Developing Visualization Techniques for Improved Information Comprehension and Reduced Cognitive Workload

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Abstract. In today's data rich environments, enormous quantities of digital information can now be collected and made available to end-users in a wide variety of domains. With so much information now readily accessible, effective display methods that integrate and make sense of the data are needed; otherwise end-users may quickly become overwhelmed. HF Designworks, Inc. and Alion Science & Technology have developed tools that leverage large quantities of information to provide useful visualizations to the warfighter. This paper describes the approach and results of two related projects, iWarrior and My Heat Maps, where we provide end-users with deep data comprehension without imposing cognitive overload.

Keywords: Applications of Augmented Cognition.

1 Introduction

Military, commercial, and medical sectors now typically yield enormous quantities of data for personnel to interact with and interpret. For example, typical modern military areas of operation continuously collect data from advanced sensors and other intelligence-gathering tools. These large amounts of information can offer valuable insights into a variety of battlefield contexts. However, for this information to be usable, novel and effective techniques are required in order to sort, filter, and display data to end-users without overwhelming them. Without effective display techniques, high volumes of data can become unusable and potentially hinder military operations by pulling time and manpower from needed areas. A prime example of a fielded system that yields high quantities of data is "blue force tracker" (BFT) situational awareness data from the battlefield. BFT data provides the current and recent past location of military ground-based assets, and is vital for logistics, mission planning, and identifying gaps in strategy and area coverage. Yet much of this valuable information is not leveraged to its full potential because of the sheer quantity and format of data. With Blue Force GPS data, a single vehicle traveling for a few hours can generate thousands of "GPS footprints," which must then be plotted and mapped before they become useful. When tracks of multiple vehicles are gathered, the data quantity multiplies, as does

D.D. Schmorrow and C.M. Fidopiastis (Eds.): AC/HCII 2013, LNAI 8027, pp. 599–607, 2013.

the difficulty in interacting with the data. However, the potential usefulness of data also multiplies as patterns begin to emerge in the frequency, density, and gaps in coverage of tracks over a geographical region. To address this potential for data overload, applications are being developed to provide enhanced visualizations that expose patterns in travel behavior. Such patterns are important to warfighters because frequently traveled routes may be more likely to be observed by the enemy, and are of greater interest to the enemy, possibly resulting in attacks and ambushes along that particular route. Additionally, regions with little traffic may indicate seldom-patrolled locations where the enemy could convene or find a safe haven.

2 Approach

2.1 iWarrior

With iWarrior, HF Designworks, Inc. and Alion Science & Technology (the team) seek to provide end-users with deeper and more complete data comprehension while avoiding the cognitive overload that can quickly arise when interacting with large quantities of data. Funded as part of a Defense Advanced Research Projects Agency (DARPA) Small Business Innovative Research (SBIR) effort, iWarrior is a web-based tool for supporting battle space awareness and planning. iWarrior collects historical GPS coordinates (from military location data-tracking programs such as TiGR, FBCB2, or other sources with a minimum latitude/longitude and a Date Time Group) and uses this data to produce map-based visualizations of Soldier and vehicle tracks. iWarrior also provides route analysis capabilities with tools such as “heat map” overlays. Heat maps use coloring scales to display relative traffic in geographic regions, visually indicating heavily traveled, “hot” areas (e.g., red), moderately traveled “warm” areas (e.g., orange or yellow) or seldom traveled “cool” areas (e.g., white or light blue), Fig.1.

Fig. 1. View of iWarrior Density Visualization

iWarrior was developed through a multi-year effort that involved an iterative approach of working with subject matter experts, identifying information requirements, working with technical experts to specify what can be implemented, and performing rapid prototyping to display and test concepts. The approach for iWarrior development has been focused on user requirements; use case-based development, and frequent user testing. The iWarrior tool emphasizes practical solutions for addressing user concerns and presenting accurate representations of the data in an effort to not mislead users.

