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Improving Emergency Response to Mass Casualty Incidents

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Abstract

Mass casualty incidents generate a sequence of response events from the emergency services, requiring the allocation and use of resources in a timely fashion. In this paper we describe a pervasive system that helps emergency services optimize their efficiency and coordination. The system emulates a multiple casualty emergency response environment in which contextual information, retrieved from victims' wearable or mobile devices, guides early assessments on the health condition of the affected population. Additionally, we analyze the behavior of our system under different conditions and derive the necessary parameters for achieving accurate estimations. Our main contribution is the enhancement of the existing emergency response process for mass casualty incidents through the use of Pervasive Computing technology.

1. Introduction

Public surface transportation systems' susceptibility to terrorist attacks imposes new challenges to homeland security experts. According to the Terrorism Incident Database, maintained by the Memorial Institute for the Prevention of Terrorism (MIPT) [1], in the last decade there were 882 incidents, 6,924 injuries and 2,062 fatalities attributed to terrorist attacks on transportation systems worldwide. Of those attacks, 39% were carried out in subways, trains and stations [2]. The general consensus among transit officials and security specialists is that surface transportation systems, especially the passenger rail systems, are inherently vulnerable due to the very nature of their design and operations, characterized by high passenger flows and fixed routes with predefined stops. Thus, it is virtually impossible to defend against random attacks [2],[3]. As a consequence, transit agencies have focused on containing consequent harms rather than preventing them.

In this paper, we suggest improvements to the emergency response process involving multiple casualty incidents by means of Pervasive technologies. Through analyzing the sequence of events enchained during emergency response, we have identified improvements that can be brought to the context of terrorist bombings performed inside a metro carriage. We have built a system that emulates a pervasive response environment in which health data is retrieved and gathered from mobile and wearable devices carried by passengers. The system uses sensed data to derive estimations on the number and condition of patients, which are subsequently passed on to emergency and medical personnel. Here we analyze the behavior of our prototype under various conditions and identify the optimum parameters for generating accurate estimations.

2. Background and related work

As a reaction to the high incidence of current terrorist attacks, emergency and disaster management communities have focused on enhancing the emergency management process by applying advanced and Pervasive technologies [4],[5],[6],[7],[8],[9]. Pervasive systems used in emergency situations, more specifically to support the emergency response stage, are recent in the literature. Practical work in this domain has focused on enhancing the existing response process to single casualty incidents. Kalasapur et. al. [5] applied techno-rich computational devices and sensors to the inner infrastructure of a car in order to enable the assessment of passenger's health information in case accidents occur. Further on, Tognalli [6] employed agent systems on a heterogeneous distributed environment to aid ambulance controllers who, equipped with Java-compliant cell-phones, are able to book specialists, and to find and query nearby hospitals.

Nevertheless, in mass casualty incidents the overall goal of treatment shifts from the individual to the

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affected population as a whole [10]. This suggests that, in these circumstances, support systems should be used to identify victims in potential life threatening condition and prioritize their treatment.

The emergency response process for multiple/mass casualty incidents, known as the *casualty sequence flow*, consists of five consecutive steps [10]: rescue and decontamination, triage of patients, stabilization, evacuation and definitive treatment. Identifying the number and condition of victims, referenced to as *scene assessment*, occurs during triage and is of great importance as it triggers a chain of events involving personnel and resource allocation by several emergency services. Triage is performed upon the arrival of a specialized medical first responders' team on site which conducts initial triage by attaching RED (immediate), YELLOW (delayed), GREEN (minor) or BLACK (deceased) colored paper triage tags to patients based upon assessed priority [11]. Research in this domain has focused on improving the triage process through the use of electronic tags, employing tag readers and mobile devices to collect data about the mass casualty events [7],[8],[9].

Considering the importance of the time window in which triage activities are undertaken, there is a significant time sensitivity attached to the arrival time and number of emergency responders at site as well as on the amount of victims in need of assistance. Therefore, speedups at this stage can lead to a significant optimization regarding the allocation and utilization of emergency-related resources (e.g., ambulances, beds in hospitals, etc) and can identify the number of required personnel (e.g., surgeons, rescuers, ambulance drivers, etc). More importantly, such gains in time have been shown to reduce the *overall critical mortality rate*, i.e., the percentage of deaths among only the critically injured survivors [12].

Taking into consideration the conditions under which triage and treatment take place, here we focus on providing an early assessment and early warning of the number of victims that the emergency services may expect. Specifically, our work focuses on gathering contextual information retrieved from users' mobile/wearable devices, which follows the Simple Triage Rapid Treatment (START) [11] scheme, in order to guide such estimations.

