DIORAMA: Dynamic Information Collection and Resource Tracking Architecture

Aura Ganz*, Fellow, IEEE, Xunyi Yu*, James Schafer*, Sophie D’Hauwe*, Larry A. Nathanson**, Jonathan Burstein**, Gregory R. Ciottone**, Graydon Lord***,

*Electrical and Computer Engineering Department
University of Massachusetts, 01003
**Beth Israel Deaconess Medical Center
Harvard Medical School
***MS, NREMT-P, Associate Director, Office of Homeland Security
The George Washington University

Abstract—DIORAMA is a real-time scalable decision support framework built on rapid information collection and accurate resource tracking functionalities. Using RFID technology the proposed system tracks emergency responders and victims at the disaster scene. DIORAMA improves the accuracy and decreases the time it takes rescuers to triage, treat and evacuate victims from a disaster scene, as compared to the traditional methods and process that involves using paper triage tags. The information can then be viewed from a website that shows a satellite image of the disaster area with icons representing the paramedics and victims.

Index Terms—Outdoor localization, active RFID, triage, disaster, mass casualty incident.

I. INTRODUCTION

Disasters are by definition unpredictable, dangerous and overwhelming. Our project, DIORAMA, is designed to assist incident commanders in their attempt to bring order to the chaos as they direct rescue operations. This technology can also be used to keep track of personnel; particularly should there be secondary events that put the rescuers at risk.

Once the first responders arrive at the mass casualty incident site, they deploy the DIORAMA equipment. The Emergency Medical Service (EMS) providers will triage each patient in the disaster scene and tag them with a DIORAMA electronic tag (D-tag) which reflects the severity of the patient’s injury (red, yellow, green and black) and will be used to track the patients’ location. Moreover, each emergency responder (paramedic, firefighter, police personnel, etc) and resource also carries a DIORAMA tag. Using our DIORAMA system, we will have an accurate knowledge of the real-time location of each of the patients as well as of the emergency responders and resources (see Figure 1). Some specific scenarios to demonstrate the benefits of this technology: On January 12, 2010 a catastrophic earth quake struck the island nation of Haiti. This disaster is ongoing, but what is known is that over 3 million people are affected and the death toll will likely exceed 150,000. The injured and dead are dispersed over approximately 700 hundred square miles. Many of the dead have been removed from their collapsed buildings and buried making identification and location issues nearly impossible. If initial response teams had the DIORAMA system the triage system would not only determine who needs what resources and where they are, but they would also insure that the deceased patients would be tracked. In large disasters, such as what is currently ongoing in Haiti, patients are frequently identified by their location. With DIORAMA the system would have captured the deceased initial location at tagging which could allow the victim to be identified. In the Wenchuan earth quake in Sichuan Province, China in 2008, there were 16,000 missing victims. Many were buried in mass graves or carried away in the rubble when it was removed. DIORAMA could allow the identification of many of those victims through its location technology.

Disaster response and recovery efforts require timely interaction and coordination of emergency services in order to save lives and property. WISARD[1], CodeBlue[2], and AID-N[3] are among the recent efforts to develop new technologies for disaster management. While these systems provide a large amount of useful operational and clinical data to rescuers, the expense, size and complexity of the client device they use make it impractical to distribute an adequate number of devices to all of the victims on the disaster scene.

The remainder of the paper includes the following sections. Section II introduces DIORAMA architecture and Section III introduces DIORAMA software overview. The localization engine is described in Section IV. Section V summarizes testing results and Section VI concludes the paper.

II. DIORAMA ARCHITECTURE

The DIORAMA architecture overview is presented in Figure 2. Each victim is tagged with an active RFID tag which we denote D-tag which is worn by the End Users
(victims, paramedics and other rescue personnel). The D-tags color coded according to US Emergency Services conventions. In case of victims, the tag information (severity of injury, time and location) is sent to the DIORAMA server (no victim or paramedic intervention is required). The 433 MHz M160 Wristband Tag manufactured by RFCode is a battery-powered RF transmitter designed to be worn as a bracelet. M160 Tags can be programmed to operate at a 2-second beacon rate for security applications. With typical read ranges of 300 feet, a single reader can provide coverage for a large area. The M160-series tags are designed to be comfortably worn by the user when attached with standard single-use ½” wristbands. The paramedic wears a helmet (D-helmet) which includes 15 D-tags used for precise localization. Each D-track is implemented by a M220 active RFID reader, ASUS WL-500g Premium Wireless router and a Duracell portable battery. D-Track is the information retrieval and communication device that collects the D-Tags’ signal strengths (RSSI) and ID numbers (ID#) at the scene. The RSSI and ID# readings are then sent to the DIORAMA Server through the D-Gateway. The D-Gateway is a networking device that creates an ad-hoc network at the emergency site and interconnects the disaster site with the remote DIORAMA server. It is the combination of a Broadband USB modem and a mobile wireless router. It interconnects between local network (e.g. Wi-Fi) and the Internet using vertical links (e.g. cellular, satellite).

