Improving Situational Awareness for First Responders via Mobile Computing

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Abstract

This project looks to improve first responder situational awareness using mobile computing techniques. The prototype system combines wireless communication, real-time location determination, digital imaging, and three-dimensional graphics. Responder locations are tracked in an outdoor environment via GPS and uploaded to a central server via GPRS or an 802.11 network. Responders can also wirelessly share digital images and text reports, both with other responders and with the incident commander. A pre-built three dimensional graphics model of the emergency scene is used to visualize responder and report locations. Responders have a choice of information end points, ranging from programmable cellular phones to tablet computers. The system also employs location-aware computing to make responders aware of particular hazards as they approach them. The prototype was developed in conjunction with the NASA Ames Disaster Assistance and Rescue Team and has undergone field testing during responder exercises at NASA Ames.

Keywords: first responders, emergency management, disaster management, pervasive computing, GPRS, GPS, situational awareness

1. Introduction

First responders routinely face dangerous environments and situations, ones ranging from fires to natural disasters to terrorist attacks. Successfully conducting operations in these environments requires rigorous training, properly chosen technology, strong incident command, and an appropriately managed flow of information. These themes are mentioned in, among other places, Chapter 9 of the 9/11 Commission Report [1].

Responders at an emergency scene need answers to questions: Where am I? What do we know about the scene? What hazards exist? Where are other responders located? Where are the victims? The hope is that by providing appropriate and timely answers to these kinds of questions, first responders will be better prepared to respond to and manage emergencies. Of course, the appropriateness of an answer will almost certainly vary by responder role, and there is little question that too much information is just as harmful as too little.

This paper describes a prototype system, the Smart Systems Research Laboratory (SSRL) Responder Tool, that was built to examine innovative ways of increasing first responder situational awareness and thus their ability to respond to the crisis at hand. The system makes use of off-the-shelf hardware, including tablet computers, personal digital assistants (PDAs), and programmable cellular phones. System software was built on Microsoft's .NET platform and brings together web services, wireless communication, and computer graphics. The system allows for report and image exchange and archiving, as well as real-time location tracking of individual responders via the Global Positioning System (GPS). Responder and report locations are visualized in real-time using three-dimensional computer graphics. The tool grew out of earlier work done at SSRL related to space mission training [2, 3].

Responders often use the term "C3" to describe the response to a disaster scene: command, control, and communication. The SSRL Responder Tool is intended as an aid for both the command and communication portions of C3. It is intended to bring a higher level of consistency to the interaction between different first response teams.

The remainder of this paper is organized as follows. First, background on the problem and the motivation to study it are presented. The methods used in constructing the system, including software and hardware architectures, are described, as are results obtained with the system. Finally, conclusions and avenues for future work are presented.

2. Background

The NASA Ames Research Center is home to an all-hazard federal emergency response and recovery team known as the Disaster Assistance and Rescue Team (DART) [4]. This team of approximately two hundred and fifty mainly volunteer members has extensive training facilities at NASA Ames, including a large Collapsed Structure Rescue Training Site (shown in Figure 1). In late 2003, DART leaders decided to reach out to engineering and science groups at NASA Ames, other federal facilities, and Silicon Valley in an effort to infuse advanced technologies into the DART emergency scene workflow. This ongoing program has led to DART members giving guidance and advice to technology groups as they strive to solve emergency responder issues. It has also resulted in periodic field tests and technology demonstrations. For more on one such demonstration, see [5].

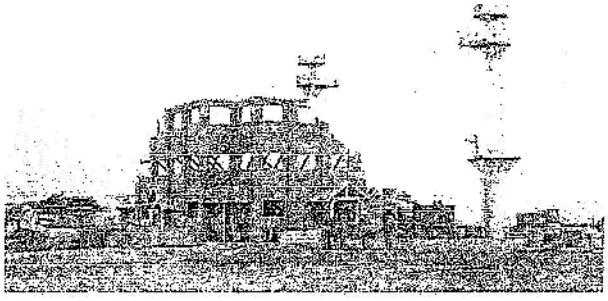

Figure 1. Photo of the NASA Ames Collapsed Structure Rescue Training Site.

