Mobile Situational Visualization: Collaboration in a Geospatial Environment

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Abstract

We present a wearable system, Mobile Sitvis, that provides fast and informative collaboration between multiple users in a virtual environment. Mobile Sitvis allows users to navigate and annotate accurate geographies while increasing awareness of events in the real world by utilizing GPS and orientation tracking, an infrastructure for collaboration among multiple users, and real-time sharing of observations and activity within the environment. We show that it is an effective tool for sharing precise activity and location information with other users and visualizing in the virtual environment events and objects from the real world.

1. Introduction

The war on terrorism has created a multitude of new communication needs where precise and up-to-the-minute space-time information is essential, from informing solders on an Iraqi road about possible ambush sites to tracking suspected terrorists on New York streets. In this paper, we present a wearable system, Mobile Sitvis, for fast, efficient, and informative collaboration and awareness-sharing between mobile clients that is valuable for both military and civilian applications. The growing ubiquity of mobile 3D graphics, GPS positioning, and wireless networking has made new mobile computer applications possible. Our system is useful for gaining awareness about the surrounding environment by sharing activity and location information with other users and visualizing in the virtual environment events and objects from the real world.

Our system is built on top of the Virtual Geographic Information System (VGIS). VGIS is a large, multifaceted virtual environment that allows navigation of and interaction with very large and high resolution, dynamically changing databases while retaining real-time display and interaction [1, 2 & 8]. Mobile Sitvis allows users to navigate accurate geographies (at a resolution of 1 foot or less where needed) with sustained frame rates of 15-20 frames per second. The user can not only see these terrains from any viewing angle but also buildings, roads, high resolution imagery draped on the terrain, and other features. Mobile Sitvis adds GPS and orientation tracking, an infrastructure for collaboration among multiple users, and real-time sharing of observations and activity within the environment. As a result, the user carries a virtual environment that he navigates as he navigates the real environment, where the virtual environment provides a significantly enhanced awareness of important activity around him.

Mobile users are equipped with a 1.8 GHz laptop with nVIDIA GeForce 440 ToGo graphics. The laptop is carried in a backpack and attached to it are a Micro-Optical head mounted display, a Garmin GPS receiver, an InertiaCube2 orientation tracker, a radio, and a Wacom touchpad for interaction (Figure 1).

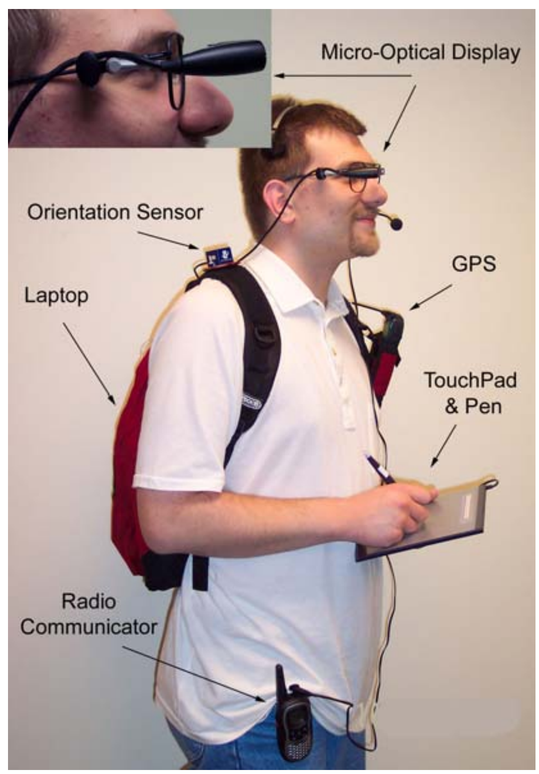

Figure 1 - User with GPS Tracker, Orientation Sensor, Radio, Eye Display, and Touchpad

Users can see their current location and a virtual representation of their surrounding environment through the display while interacting with the system by using a stylus and touchpad. Users can annotate the environment to indicate location, orientation, direction, and speed of other objects such as enemy troops or a criminal fleeing a crime scene. Through the wireless network, all users will be able to see the annotations and locations of their collaborators embedded accurately in the virtual environment, permitting effective joint action and sharing of information.