2.2 My Heat Maps

The heat mapping capabilities and algorithms explored in iWarrior have also been developed for Android-based handheld devices through the DARPA Transformative Applications (TranApps) program. HF Designworks has developed a plug-in for the TransApps 'Maps' application that converts the handheld device's recorded GPS tracks to heat maps that show the traffic density in an area, Fig.2. This capability allows Soldiers to view their travel behavior in the form of visual patterns, allowing them to readily note points of vulnerability (either frequently-traveled areas, or locations on their patrol that have been neglected and may need additional presence). These capabilities are all available directly from the handheld device without needing to rely on data connectivity. In other words, all processing is performed on the device itself. These heat-mapping capabilities also have potential for use in a variety of other applications. For instance, we have recently applied these mapping capabilities to a civilian Unmanned Aircraft System (UAS), marking where that aircraft has flown and with what frequency the area was covered. Future applications could include heat mapping not only the paths themselves of UAS deployed in environments such as combat zones, search and rescue, and land surveying, but also the area coverage captured by sensor payloads to reveal locations that have been missed in flyovers. This would allow operators to maximize area coverage, minimize fuel consumption, and avoid retracing areas unnecessarily.

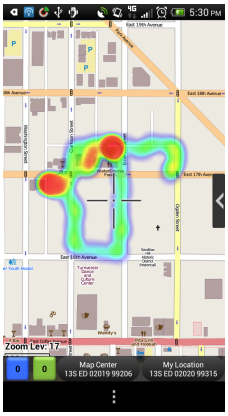

Fig. 2. View of a heat map rendered on the device

3 Requirements

A past project completed by the team demonstrated that many of the military casualties that occur during a tour of duty are due to complacency that can lead to selecting and traveling along the same route repeatedly or conducting patrols in a predictable manner. As a result, enemy forces detect patterns in the patrols or routes used, and use this knowledge to stage attacks or select locations for Improvised Explosive Device (IED) placement. Based on this finding, a tool was needed that could easily and effectively display tracks that show where vehicles have traveled for specific periods of time, presented on a map. Track-based visualizations are the core features of both iWarrior and My Heat Maps, and almost all other features within these tools build from this.

Starting with a focus on route traffic, various visualization features were developed through SME interviews and iterative designing. In addition, the development of heat mapping visualizations (which use coloring scales to display relative traffic in geographic regions, visually indicating heavily traveled, "hot" areas), Soldiers also indicated a need for identifying areas where vehicles or personnel have remained stationary for longer periods of time. This requirement resulted in the development of halt visualizations to represent where vehicles or personnel have remained stationary (based on GPS tracks recording periods of no movement) for a user specified amount of time. The GPS data is also used to provide statistics and metric visualizations to users so they can better determine how fast units move through selected areas as well as the frequency of movement based on time (year/month/day and even time of day).

Continual user feedback and SME-derived requirements resulted in a number of other features; iWarrior now also provides push pins for identifying significant events associated with a specific location or a selected region on the map. Users place pins and provide associated data (e.g., text or image files). Pins offer visual indications of vital information, allowing warfighters to recognize possible relationships between GPS traffic and push pin data.

User requirements have also guided a recent update to the My Heat Maps application which enables users to save their tracks as heat map image files which can then be uploaded to a computer and viewed in Google Earth, offering an additional method for tracking route and patrol traffic as well as allowing users to combine tracks from multiple handsets for viewing in Google Earth. Note that the popularity of viewing image files in Google Earth by Soldiers has also allowed us to implement a similar image conversion and download feature in iWarrior.

4 Prototype

4.1 iWarrior

iWarrior's features have been developed to enhance warfighter comprehension of the battle space and augment decision-making through valuable visualizations and information management tools, as was presented in Fig.1. The use of iWarrior begins with

selecting a segment of time (by choosing a start and end time) or a geographic area on the map. The tool then retrieves the GPS data for this period of time/location and plots the tracks on the map interface, allowing the data to be 'played back' at various speeds. The interface includes a variety of filters (developed based on user needs and SME feedback). These filters allow users to quickly view and hide information overlays, such as turning off the Density visualization to view only GPS tracks, turning on and off track bounds to help find areas of heavy traffic when zoomed out, and turning push pins on and off. The interface is designed in "layers," which allow the user to select and display different types of data. This lets the user compare items of interest (e.g., density and push pins) without cluttering the display unnecessarily. The layers provide users the ability to switch between (or display simultaneously) the map itself, the GPS track layer, Density layer, push pins layer, or track bounds layer. Map tools for measuring distance and area are also included. A background fader has also been developed which allows users to lighten or darken the map background to improve the clarity and contrast of tracks and densities, which also are supported in multiple color schemes. Due to its popularity, this fader feature has been carried over to other map based programs as well. Features such as density, clusters, push pins, the background fader widget, and a statistics tool (density by time of day in this example) are shown in Fig.3.