3. Proposed multiple casualty emergency response environment

To enhance the emergency response process to mass casualty incidents, we focus on employing Pervasive technologies to facilitate the collection and gathering of passengers' emergency-related contextual information in the context of a metro terrorist attack scenario. A fundamental feature intrinsic to our scheme is the augmentation of metro carriages with hazard detector transducers (e.g., peak overpressure sensors) and with inner dedicated emergency communication channels (e.g., Bluetooth, WiFi, UWB and so), as depicted in Figure 1. Abnormal events which extrapolate predefined thresholds trigger emergency procedures. The inner connection enables a non-intrusive communication interaction between passengers' devices (mobile phones, PDAs, smart wristwatches, etc) and the metro infrastructure. This feature is important so that, in case of an emergency, passengers' contextual information may be non-intrusively retrieved through their mobile devices. This data is then used for further estimations on the number and condition of victims on site.

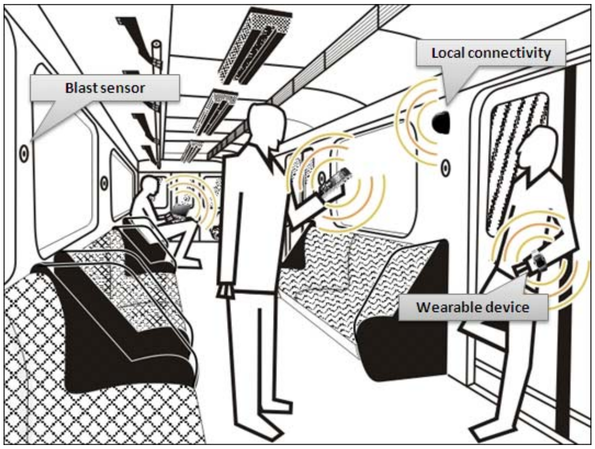

Figure 1. Pervasive metro emergency response environment.

3.1. System architecture

Our pervasive system has been built on top of a multi-agent architecture. Agents cooperate and collaborate to emulate the proposed emergency response environment. *Environmental agents* are installed in the infrastructure of the carriage and are responsible for a series of activities: management of train schedule stops, aggregation/interpretation of data acquired by hazard detection transducers, supervision of passengers' boarding and disembarking activities, among others.

Moreover, we assume that *emergency service agents* are running on the emergency services systems (e.g., the ambulance service center system) so that they can interface with environmental agents when needed.

Finally, *personal agents* are installed on mobile devices carried by train drivers and passengers. For train drivers, the agents act as a warning mechanism when any abnormality is sensed by environmental agents. If a hazard is detected, a series of broadcasting queries is issued from environmental agents to passengers' personal agents, so that data can be collected from users.

To collect data from users, we have designed a START [11] based self-assessment scheme that users can carry out with mobile devices (like PDAs, smart phones, cell phones and wristwatches). This scheme provides a quick high-level health assessment of the passengers by issuing symptoms-related instructions and questions. In our scheme, each passenger is classified in one of the following conditions, ranging from low medical priority to high priority: OK, GREEN, YELLOW, RED.

An alternative to using end-users' mobile devices would be on-site transit officials (e.g., train driver) to rapidly distribute auto-configurable mobile health monitoring sensors (e.g., blood pressure, oxymeters, blood rate sensors, etc) which are able to non-intrusively perform a similar assessment.

3.2. Prototype

The described agents and their intercommunications were designed and implemented by employing the multi-agent JADE [13]/LEAP [14] platform. Environmental agents were implemented with the JADE platform and were hosted on a main-container deployed on a Windows machine. Personal agents, implemented with the JADE/LEAP combination, run on the J2ME CDC implementation provided by IBM's WEME J9 Virtual Machine. For our tests, we used Softbank X01HT cell phones equipped with Windows Mobile 5.0. Local wireless connectivity, to bridge the connection among personal agents and environmental agents, was established using the IEEE802.11b/g standard.

3.3. Evaluation

While we intend to carry out a real-world study of our system, such a study is quite expensive to prepare and carry out. So far we have developed a custom modeling and simulation environment which we can use to assess the effectiveness and accuracy of our proposal under a range of environmental conditions. The simulation parameters are as follows: *(i)* each carriage has 200 passengers; *(ii)* passengers carrying mobile devices are distributed uniformly, their number defines the *sample size*; and *(iii)* after an emergency occurs, each mobile device responds with OK, GREEN, YELLOW or RED; and *(iv)* the overall response for each category defines their corresponding *response rate*.