In this paper we show that Mobile Sitvis is a tool that users can effectively employ as they move around a changing environment and respond to unexpected activity. In evaluations of command and control or surveillance scenarios, Mobile Sitvis proves to be as good as or better than traditional methods. In addition it provides important new capabilities including significantly more accurate location information than GPS alone, specific space-time annotations that can be shared immediately, and other capabilities. The evaluations suggest situations in which Mobile Sitvis can best be used and design considerations for improvements. Our most important result is to show how visualization, accurate spatial models, and shared space-time annotations can be brought together to create a new and effective way for joint action.

2. Prior Work

There hasn't been much work on collaborative mobile virtual environments, especially with visualization as a main component; however, researchers in the field of Augmented Reality (AR) have done work on mobile systems. In "Exploring Mars…" [6], Hollerer et al. present an AR system that employs separate user interfaces to allow indoor and outdoor users to manage and access information that is spatially registered within the real world. Outdoor users are equipped with a differential GPS receiver, a laptop in a backpack, a head-tracked, see-through head mounted display, and a handheld computer. They explore the outdoor environment and can interactively gain information about buildings on campus. Indoor users on a desktop can input paths for outdoor users to follow, update building information, and view an overview of the outdoor user's activities. Their system has some collaborative aspects, however, Hollerer did not have the capability for mobile uses to be aware of each others locations and their environment is limited to their campus, where Mobile Sitvis is a world model, can be used in any location, and has sharing of detailed information among multiple mobile collaborators. Other researchers have also created mobile AR systems. Feiner, Gleue, and Reitmayr [3, 5 & 14] each present a mobile AR system and the hardware and setup of that system. However, these systems do not have annotation and sharing capabilities within an accurate representation of the real world, as Mobile Sitvis does.

In "The Design and Implementation of Pie Menus" [7], Hopkins gives an overview of pie menus: a two-dimensional, circular menu system that is easier to use and faster than conventional linear menus. He discusses the advantages of pie menus over linear menus, the most important being the learning curve of menu positions. Kurtenbach and Buxton extend on the idea of "pie menus" with "marking menus" in a series of papers [11, 12 & 13] that present usability tests and design guidelines for implementing marking menus. They suggest an even number of menu items arranged along the compass directions, mark trails to assist in marking, and a 1/3 second delay before displaying the menu. Tapia and Kurtenbach [15] extend on the design principles of the appearance and behavior of marking menus. Because the current interface for Mobile Sitvis consists of a touchpad and digital pen, marking menus were chosen to be the best fit for our application. They were implemented using the design guidelines presented in the papers above.

3. Server Architecture:

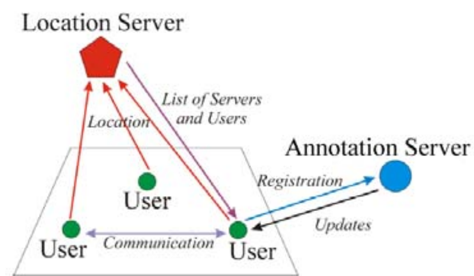

Figure 2 – Server Architecture

Our collaboration infrastructure (Figure 2) was built using ideas presented by David Krum [9&10]. Krum proposed a system of servers that can be used to share information. We have implemented both a location and annotation server, and have plans of adding more servers. The location server collects location information about connected users including their latitude and longitude coordinates, orientation, location uncertainty, as well as accurate offset information to increase location accuracy. The annotation server collects annotations made by users and distributes this data to all other connected users. These annotations include location information as well as heading, speed, uncertainty and object type. Annotations can represent static objects of interest in the environment, mobile objects, or even information and accurate location updates from tracked users. This allows for visual tracking of these objects (cars, people, etc.) that is precise in space and time, and, most importantly, sharing of all of this information in a timely manner.

At Georgia Tech we connect to the network using the wireless local area network (WLAN); however, as with any large wireless network, ours has limitations. Anyone connected to the WLAN will automatically switch between access points while traveling around the campus and may sometimes need to cross areas without network coverage. To alleviate the shortcomings of the WLAN, a confirmation service using a Sliding Window Protocol [4] was implemented on top of UDP, and a script was written for automatically logging onto the network. Mobile Sitvis can detect when the network connection has failed and periodically executes the login script until the connection is reestablished.