As part of this program, members of SSRL at NASA Ames initially set to work on the specific problem of providing information technology aids to assist the construction of wooden building shores. This problem, and the prototype system designed to address it, grew into one that addressed the broader issue of emergency scene situational awareness for all responders, including those at the incident command post.

Before conducting search and rescue operations in a building that has collapsed (due perhaps to an earthquake, hurricane, or fire), specialized responders may need to construct wooden shores for the structure. These shores are used to stabilize the structure, thereby reducing the risks to responders of operating in and around it. The process of constructing the shore involves one set of responders communicating a desired shore type and dimensions to another set of responders responsible for cutting wood [6]. The cutting team may be at a centralized location away from the structure, so communication between the two team elements may be via radio or via slips of paper sent back and forth by runners. Once wooden pieces of the shore are cut, runners ferry them to the shore site.

In striving to improve this workflow, SSRL members looked to combine wireless communication, small form factor computing, information management, and computer graphics in an effort to increase overall situational awareness. With the addition of a fifth element (real-time location determination), these information technologies can further be used to aid general situational awareness of an emergency scene.

3. Related Work

Several areas of research and commercial enterprise are relevant to the work described in this paper. Certainly the five areas mentioned in the previous section—1) wireless communication, 2) small form factor computing, 3) information management, 4) computer graphics, and 5) location determination—have vast bodies of research associated with them. The COORDINATORS effort of Wagner et al. has a similar goal to the work reported here [7]. Their work looks to provide decision support to first responders by reasoning about who should be doing what and when. It makes use of PDAs, wireless communications, and a Honeywell proprietary asset location technology to track responders, victims, and equipment. Differences between the two include the SSRL Responder Tool's use of 3D graphics, support for shoring operations, and emphasis on Smartphones.

One of the appliances used in the work reported here is a programmable cellular phone. Recent work by Roussos et al. outlines general challenges associated with using Smartphones as Information End Points (IEPs) [8]. Although it does not specifically examine first responder use, it contains many relevant lessons learned by the authors. Kun et al. and Miller et al. provide good descriptions of the challenges of integrating information appliances into first responder workflows and ensuring interoperability [9, 10]. Sawyer et al. describe techniques for providing secure mobile access to information for first responders [11].

Patterson et al. discuss challenges associated with location-aware computing [12]. They also describe a futuristic scenario where robots use location-aware computing to respond to a collapsed structure disaster. Kwan and Lee look at the applicability of location-aware computing to improve emergency response [13]. Like this

work, they describe the fusion of real-time location information with three dimensional computer graphics. The TellMaris project made use of portable computer graphics and GPS data and applied it to a maritime application [14].

Location determination is a requirement for many different applications. Probably the best known real-time location system (RTLS) is GPS [15]. It is mostly intended for outdoor use, insomuch as the transmitted satellite signals penetrate structures poorly. The Federal Communication Commission's E911 mandate [16], among other things, has prompted research and development in metropolitan and indoor location determination techniques, including ones based on television signals [17]. For a good overview of current techniques and challenges, see [18].

4. Methods

The SSRL Responder Tool is divided into three distinct components:

1) Responder components;
2) Command Post components;
3) Server components.

This section of the paper looks at the architecture, hardware, and software of all three.

4.1 Responder Architecture

Responder components are illustrated schematically in Figure 2. Responders carry Bluetooth GPS receivers with them, mounted on their helmets. Both Hewlett Packard iPAQ and Garmin GPS 10 Bluetooth receivers have been tested, with the latter device offering Wide Area Augmentation System (WAAS) capabilities for greater positioning accuracy.

Responders have a choice of IEPs when using the system. Multiple IEP types were incorporated to accommodate different responder roles. Some responders are able to make use of PDAs and small tablets while still performing their responder duties. For other responders, a device on the size of a cellular phone is all that can be accommodated. Various responder IEPs used in the SSRL Responder Tool are shown in Figure 3.

