eTriage: A Wireless Communication Service Platform for Advanced Rescue Operations

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ABSTRACT

In mass casualty incidents (MCIs) such as earthquakes, medical resources are overwhelmed by the number and severity of casualties. In this paper, we propose a wireless communication service platform in such situations for advanced rescue operations named eTriage. For this purpose, we have developed electronic triage tags by combining a small vital sensor with a wireless device. The electronic tag is attached to a casualty, and vital signs of the casualty are gathered via wireless ad hoc networks constructed by the electronic tags. Our platform provides ad hoc networks, which are very useful for various services such as localization and local map generation as well as monitoring of vital signs.

Categories and Subject Descriptors

J.3 [**Computer Applications**]: GENERAL

General Terms

Design

Keywords

Wireless Networks, Triage, Localization, Map Generation

1. INTRODUCTION

In Mass Casualty Incidents (MCIs) such as earthquakes and bus collisions, medical resources (i.e. personnel and facilities) are overwhelmed by the number and severity of casualties. In such situations, we employ triage, which is a process of prioritizing casualties based on the severity of their conditions when a large number of persons are injured simultaneously. Triage

Table 1: **Triage categories and severity.**

Category	Severity
Black (O)	Dead or dying: no care
Red (I)	Life-threatening: need immediate care
Yellow (II)	Treatment and transportation can be delayed
Green (III)	Those with minor injuries: less urgency

Figure 1: **Paper triage tags.**

aims to save as many victims as possible by deciding the order of treatment. In Japan, triage was applied for the first time in April 25, 2005 for a big derailment accident where totally 107 persons were died and 562 passengers were injured. Triage in Japan is done based on START (Simple Triage And Rapid Treatment) protocol, which categorizes a patient into one of four categories shown in Table 1. A paper tag is attached to each patient to indicate the determined category (see Fig. 1).

However, paper tags cannot monitor dynamic change of patients' condition. In Kobe Earthquake in 1995, about 13% among 372 patients were died by sudden vital changes caused by a crush syndrome. In general, it is difficult to diagnose a crush syndrome in the early stage. It is required to check patients' conditions continuously in order for avoiding such situations although we cannot expect such frequent treatment in disaster because there are not enough medical staffs for contin-

uous monitoring of all the patients. Another serious problem is difficulty in managing locations of patients and medical staffs. Medical staffs from many hospitals rushes to the disaster site, and some victims are laid on the ground without any treatment while some others may be transported to hospitals quickly. We can easily imagine it is very difficult for first responders to manage staffs and patients with respect to locations in such a chaotic situation.

Thus, we have developed an electronic triage system (eTriage) [1], which is a wireless communication service platform for advanced rescue operations. In eTriage, electronic triage tags are attached to injured persons. This tag senses vital signs of each person via wireless networks and enables medical staffs to monitor dynamic change of his physical condition in real time. Furthermore, eTriage provides locations of injured persons and medical staffs by our ad hoc localization algorithm called TRADE [3]. TRADE utilizes estimated trajectory of mobile nodes for increasing localization accuracy. We have also investigated a map generation technique [6] based on location information of mobile nodes and ad hoc communication. We may be able to use an existing map database such as Google Maps [2], however, buildings and/or walls may collapse in a disaster and such a map may have been changed as a result. For this reason, we have developed a map generation technique in a disaster. The merit of the technique is that the algorithm does not require any additional operations for first responders.

In the United States, some projects by NASA, FEMA and NLM have investigated advanced medical support systems using wireless communication technology. AID-N (Advanced Health and Disaster Aid Network) [4] uses a sensor platform called CodeBlue [8] developed by Harvard University. CodeBlue is composed of small sensor nodes, Motes, and provides vital sign gathering and estimated location information of nodes. Localization is based on fingerprinting, which requires building database of radio characteristics at each location beforehand. In addition, miTag presented by AID-N project in 2008 is capable of providing location information of nodes by an embedded GPS chipset. Similarly, WIIS-ARD (Wireless Internet Information System for Medical Response in Disasters) [5] by Tech Specs also investigates an advanced medical support system by using wireless networks.