4. Mobile Interaction

Interaction with the system is performed using a Wacom touchpad and pen (Figure 3). Three buttons are used for navigation in the 3D virtual environment, while the fourth button is used specifically for mobile interactions, such as creating annotations and waypoints, and setting offsets.

Interaction for mobile users is a difficult task because of the inaccuracies and distractions present in a mobile environment. Interactions must be fast, accurate, and be able to be performed while mobile. In addition, the user must interact with a 3D environment, which includes selecting precise locations in 3D space. For these reasons, we chose not to rely on typical wearable devices, such as the twiddler, for mobile interaction.

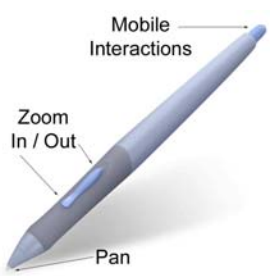

Figure 3 – Pen used for interaction

Since our buttons are used mainly for navigation, we need to perform other interaction tasks through a set of marking menus. We want the system's interaction to be as easy as possible while mobile, and marking menus make the selection task easier than if linear menus are used. A linear menu requires the user to focus on the menu in order to make a selection, and distracts that user from the task at hand, while marking menus allow a user to select an item by moving the cursor outward toward that menu item. Since all items are equally distant from the activation point, any item can be selected quickly with a swift motion. Marking menus also allow a user to make a selection without the menu being immediately displayed. This allows expert users to make selections faster, while still allowing novice users who are not familiar with the menu to wait for the menu to pop up before making a selection (Figure 4). After using a menu over time a user will learn the motion to select a particular menu item and will be able to select it without the menu being displayed. Users can perform 3 types of mobile interactions: navigation, system control tasks, and annotations.

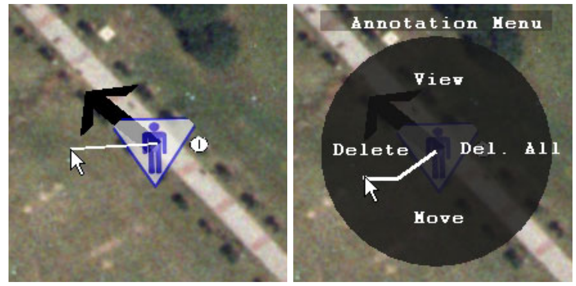

Figure 4 – Marking menu item selection for expert and novice users.

5. System Overview

For our current virtual environment, the Georgia Tech campus and surrounding midtown area, VGIS contains highly detailed terrain and satellite imagery of 1 meter resolution and 3D, textured building models.

When starting the system, users must perform a set of initialization steps using our marking menu interface, including enabling networking and connecting to the desired servers. They must then activate GPS tracking and can optionally specify the system navigation mode to freely navigate or constrain the view to stay over their current location. Since GPS location information can be inaccurate (10 – 20 meters or more), an offset feature has been included to allow users to specify their true location.

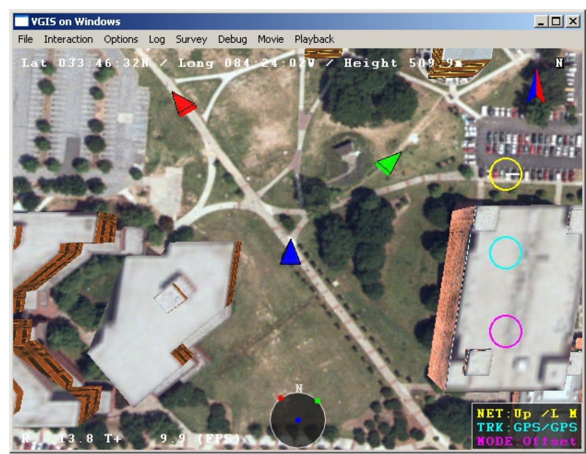

Figure 5 - A view of the current user's (blue) and other users' (red & green) location.

