Mobile DIORAMA-II: Infrastructure less Information Collection System for Mass Casualty Incidents

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***Abstract*—In this paper we introduce DIORAMA-II system that provides real time information collection in mass casualty incidents. Using a mobile platform that includes active RFID tags and readers as well as Smartphones, the system can determine the location of victims and responders. The system provides user friendly multi dimensional user interfaces as well as collaboration tools between the responders and the incident commander. We conducted two simulated mass casualty incidents with 50 victims each and professional responders. DIORAMA-II significantly reduces the evacuation time by up to 43% when compared to paper based triage systems. All responders that participated in all trials were very satisfied. They felt in control of the incident and mentioned that the system significantly reduced their stress level during the incident. They all mentioned that they would use the system in an actual incident.**

I. INTRODUCTION

The overall goal of DIORAMA-II system is to provide an information collection infrastructure for mass casualty incidents that can be easily deployed, is scalable and is durable. It will aid in rapidly assessing the patients within a disaster scene, determine the response capabilities needed, and managing assets as they arrive on the scene. DIORAMA-II will enhance the effectiveness of the response in an ever-changing, often disorganized disaster. This is the first system to provide this functionality while preserving design guidelines such as easy to use technology, seamless integration in the responders current triage and evacuation procedures, low cost and scalable technology.

While the systems presented in [1-3] introduce novel ideas to improve the triage and evacuation phase of a mass casualty incident. they lack the ability to track victims and responders in real time during the triage and evacuation stages. Moreover, they provide no collaboration tools between the incident commander and the responders. Both real time tracking of victims and responders and collaboration tools are provided in DIORAMA-II system.

In [4] we introduced DIORAMA system which provides real time tracking of responders using a fixed deployment of tracking devices. In DIORAMA-II we introduce real time tracking of responders and victims using a mobile tracking system carried by each responder. Moreover, DIORAMA-II introduces collaboration tools between the responders and incident commander as well as novel visualization tools available to the responders such as Augmented Reality.

We conducted two simulated disasters with 50 human subjects each and Emergency Medical Technicians that assumed the roles of incident commander or triage/evacuation responders. The results of these trials highlight the advantages of DIORAMA-II which reduces both triage time and evacuation time when compared to traditional paper based triage systems. We obtained evacuation time reduction of up to 43%. Moreover, we showed that in DIORAMA-II all victims were evacuated in order (i.e., red victims always evacuated before the orange ones) while in paper based trials we observed that the strict evacuation order was not followed.

All responders and incident commanders that participated in the trials liked DIORAMA-II, have mentioned that they would like to use the system in a real incident. They felt in control of the incident and while substantially reducing the triage and evacuation time, the system significantly reduced their stress level during the incident.

The paper is organized as follows. In the next section we introduce DIORAMA-II architecture. The recurrent localization algorithm is outlined in Section III. Section IV describes the trials and results and Section V concludes the paper.

II. DIORAMA-II ARCHITECTURE

DIORAMA-II system architecture which is illustrated in Fig. 1 includes the following main components: Android Smartphones and tablets running DIORAMA-II application, active RFID readers and tags and the DIORAMA-II server.

Each responder that performs triage and/or evacuation carries an Android Smartphone that runs DIORAMA-II application as well as the following devices that use active RFID technology: active RFID reader denoted DM-track and active RFID triage tags denoted D-tags. Each patient is triaged according to their injury level (red, yellow, green, black) and is tagged with a D-tag in addition to the paper triage tag. The DM-tracks collect patient's D-tag ID and the D-tag's signal strength measurements. This information along with patients' triage status and the responder current location (obtained from the GPS of the phone) is collected by the Smartphone and sent to the DIORAMA-II server. The localization algorithm which runs on the server uses this information to determine the location of each patient. An outline of the localization algorithm is introduced in Section III.

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The incident commander (IC) directs the incident using an Android based tablet that is running the DIORAMA-II IC application. The IC and responders receive on their devices (tablet or Smartphone) that run DIORAMA-II application periodic updates from the server about the location of each patient along with their triage status.

More details on the IC and responder applications are provided below.