By varying the sample size (from 12.5% to 100% of the population size) and by exploring different possible response rates (from 12.5% to 87.5% of the sample size), we were able to obtain the overall error margin (obtained by using 95% confidence interval), for each single response, Figure 2. It is notable that higher sample sizes result in smaller error margins and, therefore, an increased accuracy of the estimations. Hence, in the case of small sample sizes the lack of information will lead to vague estimations that will probably be inadequate in aiding the response process.

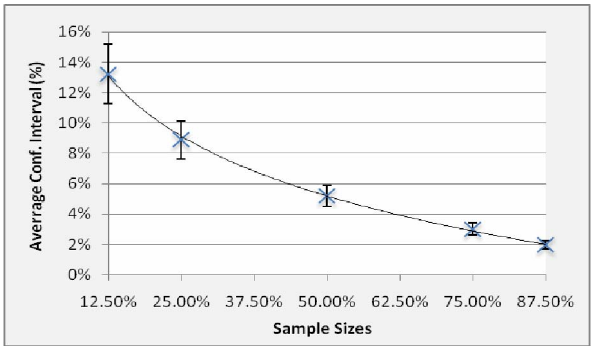

Figure 2. Average confidence interval *versus* sample sizes over an average of all response rates.

To illustrate the *de facto* use of this chart, let's assume that during an incident, 50% of passengers possess mobile devices and that 15 are evaluated as severely injured. Therefore, it is possible to assume that in overall 15/50 = 30% of individuals are in a similar health condition, with an error margin of ± 5% (as obtained from Figure 2). It is important to point out that in a real-world scenario, by employing trained personnel to identify potential victims not only optimizes resource utilization but also increases the overall accuracy of the proposal.

Additionally, we ran through a specific simulation scenario in which the actual response rate from each category was 50% OK, 5% RED, 10% YELLOW and 35% GREEN. Figure 3 plots the obtained error margins. It is noticeable that the error increases as the response rates get higher. This is due to the fact that for each individual category the confidence interval curve goes up to its maximum at 50%, and decreases after this point. This suggests that if percentages of each category (OK, RED, YELLOW, GREEN) are distributed relatively evenly, the accuracy of our system is compromised. On the other hand, should there be one category with most passengers (e.g. OK), then the accuracy of our system is strengthened.

An important note is that the error margin increases more abruptly for smaller sample sizes. Although the error margin, calculated with 95% confidence interval, may increase according to the response rate, keeping to higher sample sizes shorten

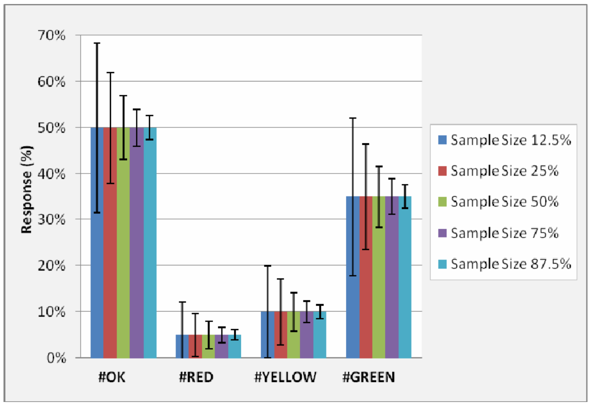

Figure 3. Error margins for predefined response rates for each category: #OK (50%), #RED (5%), #YELLOW (10%) and #GREEN (35%).

the error margin slide window, and thus increases the overall accuracy.

We should also point out that while sample sizes and response rates may seem arbitrary measures, in fact they can provide concrete guidance in commercializing such kind of system. Given known statistics about the penetration of specific technologies in the general population, authorities can make a more educated decision about which devices they decide to support. If, for instance, we know that about 10% of passengers have Bluetooth devices, then we also know that 10% is the potential maximum sample size our system can expect if an attack takes place.

4. Summary and ongoing work

In this paper we present a pervasive system for enhancing the existing emergency response process in the context of a metro/subway attack. Our aim has been to provide an early assessment of the casualties and incurred damage, even before the first medical responders arrive at the scene of the incident.

Our results demonstrate that the accuracy of our system's estimations depends on passenger sample size and response rates. This knowledge enables us to assess the quality of our systems estimations, and decide if they do or do not assist emergency services during the response process.

We note that any simulation-based study may be questioned about its external validity. In our case, a proper evaluation of our system is quite expensive and time-consuming, thus we have opted to initially use simulation to identify emergent properties of our system. So far in our work we have tested the behavior and accuracy of our system under different conditions and assuming rational user responses.

As part of our ongoing work we aim to improve our self-assessment scheme by incorporating universal accessibility features and models of user responses under extreme stress.

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