Mobile Sitvis uses a top down (exocentric) view of the virtual environment. In the VE, users will see an icon representing their current locations, and icons representing other connected user's locations. The user's own location is always blue, while other users are each assigned a specific color (Figure 5). The system provides the user with up-to-date system status information (i.e. network connection status, current view, current interaction mode), as well as a radar for quick relative location information of other users (Figure 5). The status box and menu system is color coded so the user can easily tell which menu affects what status information.

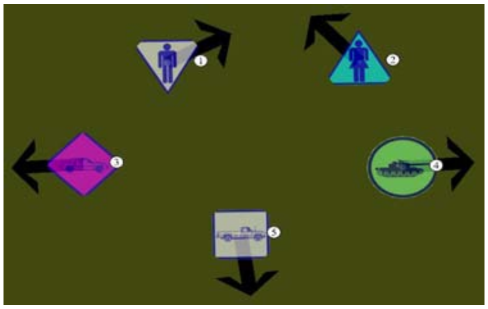

Figure 6 – Annotation Icons

When out in the environment, users will want to mark the location of other objects in the virtual representation. For example, a user might want to convey to other users that there is a tank driving across his field of view. That user could annotate the current location of the tank with a tank icon, and all other users would immediately see that icon appear at the tank's location. Currently, users can annotate five types of objects: male person, female person, car, truck, or tank (Figure 6). For each object annotation, the location, uncertainty in location, direction, velocity, and object type are collected. 3D locations on buildings can also be annotated so, for example, a user can share precisely where an observed person is in a window or on a roof. Through testing we have found that each annotation takes an average of four seconds to create; it is then sent to the annotation server which immediately distributes it to all connected users, within one second of completion. Annotations are colored the same as the creating user's location icon so that it is easy to identify who made the annotation.

Another type of annotation that can be made is a waypoint. Waypoint mode is enabled through a marking menu, and each represents a point in a connected path. This mode is useful when giving other users direction or for setting paths for users to follow. As each waypoint in the path is made, it is immediately distributed to all users, or directed to a specific user (Figure 7).

6. Scenarios

To demonstrate the effectiveness of our system we have developed a couple of collaborative mobile scenarios. These scenarios were constructed for the GT campus and surrounding midtown area, an urban environment that has been accurately modeled within VGIS. Our objective is to show that for each of these scenarios, Mobile Sitvis performs as well as or better than a typical traditional method for accomplishing the same task. In the case of mobile collaboration, the traditional method would be the use of a 2-way radio and a map. We thus compared results for one set of users who used Mobile Sitvis with another set who used maps. In both cases, the users had 2-way radios. In all scenarios the users of Mobile Sitvis has used the system often and could be considered experienced users.