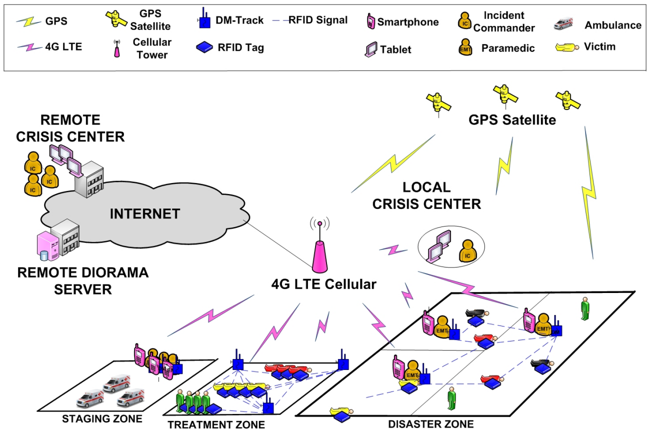

Figure 1a. DIORAMA II Architecture

A. *Incident Commander Application*

The goal of the IC application is to provide situation awareness about the incident as well as enable the IC to communicate with the responders and direct the scene. Fig. 2 depicts the IC disaster zone mapview. The map includes the location of the triaged patients, responders and other points of interest (POI). As the patients and/or responders move throughout the scene their positions are dynamically updated.

The IC has the ability to macro or micro manage the incident. For example, the IC can assign a responder to evacuate a specific patient or to evacuate patients in a specific area.

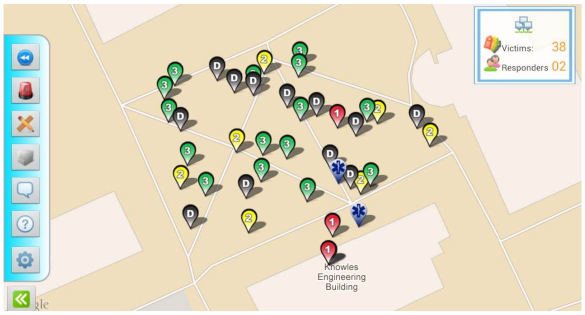

Figure 2. Disaster Zone Mapview

B. *Responder Application*

The responder application includes: a) a mapview that provides an overview of the disaster scene as well as the ability to collaborate with the IC, and b) Augmented Reality (AR) user interface which enables the responders to find the patients to be evacuated.

Fig. 3 displays the mapview which centers the map based on the responder location. This function allows the responder to understand the scene as he/she is moving without having to continually pan the map to their new location.

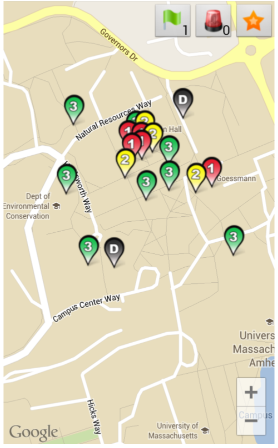

Figure 3. Responder Mapview

Fig. 4 depicts the AR view. AR fully immerses the provider in an interface that is organic to the user. It uses the smartphone's camera as the background instead of a map.

Figure 4. Augmented Reality

The responder can then hold the smartphone and see the patients overlayed on top of the camera background. This presents the provider with a Heads Up Display that fits in their pocket. This perspective is very natural as it uses the reality, what is actually in front of the responder, and augments with DIORAMA-II collected situational information giving the responder the ability to see their patients from far away and through obstacles like trees, vehicles, and buildings. When focused on a particular patient this perspective provides an arrow indicating the direction the patient is with respect to the responder as well as the distance between the responder and the patient.

C. *Collaborative User Interface*

Both the IC App and the responder App provide collaborative user interface that empowers the IC to send commands to the responders and allow the responders to clearly understand the command and provide feedback. These collaboration tools are a very powerful feature of DIORAMA-II as currently the only means of remotely directing responders in the field is using the radio unit. Due to the ambient noise during an incident it is very difficult to convey commands using the radio unit, leading to miscommunication and waste of precious time. The simplicity of the interface allows the provider to clearly see what has been assigned to him without the need to utilize the radio unit.

III. RECURRENT LOCALIZATION ALGORITHM

To achieve a scalable system, independent of the geographical span of the disaster site, as well as expediting the initial triage process we need to localize the patients using only mobile DM-tracks carried by the responders. Recurrent localization of a patient using active RFID measurements from the DM-tracks carried by the responders in the vicinity of the patient has the following three challenges:

(1) at a particular time, the current estimate of the patient location can not be approximated by a parametric model very well. For example, with one or two responders nearby, the distribution of the patient location is of a ring shape distribution and a two modal distribution respectively.