Different from these approaches, eTriage provides a location service platform including automatic map generation in addition to localization, which is especially useful in disaster in underground cities and/or dense urban areas where there area many tall buildings with large GPS errors. Furthermore, we have designed and tested our system in cooperation with medical staffs. In this paper, we show the design of eTriage and the
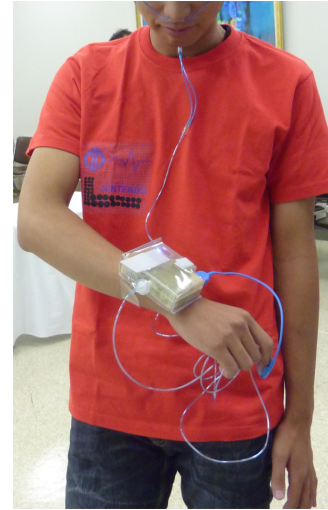

Figure 3: eTriage-Full.

Figure 4: eTriage-Light.

overviews of helpful functions.

2. ETRIAGE OVERVIEW

Fig. 2 shows the overview of our electronic triage system. Our electronic tags, eTriage-Full and eTriage-Light, are shown in Figs. 3 and 4, respectively. We have also developed a base station which is equipped with GPS and IEEE802.15.4 and IEEE802.11 in order for building wireless mesh networks (see Fig. 5). The base station is embedded in a collapsible safety cone. We assume that base stations are deployed in a disaster site in an ad-hoc manner. Base stations are used for location references in localization as well as for supporting wireless communication. We can specify rough locations of base stations manually if GPS is not available such as indoors. Each electronic tag can communicate with other tags and base stations via IEEE802.15.4. Each base station is connected to the other base stations via IEEE802.11 so as to construct wireless mesh networks. Some of base stations are also connected to a server where patients' conditions and location information are gathered and displayed.

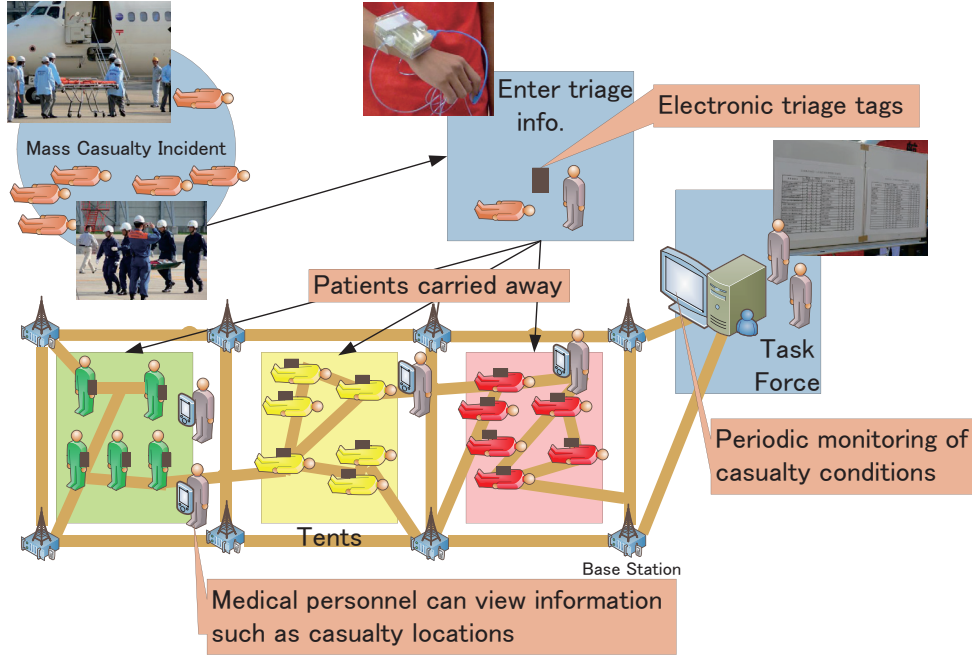The electronic tag automatically continues to moni-

Figure 2: eTriage overview.