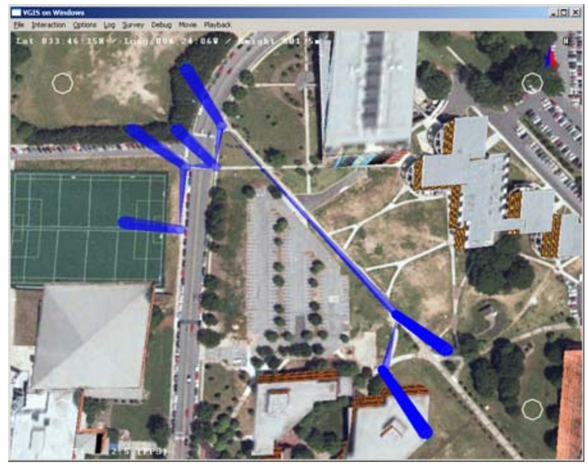

Figure 7 – Waypoint Annotations

6.1 Command and Control

Mobile Sitvis is effective for command and control tasks such as monitoring and issuing orders to units in the field. In this scenario, a commander is positioned at a fixed location with a dependable network connection, where he typically has no line of sight to the outdoor users. Three mobile users are located outdoors with wireless network connections and the commander can communicate with each user through a 2-way radio and through Mobile Sitvis. The task of this scenario is to lay out a set path and have the users follow this path. The paths each had 10 turns, and took about 30 minutes to complete at normal walking speed. Based on several trials, we found our system to be very effective for path following. Waypoints can be created by the commander and transmitted to a selected user, or to all connected users, who are then able to view and walk the entire path. The display of a user's location overlaid on the current path gives immediate feedback to the user that he is following the path correctly and provides real-time feedback to the commander of all users' current location (Figure 8). We compared this with the alternative of using a paper map and the commander's verbal path instructions. A user could follow this path, but not quite as accurately; it also takes a larger cognitive effort to translate verbal commands into real locations (as indicated by the longer time needed to complete the path in this case). Without Mobile Sitvis, the users had to try to communicate back to the commander their current locations and had no quick and precise way of knowing if they were on the correct path. The ability for dynamic path creation and editing in our system is a clear advantage over the traditional method. Another important advantage of Mobile Sitvis is that the commander can oversee several user's paths simultaneously and that mobile users can also see paths of their collaborators (both of which are not possible with the traditional system).

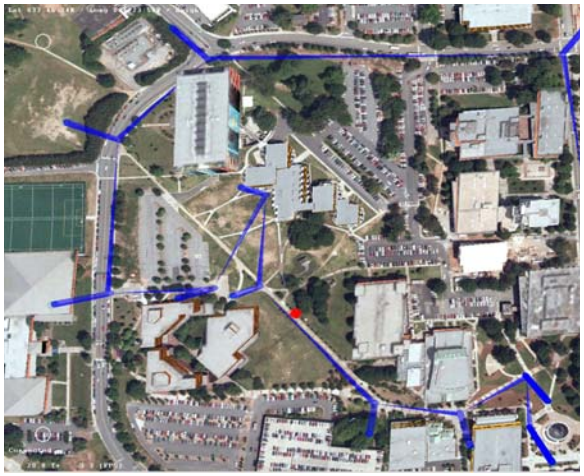

Figure 8 - A commander's view of a user following a path.

Results from one of the trials illustrate several of the above points. A commander sent two users out to follow two separate and unfamiliar paths. The paths were of equal length, started in the same area, diverged, and ended at the same point. Each user walked each path once: one path with only voice communication and a map (GPS enabled for logging and analysis only), then the other path with the Mobile Sitvis system.

After analyzing the logged data, we found that the users were able to stay on the path better, and completed the path faster when using Mobile Sitvis. When using voice commands, one user missed 3 out of 12 waypoints while the other missed 2 out of 12. When using our system, only one of the 24 total waypoints was missed. We believe the display of the path made it easier for users to follow it, and resulted in no misunderstandings about the location of a waypoint. When using the radios, there were some miscommunications, which caused the user to veer off the path and miss a waypoint. There were also periods of time where communication was lost because a user exceeded the range of the radios. This loss of communication made that task take longer than when using Mobile Sitvis resulting in a 2 minute increase in completion time.

6.2 Surveillance and Reconnaissance

The Mobile Sitvis system is a tool well suited for surveillance, reconnaissance, and tracking tasks. To show the effectiveness of the system, we set up a few scenarios consisting of three fully equipped and connected users and one subject. Their job is to keep track of the subject through collaboration by making annotations representing his/her current position. The subject is given a map with a path to follow and carries a GPS and laptop only to log his location information for future analysis. The path for the subject is drawn by a 3rd party, and the users do not know it beforehand. Another scenario consists of the three users carrying the same equipment, but not connected through the system. They log their GPS positions for future analysis, but only use a paper map and radios to communicate. In both scenarios, the subject moved at normal walking speed. Each scenario was rerun several times with several different paths. Each path took about 30 minutes to complete and each was of the same length had about the same number of turns.

Following are our general results. We found our system to be effective for this task; at least two Mobile Sitvis users could keep track of the subject at all times, even though the subject turned unexpectedly and even though they had to divert their attention to make annotations. Although performance, in terms of keeping track of the subject, was not any better (or worse) than tracking with only a paper map and radio, we found that Mobile Sitvis gave a clear additional advantage in terms of accurate information about the location and movement of the subject and of the tracking collaborators, which could immediately be shared with the commander and others.

Using Mobile Sitvis for tracking is a very different experience in comparison to using just a radio, map and a pair of eyes. The biggest advantage gained during tracking is quickly seeing the locations of other users, as well as the tracked subject, who may not be in one's line of sight. In addition, since Mobile Sitvis has a properly orthorectified and interactive representation of the urban scene, a user can quickly determine where the subject is by locating the latest annotation without having to find his own location on a paper map. Furthermore, having the ability to mark subjects and their direction of movement gives more precise information than verbal communication can.