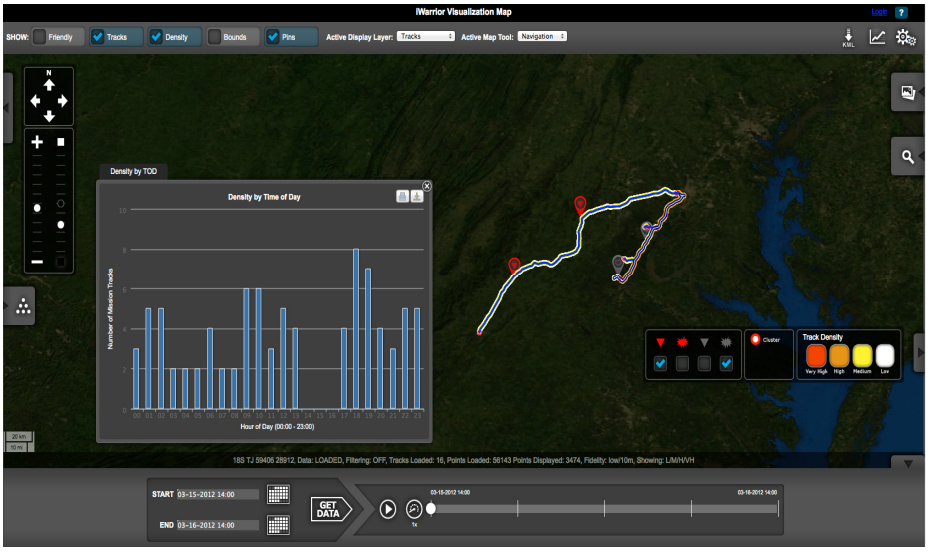

Fig. 3. iWarrior with Density, Clusters, Push Pins, Background Fader Widget, and Time of Day Density Features All Active

4.2 My Heat Maps

My Heat Maps is a plugin to the DARPA Transformative Applications (TransApps) Maps application. As with iWarrior, heat maps are based on GPS tracks; therefore, users create 'sessions' of GPS data using the device's built-in GPS. These sessions

are populated in the My Heat Maps plugin, and users then select sessions they would like to generate into heat maps. My Heat Maps can also convert the heat maps and save them on the hand held's SD card, allowing them to be uploaded to a computer and viewed in Google Earth (Fig.4) which allows for creating presentations for pre and post mission as well as collecting and displaying heat maps for multiple users.

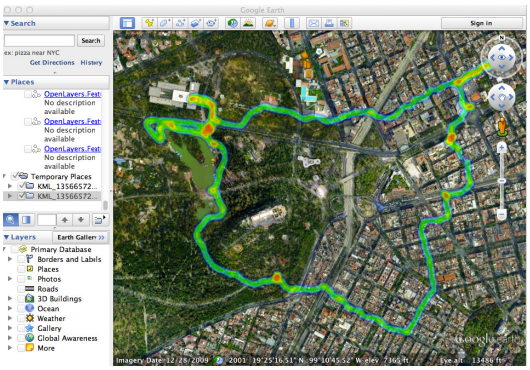

Fig. 4. A heat map image, converted, exported and viewed in Google Earth

5 Testing of Concepts and Results

The development of both iWarrior and My Heat Maps is an iterative process including periods of test-fix-test. As such, we have tested both the iWarrior and handheld applications, and identified results that are continually used to improve these applications. Results are described below.

5.1 iWarrior

iWarrior has been tested internally with our SMEs (all with recent combat experience). Additionally, iWarrior features such as density heat maps and statistics have been integrated into larger Department of Defense (DOD) information systems and tested both by SMEs as well as evaluated through limited field-testing. Utilizing this type of testing as part of our iterative design process allows us to continually improve our visualization tools. Working with end users also allows us to receive feedback on desired features, which we can then incorporate into our products.

At this time we do not have formal test results from our iWarrior tool. Initially, based on Phase I interviews and focus groups we recognized a need for such a tool. iWarrior was then developed with Soldiers as SMEs assisting us throughout the design process with the goal to eventually test iWarrior through simulated, SME-based missions .

5.2 My Heat Maps

To explore the in-field applicability of the My Heat Maps application plugin, a four-man team comprised of our SMEs performed a field test to gather GPS data of possible real-world scenarios. All four members of the team had prior military experience including several deployments to Afghanistan and Iraq as infantrymen. The main goal of the exercise was to see how the on-the-ground movements translated into heat maps and then use the heat map visualizations to assist Soldiers in conducting future operations. To accomplish this goal, the four-man team conducted a variety of basic military formations and common mission scenarios while recording their GPS data.