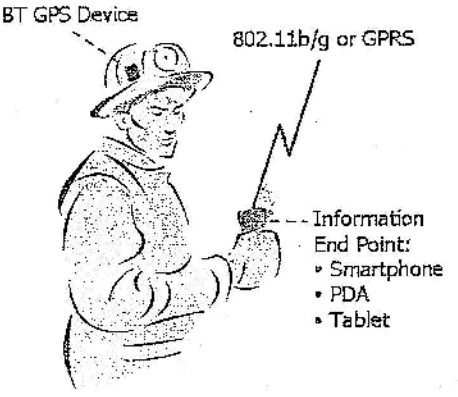

Figure 2. Overview of the responder components.

The smallest IEP is a programmable cellular phone, an Audiovox SMT 5600 running Windows Mobile 2003 Second Edition on the Cingular network. Using the phone, responders can send and receive images and text reports via General Packet Radio Service (GPRS). Location data is read from the GPS receiver via Bluetooth and also uploaded to the server via GPRS, thereby allowing the system to track responder locations in real-time. Finally, responders can browse portions of their Field Operations Guide on the phone (as they can on all IEPs).

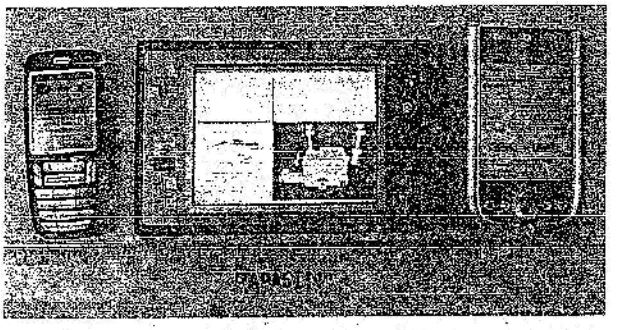

Figure 3. Responder IEPs. From left to right are the Smartphone, tablet, and PDA. All are running the SSRL Responder Tool. Ruler units are inches.

The second responder IEP is a PDA. At present, its capabilities are similar to that of the cellular phone, with the exception that it communicates via a local 802.11b/g network instead of GPRS. A combination of Hewlett Packard iPAQs and Dell Axims has been tested, again running Windows Mobile 2003 Second Edition.

The final IEP is a small-form-factor tablet computer. Devices that have been tested include a Toshiba Portege M200 and a Sony Vaio U71P touch-sensitive handtop. Since even PDAs are potentially too large for many responders to carry, some explanation of why tablets are offered is in order. The principal reasons were because they run full versions of Windows XP (thereby easing

software development) and because they offer hardware accelerated graphics. These devices are the only IEPs in the current system that offer responders a three-dimensional virtual environment of the emergency scene (although future work will look to add this feature to the PDAs). The virtual environment is also used to visualize a responder's current location and the location of other responders, as well as locations where reports were made. Figure 4 shows a screen shot of a responder tablet.

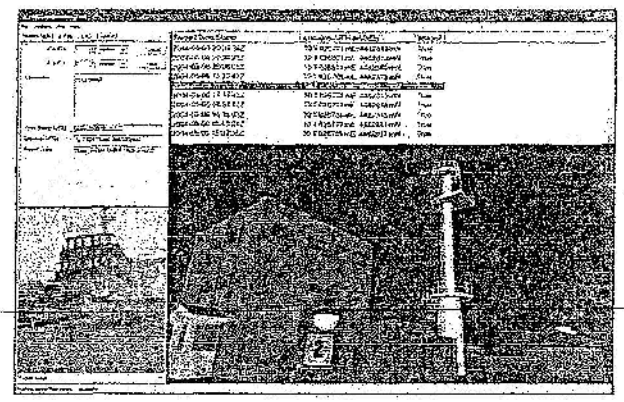

Figure 4. Screen shot of a responder tablet. The upper panels deal with text reports. Images associated with reports, along with the Field Operations Guide, can be shown in the lower left panel. The lower right panel displays a virtual environment of the scene, with the responder's current location indicated by the icon. The virtual environment models the NASA Ames Collapsed Structure Rescue Training Site shown in Figure 1.