The DIORAMA server processes all information received from the D-Gateway and runs the DIORAMA software detailed in Sections 4. The Windows based server runs .NET Framework 3.5 installed (needed to run applications), MS SQL Server 2005 Express or higher.

The DIORAMA software that runs on the DIORAMA server computes the victims’ location and displays it on the DIORAMA GUI. The system users login to the DIORAMA server and can view the victims’ location overlaid on Google maps as well as summary tabs which include information such as the total number of victims of each severity level (i.e., color) and the number of evacuated victims. See Figure 1.

### III. DIORAMA SOFTWARE OVERVIEW

The DIORAMA software that runs on the server is divided into four parts:

**DIORAMA Server Listener:** it listens for incoming socket connections from the D-Tracks. Once the connection has been established the Listener receives RFID tag ID# and RSSI from the D-Track devices.

**SQL Server:** the Server Runs Microsoft SQL Server 2008 Enterprise which stores ID#, RSSI, Victim Condition, and positional information.

**DIORAMA Localization Engine:** when a victim is discovered, its position is updated at the paramedic’s current location as determined by the localization engine (see Section 6).

**DIORAMA Web Interface:** it queries the database for Paramedic and Victim Positions. Their positions are then overlayed on a Google Maps Interface using predefined markers. As the paramedic position changes, the marker will be updated to the new location. As victims are triaged they will appear on the map and an additional interface will count the number of victims at the scene.

### IV. LOCALIZATION ENGINE

The DIORAMA system uses a signal strength fingerprint approach to localize the paramedic wearing the RFID tags mounted on the helmet. The test area is first uniformly discretized into small grids which are indexed. For each grid, the expected received signal strength of beacons sent at that location and received by all RFID readers deployed will be calculated according to a radio propagation model. The expected received signal strength is unique for each grid, and constitutes the fingerprint of the grid.

Let $d_{ijk}$ the distance from the center of the grid $(x,y)$ to reader $k$, the expected signal strength at grid $(x,y)$, from reader $k$, the expected signal strength can be approximated as a second order polynomial of the distance as

$$s_k(x,y) = 0.71 \log(d_{ijk})^2 + 8.49 \log(d_{ijk}) + 39.3. \quad (1)$$

The parameters are determined using curve fitting under outdoor environments. The raw measurements and the fitted curve are shown in Figure 3.

The fingerprint of a grid is a vector composed of expected signal strength from all readers. For a configuration including $N_r$ readers, the fingerprint of grid $(x,y)$ will be $[s_1(x,y), s_2(x,y), ..., s_{N_r}(x,y)]$. The fingerprint vector is calculated for each grid and stored at the server.

To estimate the location of a paramedic, we calculate the average signal strength for each reader by averaging the signal strength readings of RFID beacons sent by 15 tags mounted on paramedic D-helmet over 12 seconds. Given a beacon interval of 2 seconds, there are 6 measurements for each tag.

Let $s_{ijk}$ be the $i$th signal strength measurement of tag $j$ received at reader $k$, the average signal strength for reader $k$ is

$$s_k = \frac{1}{15} \sum_{j=0}^{15} s_{ijk}. \quad (2)$$

The localization algorithm search the best match fingerprint in the signal strength fingerprint database, and use the grid location as the location estimate. A cost function is defined according to how close the actual measurement $s_k$ matches the fingerprint $s_k(x,y)$ at each grid

$$Cost(x, y) = \sum_{k=0}^{N_r} \left( s_k - s_k(x,y) \right)^2. \quad (3)$$

With the cost function defined in equation (3), the location can be estimated as
\[
[x, y] = \arg \min_{(x, y)} Cost(x, y).
\]  

(4)

Figure 4 shows an example of cost function for a 100ft X 100 ft setup, with a paramedic standing at (40,30). In this example, the minimum of the cost function is achieved at grid (24, 44), which will be used as the estimated location.

V. TESTING

To evaluate quantitatively the performance of DIORAMA we conducted multiple simulation trials in a 100ft x 100ft zone with different number and placement of victims (up to 27) and different environmental conditions (daylight, darkness, obstacles). In the remainder of this section we will provide two sets of results:

1. “Accuracy” trials, which measure the achieved accuracy of the localization algorithm
2. “Simulation” trials, which compare the evacuation time and evacuation completeness between the DIORAMA system and the paper-based system

In each trial we followed a specific grid where the position of each victim is defined in advance. An example of the simulation grid is depicted in Figure 5.