(2) the measurement model is non-linear even for the free-space attenuation model, and becomes more complicated when the inaccuracy of the responder location given by GPS, and the likelihood of an obstacle needs to be taken into consideration.

(3) the motion of the patients is too arbitrary to be accurately modeled and poor and intermittent RSSI measurements make it very challenging to maintain the states of the motion model to improve location estimates.

To localize and update the victim locations, the localization engine processes the information in the following steps:

Step 1: Acquire all the readings information from each responder in the past 10 seconds. Each reading includes RSSIs received from nearby D-tags, Responder ID, Patient ID, timestamp and GPS coordinates. We know for each responder his/her GPS coordinates as well as the RSSI received from the patients in the vicinity.

Step 2: Calculate the distance between the coordinates of each grid and the GPS coordinates of the responder. Fig. 7 shows the signal strength attenuation model used to obtain the RSSI given the distance. Using this model, the program calculates the expected RSSI on each grid and uses the cost function to calculate the cost on each grid. Following the position estimate function, the localization engine will compute the estimated location of each patient within the range of the responder.

Step 3: Using the attenuation model in Fig. 5 we define a cost function

$$Cost_{(x,y,t_i)} = \sum_{t=1}^{t=i} |S_{expected(x,y,t)} - S_{measured(t)}|^2 \quad (1)$$

The cost map is depicted in Fig. 6.

The algorithm computes the location in the sampling area with the minimum cost as the estimated location of the victim. With the cost function defined above, the location can be estimated as

$$[\hat{x}, \hat{y}]_t = argmin_{(x,y,t)}\, Cost(x, y, t) \quad (2)$$

For example, if we take a look at Fig. 6, we observe that the estimated location will be in the darkest grid because of the minimum cost at that grid.

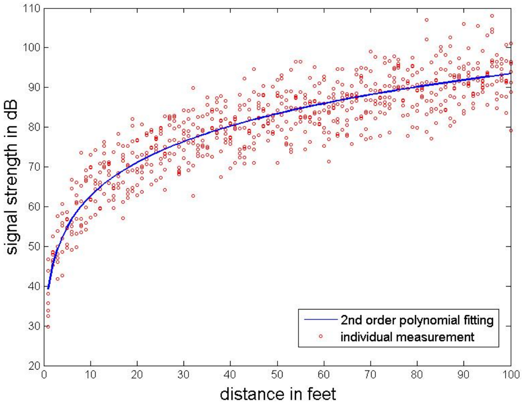

Figure 5. Signal Strength Attenuation Model

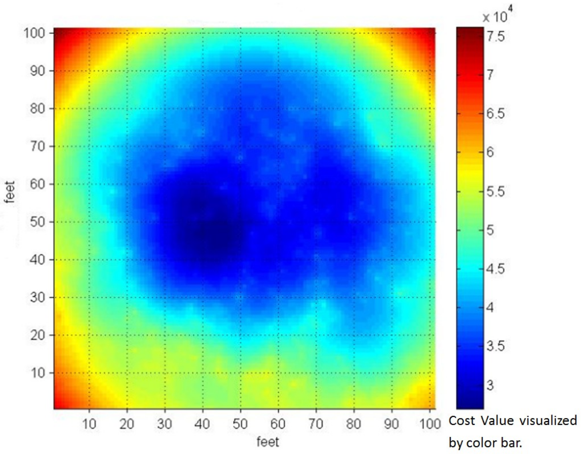

Figure 6. Sample Cost Map

It is important to mention that steps 2 and 3 are performed for each victim.

Since the localization devices, i.e., the DM-tracks, are mobile and carried by the responders the localization accuracy depends on the distance between the responder and the victim as well as the time the responder spends in the vicinity of the victim. The shorter the distance the better quality RSSI readings we obtain. The longer the time spent at shorter distances the more RSSI readings we obtain. In our trials we obtain a localization accuracy of less than 6 meters if we obtain an average of 3, 6 and 4 readings at each of the following distance ranges: 0-6, 6-12, 12-18 meters, respectively.