In an effort to reduce hardware costs, the current prototype does not use hardened IEPs. A deployed system would unquestionably utilize devices that were resistant to dust, heat, moisture, and impact. Such devices are increasingly common and affordable. For example, Panasonic offers a hardened line of notebooks (known as Toughbooks) and non-hardened PDAs can be encased in armor (e.g., the OtterBox line of Armor from Otter Products).

4.2 Command Post and Server Architectures

The other two components of the SSRL Responder Tool are the Command Post (CP) and server portions, illustrated in Figure 5. The CP portion includes software and hardware for the Incident Commander (IC) and other staff to monitor reports, imagery, and responder locations, as well as possibly using the tool for overall emergency response coordination and management. It also includes an 802.11b/g wireless communications infrastructure, intended to cover not only the CP but also the local area where responders are working. The IC can use any of the responder IEPs to interact with the system. However, if the IC is fairly stationary (or perhaps has a command vehicle available), a conventional notebook computer can be used.

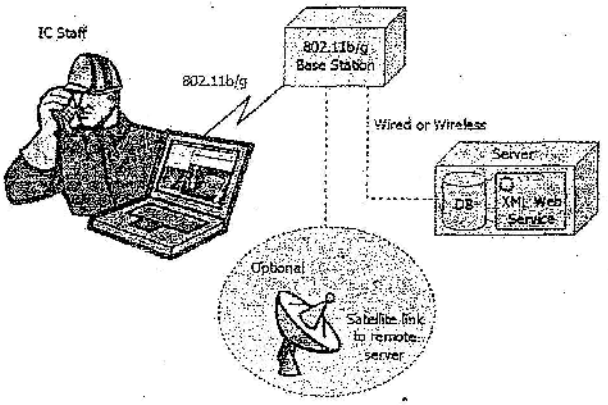

Figure 5. Overview of the Command Post and server portions of the system.

Wireless communication is a critical aspect of the SSRL Responder Tool. The power of the tool lies in large part with the ability to collect and share information amongst responders and the IC. The various responder IEPs need network connectivity, which in the current prototype has been delivered either via a field-deployable 802.11b/g network or GPRS. At least in metropolitan areas, GPRS is reasonably ubiquitous, although it offers relatively little bandwidth. In the event that the cellular network is unavailable, a local 802.11b/g network can at least give some coverage to the responders and IC. It requires the deployment of a combination of wireless routers, access points, and range extenders (and making sure these devices are powered, either from batteries or generators). A final component of the communication infrastructure can include an optional satellite data link.

The server is the communications hub. It stores text reports, images, and responder locations in a database. The server accepts and delivers information via an XML web service. It can either be collocated at the CP or, if a satellite link is available, remain at a remote facility (a local mirror would reside at the CP in case the satellite link fails). This configuration, with the server resident at a remote NASA facility and a satellite link bridging the local network, has been tested during a disaster exercise. The current system uses a single Dell Inspiron 8200 running Windows Server 2003 as the server.

4.3 Software

Custom software was developed for all three components of the SSRL Responder Tool (meaning the responder IEPs, the CP computers, and the server).

Microsoft's .NET platform was used as the implementation platform and all of the code, including the graphics code, was written in C#.

The desire to cater to a wide variety of different computer platforms (i.e., cellular phones, PDAs, tablets, servers) with maximum code sharing between the platforms made either J2EE/J2ME or .NET the natural implementation choices. The project could have unquestionably used either one. That said, we have been impressed with the .NET platform and its supporting software development kits. The SSRL Responder Tool makes use of, among other things, ADO.NET, managed Direct3D, and the .NET Compact Framework. They have made it easy to rapidly move ideas from design concept to working prototype.

The major unit of data in the system is a *Report*. A report can contain free-form text comments, shore dimensions (recalling that the tool's origin was to assist with the construction of wooden building shores), a digital image, and a location. Responders can create and share these reports on the various IEPs. Reports are pushed to and pulled from the server via an XML web service published by the server. Reports are archived in a database on the server and are made available in chronological order to all the responders on a team and the IC. Figure 6 shows aspects of the report user interface on the Smartphone and PDA.