The trials included various settings such as: Visibility (daylight or darkness), number of victims (10 to 27), victims’ triage level distribution (number of Red, Yellow, Green and Black), victims’ representations (cones/human subjects), and scene visibility (with or without obstacles).

Accuracy Tests

We conducted numerous trials in which we computed the difference between the estimated position and the real location of the victims. The average and standard deviation of all displacements was then calculated. We recorded no statistical differences in the location accuracy by changing the trials’ settings. Since we need to locate humans which are significantly larger than a cone, the correct way to represent the location accuracy is using the body length metric (6 feet). Therefore, errors less than 6 feet are counted as zero unit, errors between 6 to 12 feet are as one unit, etc.

We have obtained average accuracy of 10.66 (1.78 body length) feet with standard deviation of 5.26 feet (0.88 body length) over 16 trials. We showed that most poor localization estimation can occur for victims placed on the border, from a mirroring effect for some positions on the grid or just when the readers are globally far from the tags and make the estimation more sensitive to background noise. However, despite this phenomenon, the average accuracy stays consistent.

Evacuation Time and Evacuation Completeness

We compared the evacuation time between the DIORAMA arm and the paper-based triage arm. For each layout and settings we had a DIORAMA trial and a paper based trial (see Figure 5). All trials were performed by four certified EMTs. Each of them were attributed a permanent role for all the simulations: Incident Commander for the DIORAMA phase, Evacuator for the DIORAMA phase, Evacuator for the paper-based phase, Triage EMT for both DIORAMA and paper-based phase.

Only the DIORAMA team knows the grid used for deploying the victims in the field (see Figure 5). The EMTs have no knowledge of the grid and do not have any visual contact with the scene before they assume their role (triage and evacuation) in the trial scene. The I.C. has no visual contact with the scene and only uses the information provided by the DIORAMA GUI to instruct the paramedic in the evacuation phase. This demonstrates the utility of this system in allowing a commander who is not able to directly visualize the scene to effectively direct the rescue personnel.

For both DIORAMA and paper trials we recorded the evacuation time, the evacuation completeness (percentage of victims that are evacuated from the total number of red and yellow victims to be evacuated) and the total number of incorrect visits (visits of the EMT to victims that do not need to be evacuated).

Our results show an average reduction of 30% in evacuation time in the DIORAMA trials compared to the paper triage trials. The savings in trials with obstacles is as high as 54%. The significant reduction in evacuation time is explained by the drastic reduction, average 80%, in the number of incorrect visits in the DIORAMA trials compared to paper trials. This is due to the fact that in the DIORAMA system the evacuator is guided by the IC to the victim that needs to be evacuated (a red victim or a yellow victim, depending on the situation), i.e., there are very few incorrect visits. On the other hand, in a paper triage trial the evacuator has no guidance, and therefore scans the disaster area multiple times. In a large disaster site the time taken by incorrect visits can significantly increase the evacuation time during the paper triage trials, improving the relative efficiency of the DIORAMA system.

Another interesting result is the evacuation completeness. In the DIORAMA system we obtained always 100% evacuation completeness while in the paper trials we obtained as low at 80% evacuation completeness. This is due to the fact that in the DIORAMA system the IC knows the number of victims of each severity level and therefore, no victims can be left behind.

Qualitative Assessment

We have collected qualitative feedback from the EMTs that participated in the trials including the EMT supervisor that attended most of the trials. Overall the collected feedback was extremely positive and encouraging. The current prototype is evaluated as already very useful to provide a bird’s-eye view of the triage and evacuation situation and to provide direct guidance to the EMTs on site. The system is recognized by the EMS community as “potentially being incredibly useful and providing remarkable improvements in MCI’s”, especially for large scale disasters. They recognize that the system can considerably reduce the evacuation time on large areas. The participating EMTs, particularly appreciate the quality assurance DIORAMA brings to the rescue because it ensures a 100% complete evacuation.

Most identified weaknesses are related with some GUI improvements, with the suboptimal hardware used or with the fact that the system does not support multiple EMTs simultaneously. These elements are understandable for a
prototype system and could easily be solved or improved by implementing some changes in the code and by using customized hardware for the D-tags and D-tracks.

VI. CONCLUSION

In this paper we introduced DIORAMA system which provides real-time localization and tracking of victims in a disaster scenario. As presented in the paper the system deployment is inexpensive while providing very good location accuracy of victims during a mass casualty event.

In order to deploy the system as a commercial product we need to 1) miniaturize and ruggedize the hardware, 2) address the scalability issues in both software and hardware, and 3) run large scale trials to prove the feasibility and usefulness of the system.

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