The results of the heatmap evaluation showed us that we were on the right track in terms of visually indicating to users where they had been, what type of movement was made, and with what frequency and speed they had moved through select areas. Results and later discussions also indicated to us that we needed to heat by mission rather than track if the heatmaps for multiple personnel were being viewed at the same time. Displaying heatmaps for multiple personnel can be performed via uploading to a computer and displaying in Google Earth, or uploading data to iWarrior (a single hand held device using My Heat Maps only renders heat maps for a single user). Additionally, because some units may have several hand held devices while others might only have a single hand held device, we would need to revise our algorithms so that each mission, regardless of how many tracks were included, received one heat value. The more missions in the same area would result in a higher heat value. This was because we were making the assumption that the enemy was more interested in the fact Soldiers travelled through an area and how often, rather than how many Soldiers travelled through that area (which could be confusing to the system since there is no way to know in advance just how many Soldiers would have hand held devices).

The team found that heat maps were an easy and effective way of visualizing routes taken. The heat maps also helped identify choke points in areas of slow movement and areas covered in clearing operations. The team agreed that the information from heat maps would be very useful for mission planning, after action reviews and debriefs. The team also suggested that heat maps could be improved by providing additional capabilities. Capabilities that could enhance the utility of the program include: the ability to vary the rate of 'heating', the ability to vary the thickness of heat maps for different terrain (e.g. jungle vs. desert environments), introducing improved methods for indications movement speeds, and an option to have heat maps fade overtime (i.e., stale out).

For future work we plan to show these heat maps to SMEs who were not part of the original missions. We will then asking these new SMEs to evaluate the heat maps and provide feedback on what they think is being presented (i.e., movement details), to help ensure our heating algorithms are fully accurate over a variety of environments and mission scenarios.

Fig.5 and Fig.6 display the heat mapping data of four users traveling in a fire team formation on line. Fig.5 shows the fire team as they spread out, moving across the image area from left to right. Fig.6 shows the fire team spreading out and then collapsing back in as they move across a field.

Fig. 5. Fire Team's heat map as they spread out, moving from the left to right side of the image

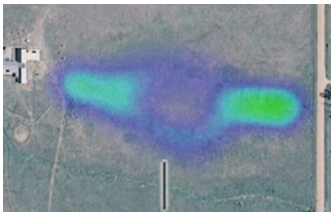

Fig. 6. Fire Team's heat map as they spread out and then collapse back together as they move across a field from the left to right side of the image

Fig.7 shows a heat map for a patrol starting at point A and moving to point B *(The screenshot has an overlay to clarify movement).* The heat map visualization allows Soldiers to easily determine where they have been in order to plan future missions to maximize area coverage and reduce predictable routes.

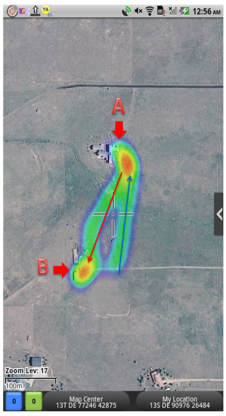

Fig. 7. Heat Map of a Patrol scenario starting at Point A and patrolling to Point B. The arrows indicate the different routes taken to and from Point B.

6 Next Steps

We will continue to work with the warfighter, identifying methods for evaluating data then using that information in an intuitive manner to help the warfighter with their tasks. This can include improving heat mapping (adding the ability to customize how

and when GPS points get heated) or even developing cultural conversion applications so Soldiers can better understand foreign communities they encounter. Further testing will include mission-based scenarios to gather data by one team of SMEs, and reviews/interpretation by a second group of SMEs. When the second SMEs have developed their understanding, we will have them present to the first group. This will allow us to identify potentially misleading data visualizations, and to develop solutions that make sense to all users.

7 Summary

Current and rapidly emerging technologies can provide users an abundance of vital data. The data itself however, is not necessarily useful until it is displayed in a way that end-users can comprehend. With visualization techniques that organize data in a meaningful format for the intended end user, digital data can be used to provide key information to users without contributing to, or causing, information overload. In the cases of iWarrior and My Heat Maps we were able to successfully take historical GPS data and enhance a user's situation awareness and decision making through statistical charts (including showing critical times of day Soldiers are conducting missions) as well as heat maps of what areas are being covered and with what frequency.

Additionally, by following an iterative design cycle where end users are involved throughout, including a final test-fix-test cycle at the end of each build, we can further ensure the products meet the needs of the users and are robust enough to work, and work well, in the field.

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