Figure 5: eTriage base station and collapsible safety cone.

Figure 6: Vital signs shown on a server display.

tor each patient's SpO2 (Blood oxygen level) and pulse rate by inserting a finger of the patient into the tag. The monitored vital sings are periodically transmitted to the server via wireless mesh networks constructed by electronic tags and base stations. The gathered vital signs are recorded in a database at the server and can be accessed by Web browsers. The system can alert medical staffs to dangerous conditions of patients based on the collected vital signs if the condition of a patient becomes worse suddenly. A snapshot of vital signs displayed on a server is shown in Fig. 6. Medical staffs carry hand-held terminals such as iPhone, and can ac-

cess to the same information through IEEE802.11 networks (see Fig. 7). Localization is processed by the server based on the collected information about neighbor nodes of each node (i.e. nodes within its communication range) in IEEE802.15.4 networks. Locations of medical staffs can be estimated if they hold small wireless sensors that have IEEE802.15.4 wireless devices.

2.1 Localization Using Trajectories

In Ref. [3], we have proposed a new trajectory estimation method named TRADE (TRAjectory estimation in DEcentralized way). TRADE is a range-free localization algorithm in fully decentralized mobile ad hoc networks. In TRADE, each mobile node periodically transmits messages containing its estimated trajectory information, re-computes its own trajectory us-

Figure 7: Vital signs shown on iPhone.

Figure 8: Target field (left) and generated map (right).

Figure 9: Wide-area view.

ing those received from its neighbors by considering the constraints on the connectivity with its neighbors, and updates its trajectory using a vector that corrects the current position to satisfy the constraints. This information exchange contributes to improvement of the position accuracy. The details about the performance and accuracy of trajectory estimation in TRADE are given in Ref. [3].

2.2 Local Map Generation

In Ref. [6], we have proposed a local map generation algorithm for recognition of an accident site in emergency situation. We assume that each member in rescue teams, called a mobile node, is equipped with a GPS receiver and a mid-range communication device like IEEE802.11 or IEEE802.15.4 that can communicate with others several tens of meters away. The algorithm estimates movable areas and obstacles using position information from GPS receivers and communication logs between mobile nodes. We need to take into account that GPS errors and uncertainty of radio propagation with presence of obstacles may have negative effect on map accuracy. To cope with this problem, we conducted several preliminary field experiments, and we take an approach using probabilities and counters in order to determine whether each sub-region is occupied by an obstacle or it is in movable space. After generating rough form of obstacles, some image processing techniques are applied to increase the readability of the map. Figure 8 shows the target field and the generated map. We can see that the generated map represents the obstacles and free space well. For details, see Ref. [6].

2.3 User Interface for Different Cases

We have implemented an emergency medical support system for rescue commanders, medical staffs, and first responders that provides the following three views of the rescue scene: (i) Wide-Area View, (ii) Detailed View,
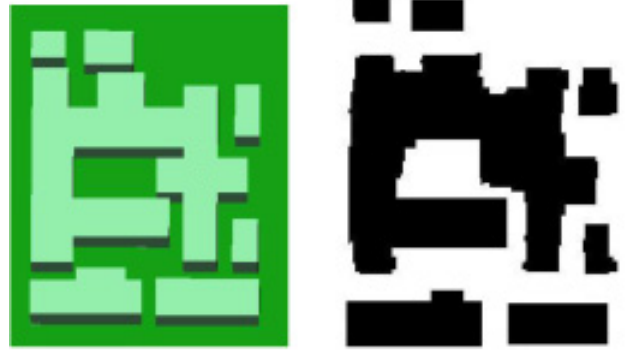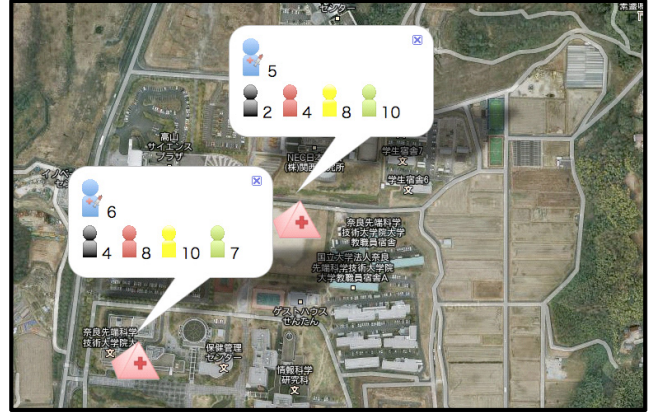
and (iii) Individual View.