On the other hand, using Mobile Sitvis has its disadvantages in its present configuration. First, the entire mobile set-up is heavy and uncomfortable to wear. Because the user is mobile, the eye display is constantly in motion making it sometimes difficult to focus. Moreover, sunlight can interfere with the display, causing uncomfortable glare. While this can be reduced by covering the display with sunglasses or a patch, we are hesitant to do this because it may limit the user's view of the real world and causes safety concerns. Furthermore, while tracking, the user must pause a few seconds (taking his eyes off the subject) to create an annotation. In addition, infrequent technical problems such as a laptop overheating can interfere with effective use of the system. We are taking steps to alleviate these problems. Better interaction techniques are in the works to enable the user to annotate successfully while in motion. Also, we expect that the laptop will soon be replaced with a much more compact wearable computer that will be just as powerful but will be lighter and produce less heat.

Unlike Mobile Sitvis, tracking with a paper map and a radio requires no knowledge of any software or hardware, and few technical difficulties. The subject location and direction is conveyed through voice communication alone; therefore, it is not necessary to stop moving as one must when making an annotation. In addition, the lack of the eyepiece allows trackers to blend into the environment without generating notice from other pedestrians. Nevertheless, the paper map and radio method has its drawbacks. It is hard to accurately direct another user to a specific location if that user is unfamiliar with the environment, and verbal communication can deteriorate as more users are added into the scenario. Verbal communication is essentially a two-way (or broadcast) medium and does not scale well to multiple collaborators.

In general Mobile Sitvis provides better location information than either standard GPS or voice communication. For example, one has the ability to relocate oneself with other users if lost. To illustrate, during one of our sessions, a user became separated from the group. Even while remaining in contact with the rest of the trackers, the user was temporarily unable to determine where he was in relation to the subject. However, by using the radar feature, which is continuously updated with the other users positions, the lost user was able to immediately tell in which direction his collaborators were located. In addition, the latest position and direction of the tracked subject enabled the lost user to intercept the subject by inferring his likely future path. With a radio it would be difficult for his collaborators to tell the lost user where to go if he is unfamiliar with the area. This problem is heightened since the collaborators are not sure where they are headed either. Finally, the time spent trying to get the lost user back in position could detrimentally affect the quality of tracking. When using Mobile Sitvis, it is only necessary for one user at a time to keep the subject in sight. When not actively tracking, the other users can use the system to rejoin the tracking team or to coordinate in some other way.

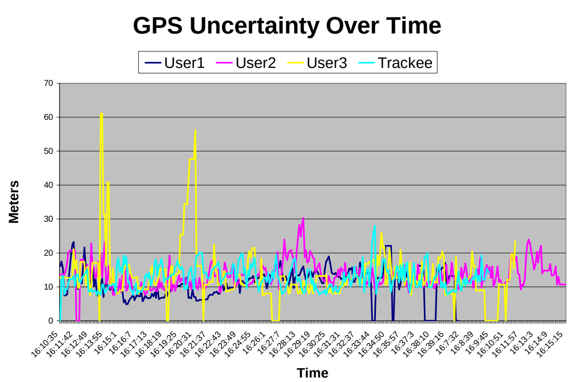

Figure 9 – GPS Uncertainty

Mobile Sitvis is also superior to GPS alone for positional accuracy, as the following shows. With the system, offsets can be set for a more accurate representation of position, and annotations are also logged for later analysis, adding to the quantity and quality of the data that can be stored and shared. If the user has an accurate high resolution virtual model of the urban environment, these offsets are often easy to determine because location relative to features in the real environment (e.g., sidewalks, buildings, trees, etc.) can be scaled to appropriate relative locations with respect to the same features in the virtual environment. What's more, once the offset is made, the GPS positioning often remains more accurate for a while. All this helps overcome the inherent inaccuracies of GPS. The average uncertainty when using a consumer GPS in an urban environment is between 10 and 20 meters (Figure 9). (There are higher accuracy GPS units, but they are bulkier or require additional hardware and usually require much longer to provide an accurate reading.) However, through the use of offsets, a user's estimated uncertainty can be much lower. Thus an effective strategy within Mobile Sitvis is to use GPS for general locating (e.g., for automatically choosing the overview that contains the user's approximate position) and then to use offset annotations for accurate locating. This strategy applies best to urban environments because features are more readily identifiable and because lower GPS accuracy and even occlusion of the signal by tall buildings is more prevalent. The strategy would work less well in open environments (e.g., a large field) with fewer easily recognized features and less occlusion.

