all of these points. These points were under a set of high-tension power-lines, and this may have been the cause of the poor accuracy, as the differential GPS signal was carried on a radio signal.

The forth waypoint was 400 meters to the east, and we followed the bearing provided. A nearby fence proved to be an obstacle. Walking alongside the fence for the distance worked, the bearing was then at right angles to the fence, and distance correct, to about 5 metres accuracy.

The next waypoint selected was some distance away along a road. The determined waypoint was 17 metres away from the survey marker. We do not know why this one was so far off, and we are investigating the reason.

Finally, the last waypoint was off to the west with a distance of about 400 metres. Once again we were forced to follow a fence, and we came to within 5 metres distance of the waypoint. As a further test, the first waypoint was tested a second time starting from the final waypoint position, and this time accuracy obtained was within 5 metres. Light tree cover on occasions interfered with the GPS signal, and like the previous day, the signal was lost for a short period of time out in the open with no blocking terrain.

5.3 Trial 3 – Urban Setting

This trial was performed at a location where we were given waypoints we have not seen before. [2] A series of five waypoints were visited, all within 200 metres of each other and in a city environ, walking around the city buildings was used to assess how the GPS would perform in an urban setting. This was not expected to be easy for the GPS.

Initially, no GPS signal was procured due to the buildings and trees prevalent near the university in the city, but three satellites were obtained with a DGPS fix by standing in an open parking lot. We followed the bearing to the first waypoint. The closest distance to the waypoint was 5 metres. The next point was chosen, and found to within 10 metres accuracy.

Waypoint three was much the same as waypoint two observations; the diamond cursor jumped considerably within the final 20 metre radius. Attempts were made to reduce the distance to the waypoint by not following the bearing when closer than 20 metres, but rather by finding the closest distance measurement. The result was an accuracy of 5 metres. Journeying to waypoint 5, the final test for the day, produced an accuracy of 2 metres.

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[2] These were supplied by David Silcock from the School Geoinformatics, Planning and Building at our university.

6 Observations

By using the wearable computer system with map-in-the-hat software, a number of observations were made. They are as follows:

- The digital compass is susceptible to vibrations while walking on rough terrain. Periodically the user needed to stop moving to settle the compass to get proper information.
- The see-through display has a control to adjust the back lighting of the screen; this adjusts how opaque the screen becomes. This turned out to be a very useful feature in changing light conditions. For example, cloudy versus sunny days or walking under trees as opposed to walking in open fields.
- Excessive sunlight is a problem, and obscures the SONY display. Most of the light enters from around the side of the headset.
- The waypoint diamond marker is very hard to see in extremes of bright and low light. We are planning to thicken the waypoint marker to two or three pixels thick, making it much easier to see.
- The waypoint data is attached to the diamond, however this can sometimes clutter the screen, so a decision has been made to place it with the LAT/LONG coordinates, toggling between the two at leisure.
- Increasing the size of the diamond cursor proved to be a subtle but effective cue in determining when the user is becoming closer to a waypoint.
- As with most wearable computer systems, the power management proved to be a major concern of our system.

7 Conclusion

With our system, we have demonstrated a hands free navigational aid to a person navigating on foot. The use of a wearable computer system with a see-through head mounted display provided a functional platform to develop our system. Differential GPS proved to be effective for locating one's position to under 20 metre accuracy, and often with better accuracy.

The map-in-the-hat application provided useful visual cues for the navigation task. Further work is needed to better understand the form and content of the presented information to optimise visual cues. It is a delicate balance that must be maintained between presenting enough information and obscuring the user's view of the physical world.

In future work, we plan to extend the hardware system to allow extra peripherals, such as hand held input devices, to be attached so that the user can interact with the virtual world they are walking around in. The software will also be enhanced so that maps, text information, and other graphics could appear on the display to give the wearer more information.

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