As shown in Fig. 9, the wide-area view provides the 2D map including multiple rescue sites with the number of patients of each Triage category and the number of assigned physicians using Google Maps so that the rescue commander can easily grasp the overall situation of the rescue operation.

As shown in Fig. 10, the detailed view provides the 3D panoramic view of each rescue site where the position and the Triage category of each patient is drawn by the virtual object. It also shows and updates the list of patients conditions in real-time. This view facilitates the leader of each rescue site to detect the sudden change of a patient's conditions and dispatches a physician to take care of the patient.

As shown in Fig. 11, the individual view is implemented on iPad with ARToolKit and shows the latest vital signs as well as Triage category of each patient by recognizing an AR marker[1] attached to the patient.

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[1]The marker must be associated with the e-Triage tag in advance.
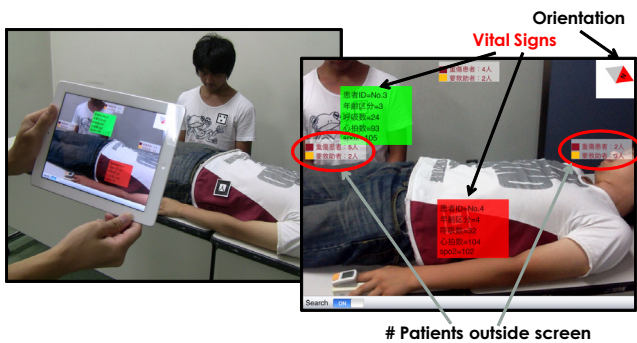
Figure 10: Detailed-area view.

Figure 11: Individual view.

This view is used by a physician to find and examine the patient whose condition suddenly changed and so on.

For details of the system, see Ref. [7].

3. TEST OPERATION IN EMERGENCY DEPARTMENT

Medical staff members in emergency departments have difficulty in dealing with a great number of patients especially in holidays and after hours. Our eTriage is also expected to be helpful for such situations while it has been developed originally for disaster operations. To see the efficiency, we conducted test operation at an emergency department in Juntendo University Urayasu Hospital for two years from January 2009 to December 2010. In the operation, an eTriage-Light was attached to a patient whose symptom could empirically lead to sudden change to worse conditions, and vital signs of those patients were monitored.

From the result, we have confirmed that the ratio of sudden change decreased by 2/3 compared with that before the test. We believe that this indicates the effectiveness of eTriage in emergency departments as well as disaster areas although there are some other factors such as an improvement in management of patients.

4. CONCLUSIONS

We have developed an electronic triage system (eTriage) based on wireless ad hoc networks in order for supporting disaster relief. For the purpose of testing eTriage, we held disaster training using eTriage every year since 2008 at Juntendo University Urayasu Hospital together with medical staffs. From the training, we could confirm the effectiveness of eTriage. However, some problems such as localization accuracy in small rooms were also revealed. To solve such remaining problems, we are planning to continue the development of our electronic triage system through tests in hospitals.

5. ACKNOWLEDGMENTS

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