The following results illustrate the above points. Figure 10 shows the uncertainty of a user's estimated location. These values were collected as one user walked a random path, setting his offset throughout the session. The user was instructed to carefully and conservatively set his offset and uncertainty, using landmarks he could see both in the real world and in the virtual view. The actual uncertainty is thus within the user-specified offset uncertainty. Two other users tracked that user and marked his location with annotations at the same time that he set his offset. The GPS uncertainty estimate is collected from the GPS receiver. The offset uncertainty averages about 2-3 meters and is typically 5-10 times smaller than the collected GPS uncertainty. This may vary depending on the location of the user and the proximity of visible landmarks. This is reflected in the distance between the offset and GPS positions, which are typically 10 or more meters apart (Figure 11).

The two other users were on average about 50 meters from the user, and their uncertainties are typically also less than the GPS uncertainty. This varies depending upon the distance between the tracker and subject, and the viewing angle of the tracker. This gives a measure of expected tracking uncertainty for a real world situation.

Because the offsets were set very carefully, the offset distance represents the true uncertainty between GPS and true position. As shown in Figure 11 the GPS uncertainty and offset distance vary greatly in about half of the samples. This shows that the GPS uncertainty is only an estimate and is often unreliable.

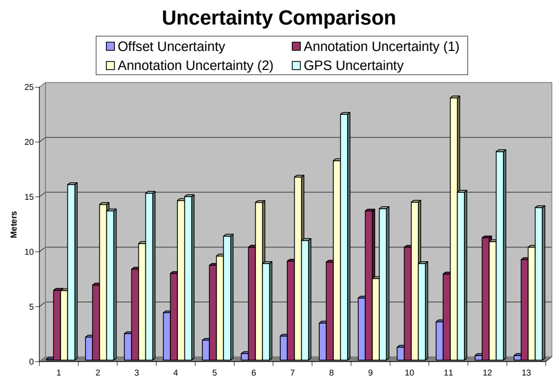

Figure 10 – The estimated uncertainty is lower for users who specify a GPS offset.

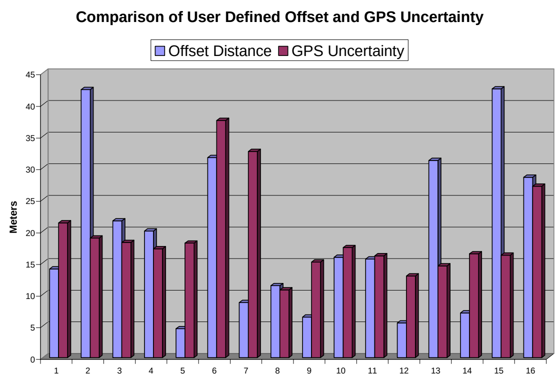

Figure 11 – Distance between the offset and GPS position is typically more than 10 meters

GPS inaccuracy can cause more misinformation than just an incorrect location. For example, in our scenarios, there were instances where the GPS position would be on the wrong side of a building from the actual position of the user. This is something that a user can easily see and correct in the Mobile Sitvis display. Being on the correct side of large, occluding obstacles such as buildings is, of course, quite important for precise surveillance and coordination among mobile users. Figure 12 gives an example. The red cubes fading out represent the GPS positions of a user over 60 seconds. The annotations represent where the user really went. A building separates the real location from the GPS reported location.