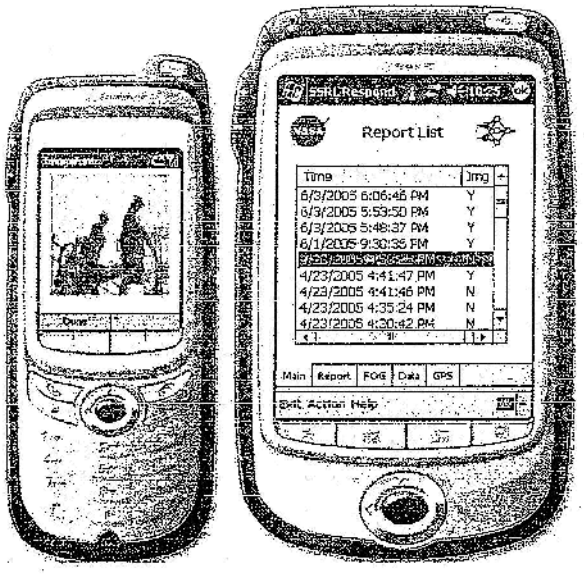

Figure 6. Part of the report user interface on the Smartphone and PDA responder IEPs. On the Smartphone, the user has selected the image associated with a report (created during one of the field tests) and is viewing it. On the PDA, the user is viewing the chronological list of reports.

Digital images associated with a report can assist the cutting crews and the IC in assessing a particular shore site. Digital images can either be acquired directly by the IEP or via an additional camera. The disadvantage of using an additional camera is that it is yet another device that consumes batteries and has to be hardened to work in a real disaster environment. The advantage is that, at least for now, such cameras have better optics than the cameras built into cellular phones.

The location from which a report is uploaded is captured and associated with the report. Latitude and longitude are read from the GPS receivers, although these are converted to Universal Transverse Mercator (UTM) coordinates [19] in software in order to facilitate use of the coordinates in the virtual environment. The upload location of a report and the real-time location of responders are marked with icons in the virtual environment of the disaster scene. The virtual environment is available to staff at the CP and responders with tablet IEPs.

The virtual environment uses pre-specified models of a particular disaster scene. That is, the mesh geometry is not determined in real-time at a disaster scene but instead in advance, through a combination of examining blueprints, CAD models (if available), and pictures. The mesh is stored in DirectX format in units of meters. A transformation matrix stored with the mesh aligns it with the local UTM grid, so positive z in the model corresponds to north and positive x to east.

Unquestionably we would prefer to use graphical models generated in real-time at a disaster scene. Such models, if they could be generated quickly and accurately, would have the advantage of reflecting the scene as it truly is (e.g., the partial collapse of a structure could be captured). Pre-modeling, on the other hand, has the advantage of being able to capture information that would be hard or impossible for any real-time technique (say 3D photogrammetry) to obtain, such as the location of buried gas or electrical lines. The expense of pre-modeling a scene with enough fidelity to be useful to responders may be justifiable for high-value or high-risk assets (e.g., nuclear power facilities, refineries, prominent commercial and government buildings, mass transit infrastructure, etc.). The current prototype uses a single pre-modeled scene of the NASA facility shown in Figure 1. Constructing the scene took approximately 20 hours of work by a skilled 3D graphics modeler.

The decision to use a web service to move data between computers was largely driven by the ease with which they can be implemented and consumed in the .NET environment. Experiments with a custom TCP protocol hovered between difficult and impossible on a real GPRS-based provider network. While such a protocol was possible, actually getting it to work would have almost certainly required assistance from the carrier.

Conversely, consuming a web service over carrier networks under Windows Mobile is straightforward. The disadvantage of the web service is that it has architecturally required responder IEPs to poll for new reports instead of having the server push new reports only when and if they become available.

The current prototype does not directly address security issues. Data is stored and transmitted as clear text and there is no user authentication (via passwords or biometrics). Real-time responder locations and report data are likely to be sensitive. For example, reports may include personal information about victims. While the current prototype has been architected to allow for eventual insertion of certain security-related features, a deployed system would need a more comprehensive security solution.