We would like to emphasize that the localization accuracy is not the main objective of the system since absolute coordinates of the victim are very difficult to understand on a user interface. One of the most important design guidelines in our system is the localization system mobility and the fact that we do not need to calibrate the system when we arrive on the mass casualty site. Obviously if we have a fixed system which requires careful calibration and significant more cost we can obtain better localization accuracy. As shown in the next section we show that we obtain sufficient accuracy with the localization algorithm introduced in this paper.

IV. TRIALS AND RESULTS

The trials compare the triage and evacuation procedures of the DIORAMA-II system and the traditional paper-based system. We measure the improvements of the DIORAMA-II system in terms of triage time, evacuation time, evacuation order and evacuation completeness.

We conducted two simulated disasters at the University of Massachusetts Amherst campus. In each simulation we assume a tornado touches down and many students are injured. In each simulation we have two regions:

Region 1 (North): A region of approximately 29,000 square meters that encompasses 7 academic buildings.

Region 2 (South): A region of approximately 43,200 square meters that encompasses 2 academic buildings.

All simulations were performed by certified responders from the local EMS unit of UMASS Amherst. In each trial we have one IC, two responders that perform triage and two responders that perform evacuation. The patients were students (18 years or older). We deployed 25 patients in each region for each simulation (total of 50 patients per simulation). Each patient is designated to a specific location within the trial region along with a priority card that determines the patient triage priority level. The responder triages each patient based on the priority card.

In our simulations we use crossover design as follows: each trial is divided into two separate simulations. Each simulation has two simultaneous triage and evacuation trials. One trial will perform a DIORAMA-II triage and evacuation while the other will perform a paper-based triage and evacuation. The following simulation will occur on a separate day. The responders that performed a DIORAMA-II trial would then perform a paper-based trial using identical trial setup. The responders that performed the paper-based trial would then perform a DIORAMA-II trial with an identical trial setup. These two simulations must be separated by a period of at least two weeks time, defined as a washout period. Since the participants will be performing the same trial setup this washout period is necessary for the participants to forget the details regarding the trial setup such as patients locations and priorities. Each emergency responder involved will perform the exact role in each simulation. In effect, each responder serves as his/her own control. Also, since the same responder will experience both paper tags and DIORAMA-II tags, there is no possibility of covariate imbalance.

A. Quantitative Results:

Triage: in Region 1 trials we have 34.3% reduction in triage time with DIORAMA-II compared with paper based trials. In Region 2 we have 14.7% reduction in triage time with DIORAMA-II compared with paper based trials. We obtain this significant reduction in time due to the use of the collaboration tools between the IC and the responders. The DIORAMA-II collaboration tools display clearly to each responder what is their assigned area and there is no overlap between the areas triaged by different responders. In the paper based trials we observed significant overlap between the areas where the responders are looking for patients that have already been triaged.

Evacuation: in Region 1 trials DIORAMA-II evacuation was faster than paper based trials by 39.3% and 47.4% for red and yellow patients, respectively. DIORAMA-II trial finished evacuating both the red and yellow patients before the paper based finished evacuating the red patients. In Region 2 DIORAMA-II evacuation was faster by 30.6% and 25.6% for red and yellow patients, respectively.

We obtained the significant reduction in the evacuation time due to the following reasons: 1) DIORAMA-II responder user interface (either mapview or AR) enabled each responder to easily find the patients to be evacuated, and 2) each responder was assigned by the IC the area and the patients that need to be evacuated. In contrast, in paper based trials the responders were searching for patients randomly. They did not know the patients location, their priority nor the number of patients of each priority.

Evacuation Order: In Region 1 all patients were evacuated in proper order, i.e., all red patients were evacuated before the yellow patients. However, in Region 2 during the paper trials the responders did not evacuate the patients in proper order. A red patient was evacuated after two yellow patients

B. Qualitative Results:

The responders that participated in all trials were very satisfied with DIORAMA-II in multiple dimensions. They all felt in control of the incident while understanding that the system provides measurable benefits in reducing the triage and evacuation time. They all mentioned that they would use the system in an actual incident.

V. CONCLUSIONS AND FUTURE WORK

In this paper we introduced a low cost easy to use DIORAMA-II system that provides situation awareness to the incident commander and responders. As shown in the simulated incidents with human subjects, the system can significantly reduce the triage and evacuation time of patients at a Mass Casualty Incident, significantly improving survival rate of these patients.

VI. REFERENCES

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