7. Data Analysis

An advantage of Mobile Sitvis is its ability to record and playback any session allowing for analysis of the way tracking techniques were used, the quality of GPS, or just to see who was where at what time, and who may have gotten lost and why. This playback can also be quite important to commanders who must plan or respond to activity over time. We have implemented a post session analysis tool into the system. When running a scenario with Mobile Sitvis, all annotations and locations are logged to files. These files can later be loaded into our tool for closer analysis. Our tool is able to visualize the track of users (or subjects) over time and display annotations, uncertainty information, as well as perform error calculations and output the data into MS Excel format to enable easy creation of charts and graphs (Figures 12 & 13).

Figure 12 – The GPS recorded path of a user is shown in red. The annotations represents the true path of the user.

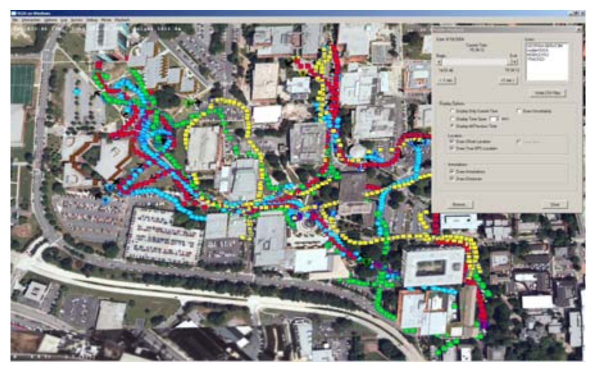

Figure 13 – A Visualization of all user's locations and annotations over a 45 minute period.

8. Conclusion

In this work we have developed the Mobile Sitvis system, which takes space-time annotations from multiple users and sensors and shares them. Through evaluations, we have shown that Mobile Sitvis is useful for command and control, surveillance, and tracking applications. It should also be useful for other applications where collaborators share precise, dynamic annotations of their surroundings and the entities therein.

We derive the following specific conclusions from this work.

- Mobile Sitvis works in an environment where the user must capture changing and unexpected information while moving around. This is a significant result since it was not clear how well it would work (given the prototype interface), especially for tracking a subject.

- It does as well as the traditional method (radio + map) for tracking a moving subject.
- It does better (in terms of accuracy and time for completion) than the traditional method for command and control, especially when multiple units are directed.
- It provides important new capabilities. These include significantly more accurate location information than GPS, specific annotations in space-time that can be shared immediately, overviews of several moving, annotated entities that can be understood all at once, and histories that can be used for tracking and analysis.
- The evaluations offer specific design considerations. The positioning annotations from Mobile Sitvis are particularly useful in an urban environment with tall buildings and other occluders. Here there are plenty of landmarks that can be used for positioning and the GPS signal can frequently be blocked. Thus in the urban environment, it is best to use GPS as an approximate locator for overviews and then use annotations for specific locating. On the other hand, GPS would be superior in an open environment with few landmarks (such as an open plain). An environment such as a heavily wooded forest would be challenging for both methods of locating.

Of course more evaluations and some user studies should be done. However, we do not expect these main conclusions to change significantly. Also, this work suggests new scenarios where Mobile Sitvis will have even greater impact, as discussed in the next section.

9. Future Work

There is still much work to be done. Mobile Sitvis is an initial prototype, but shows the possibilities of systems of this kind. As technology advances, and mobile computing devices get smaller and more powerful, situational visualization applications will become more useful. We are investigating using a much lighter wearable setup for running the system. An eye piece with a higher resolution and a brighter color display would be useful.

Difficulty interacting with our system while mobile is one of the main problems to overcome. Making annotations and performing complex interactions requires the user to stop moving and can detrimentally affect the experience. Replacing the touchpad/eye display with an ultra light tablet PC could be one solution. PDA’s are also becoming more and more powerful. A PDA sized device with 3D graphics capabilities may be worth investigating. The integration of a twiddler for text input and mode switches could also be useful. If a twiddler is used, the large touchpad currently being used would need to be replaced with an alternative for precise cursor positioning.

We are also looking into speech annotations. Users could record a message to accompany an annotation. This message could be translated into text and transmitted to other users. Others users could choose to listen to the message or read it when more detailed information about an annotation is needed.

Finally, we have begun work on decision support capability, beginning with a path engine that determines paths that avoid annotated risks inserted by mobile users. We will report on the results of this work elsewhere.

10. References

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