5. Results

Initial design work on the SSRL Responder Tool was done in November 2003. The first substantial field test occurred in May 2004 at the NASA Ames Technologist-Meets-Responder Exercise [5]. The system was demonstrated and used as part of the exercise scenario by engineers who had worked on the prototype (as opposed to responders). Responders and ICs that observed the system made many useful comments on how the tool could be refined and expanded. For example, several responders saw it as a useful tool for enhancing situational awareness by giving easier access to critical information during in-field briefings to relief teams. Before going into a structure or helping with the construction of a shore, a squad leader could use the reports, images, and virtual environment to help orient squad members and alert them to potential dangers. Other responders felt that the tool's archiving capability would be useful for after-action reports and for developing training scenarios.

Responders also expressed several concerns. Any device that consumes batteries is always a potential problem in the field—one responder remarked that no matter how advanced the tool, he would never leave his pencil and notebook behind. Concerns were also raised about the practicality of setting up a local 802.11b/g network in the field. For this exercise, we did deploy a network in the field, powering the access points off a generator, although even with multiple access points there were areas in and around the structure of inadequate signal strength.

Beyond routine field testing, two other substantial field tests have been performed using the SSRL Responder Tool. It was used during a responder workshop in April of 2005, where the various components of the tool were once again operated by engineers (although this time in close cooperation with individual responders). A third field test in June 2005 demonstrated key features of the tool to NASA and Department of Homeland Security representatives.

6. Conclusions and Future Work

There seems little doubt that technology aids intended to increase situational awareness will become more and more common at disaster scenes. The process of accepting a system should—and hopefully will—be rigorous. Only those tools that can definitively show a significant increase in overall situational awareness should be accepted.

For fire and urban search and rescue (USAR) teams, accurate location determination within structures is of vital importance. As has already been mentioned, this is a very active area of research and development. When fused together with other modalities, such as GPS, this perhaps more than anything will bring immediate and real situational awareness benefits to both responders and commanders.

Low-cost and robust field-deployable wireless networks are needed. In the event that metropolitan networks are down, responders would benefit by being able to deploy their own system, even if the range was relatively limited. Base stations could be mounted permanently on vehicles with some additional access points and range extenders deployed in a working area by responders. When the work area shifts, the network could be shifted with it.

With the power of networking comes the associated risk of information overload. Careful attention will have to be paid to filtering the information presented to individual responders and to commanders. The SSRL Responder Tool has taken preliminary steps in this direction by delivering location-specific content (LSC) to responders via their IEPs. At present, the IEPs are pre-loaded with information about points of potential hazard or interest, no different from many off-the-shelf GPS devices. When a responder moves within a certain distance of the trigger point, the IEP flashes and issues an audible warning that LSC is available. Future work will look to deliver real-time over-the-air (OTA) LSC. For example, when approaching the entrance to a structure, the IEP will present the responder with an electronic version of any Building Marking System (BMS) [6] data associated with the building. BMS marks are currently made with orange spray paint on the sides of buildings and denote such things as the building address, structure and hazards evaluations, victim locations, search assessment marks, and team identifiers. Although BMS markings are standardized, interpreting marks and mark updates made by different teams can be a challenge at a long-duration disaster scene.

Future work will also continue to address the specific problem of shoring. Shoring dimensions entered into the tool will be used to compute wood cut lengths. The 3D graphics capabilities of the PDA IEPs will be used to provide a dimensionally-accurate real-time visualization of the shore being constructed, along with the proper assembly sequence. Once complete, the SSRL Responder Tool will hopefully achieve a limited deployment with structure specialists at NASA Ames DART, growing into a larger deployment with other team elements.

More work is needed on the human-computer interface issues associated with responders and computers. Smartphones and PDAs have the advantage of being inexpensive and easy to develop software for, but they may not represent the best interface appliance. Small screens can be difficult to read under the best circumstances; a stressful situation, or even bright sunlight, can greatly increase the difficulty. Operating small devices with gloves on is challenging, meaning robust hands-free techniques for interacting with IEPs would be welcome. Making effective use of heads-up displays (HUDs) is an interesting avenue for future research.

7. Acknowledgements

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