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Hybrid approach for management of patient-related information in mass casualty incidents

Simon Nestler, Manuel Huber, and Gudrun Klinker

Fachgebiet Augmented Reality
Technische Universität München
Fakultät für Informatik, I16
Boltzmannstraße 3, 85748 Garching bei München

Abstract. This work demonstrates how a combination of paper based and electronic objects can improve information access in mass casualty incidents. At the moment patient-related information is documented on Paper Based Patient Tags (PBPTs) which are attached to every patient. Current research in the field focuses on the introduction of RFID based patient tags (RBPTs) which depend on more complex tools or even on wireless networks.
We propose to improve the relief workers' documentation task by combining PBPTs with RBPTs. This combination, which we call RFID Enhanced Patient Tags (REPTs), is capable of combining advantages from both approaches. On the paper part paramedics can easily scribble down medical results, it can be read and extended easily by succeeding relief units, colored paper bars can be identified even from far away and for extending patient related information nothing but a pen is needed. The use of electronically readable tags enables the paramedics to log their patient contacts, provide the incident commanders with evolving information, to acquire the patient location and to review information on previously triaged or medicated patients.
Using our implementation, all Disaster Control Data can be stored electronically on REPTs and continuous wireless communication is not mandatory anymore. Furthermore all Patient Data can be stored handwritten on REPTs and complex electronic input of textual information is not neccessary.

1 Introduction

In mass casualty incidents (MCIs), relief units have to take care of a large number of victims spread out across a sizeable area. There are not enough relief units to focus on individual patients. Rather, they have to move around between many patients and synchronously go through several work phases. A new phase is started only when all relevant patients have been treated with respect to the previous phase.

The distribution of work within a phase and the switch to the next phase is centrally coordinated. In the initial phases, information from individual relief units and patients has to be propagated to the incident commanders and then relegated back to all units, providing them with both spatial and temporal information on the current state of the relief operation.

This situation is prototypical of scenarios generating and spreading ambient intelligence that involves increasingly detailed information both for the individual relief units and at the coordinating incident commanders.

1.1 Paper Based Information Flow

Currently, Paper Based Patient Tags (PBPTs) with unique ids are attached to every patient to accumulate and document all treatments. The PBPTs are incrementally filled with information by the various relief teams whenever they get in touch with a patient for further treatment.

At first contact, during the triage, the condition of each patient is quickly assessed. The paramedics hang a new card around the patient's neck. A color bar signals the emergency of required care (see Table 1 and Figure 1). During the next contact with the patient, another medical team adds a short diagnose and the patient's vital signs to the PBPT while administering first medication. Later, the patient is transported to the local medication center. There, further medical treatment is provided and the patient is registered by name, with all information and the time being recorded on the PBPT. Finally the patient is transported to a hospital. The transportation vehicle, transportation modalities, destination and the transport priority are written on the PBPT. Thus, all information regarding the treatment of a patient is accumulated on a piece of paper that stays and travels with the patient.

Table 1. Triage categories encoded on a PBPT

Category	**Care**	**Color**
I	Immediate care	Red
II	Urgent care	Yellow
III	Delayed care	Green
IV	No care	Blue
Deceased	No care	Black
Empty	No triage	White

In order to gain an overview of the overall situation – especially during the intial triage process – the relief units also make a check mark for each triaged patient on a tally sheet, according to the assessed severeness of injury. This list is brought to the incident commanders after completion of all triage processes. It contains information on the number of patients in each triage category and assists the incident commanders in the estimation of the extent of the MCI.

(a) Paramedics apply a PBPT

(b) Patient with a red PBPT

Fig. 1. Using PBPT in MCIs

1.2 Digital Information Flow

A number of concepts toward RFID Based Patient Tags (RBPTs) have recently evolved. The core concept involves use of RFID tags at the patients that can be read and modified by mobile devices that are carried by the relief units and that, in turn, are connected via a wireless network.

Inoue et al. developed a triage system which uses RFID tags [8]. They showed the capability of their system in a disaster control exercise with 82 injured persons. They assumed, however, that for the communication between the mobile RFID readers a mobile network is either available or can be built up easily. Chao et al. proposed a similar solution to identify patients with RFID tags in combination with a wireless network [2].

Massey et al. proposed a decentralized triage and sensing system [10]. Their disaster aid network (AID-N) consists of embedded systems which are connected to sensors which monitor the vital signs of the patients. Furthermore the tags visualize the patient's triage category by using LEDs in four different colors. A possibility to store further patient related information on the embedded systems was not included in their system. The approach by Gao et al. [6] is quite similar to the AID network. Patient identification is performed with mobile hand-held devices which are equipped with 2D barcode scanners capable of scanning the 2D barcodes on patients' driver's licenses.

The intelligent triage tag (ITT) is an electronic device to coordinate patient field care. The system which was developed by Lenert et al. combines a microprocessor, non-volatile memory and wireless transmission capabilities [9]. Their module is capable of giving signal alerts, marking patients for transport or immediate medical attention.

Since RFID is a promising technology for the use in medical applications, numerous further publications exist that propose such patient tagging in a more general medical context [5], [1], [13].

1.3 Comparison

A number of trade-offs exist between using a paper based system and an RFID based system.

The major advantage of paper based patient tags (PBPTs) is that information can easily be scribbled down during triage and medication. The PBPTs guarantee that the information can be read and extended by succeeding relief units. A large colored bar at the bottom of the card helps the relief units identify patients' triage categories even from far away. Using PBPTs guarantees that all relief units who medicate the patient have an immediate overview of previously performed triage processes or medications and can easily extend the existing information if required [7], [3]. For extending existing patient related information nothing but a pen is needed. In contrast, purely digital solutions (RBPTs) depend on more complex tools (hand-held devices) or even on the permanent availability of a wireless network [8], [2], [9]. Furthermore, identifications methods are slow and error-prone [6] and decentralized data storage is lacking [10]. The paper based patient tags (PBPTs) allow relief workers to continue striving for their primary goal of helping victims at all times during a catastrophic event. Even if this may cause temporary temporal and spatial misalignment with the work of other relief units, it may be considered a more humane solution that relief workers can morally cope with more easily.

On the other hand, RBPTs are better than PBPTs in providing the incident commanders with evolving information on the number and status of patients. The incident commanders are thus able to react more decisively and to adjust the motions of the relief units to go to the most critical areas. By relaying overview information back to the relief units, these are able to make more informed and up-to-date decisions, e.g.: in which direction to go to help further patients. In comparison, the summarizing tally sheets reach the incident commanders only very slowly. The compiled overview may be inconsistent due to outdated data (a patient's condition may have changed) or due to lost paper sheets. Furthermore, the tally sheets do not contain detailed spatial information - aside from a general description of the relief unit with regard to the area that it has covered. It is hard to speed up the triage process by identifying areas where more support is needed and to redirect relief units accordingly. Third, since no individual patient information is propagated toward the incident commanders, such information is only available when a relief unit is actually at the patient. The relief units themselves have no possibility to look at the PBPTs of previously triaged or medicated patients. These logs are of special importance if later relief units have open questions regarding the patient or the PBPT due to inconsistencies. Physically going back to one of the last patients can be laborious and time consuming.

2 Combined Use of Paper Based and Electronic Information

We suggest the combined, well balanced, use of both paper based patient tags and RFID based patient tags. The resulting RFID Enhanced Patient Tags (REPTs) are physically identical with the paper tags that are already well known to the relief units. Additionally, the tags carry an RFID chip in the upper right corner under the unique id of the paper card. The relief units can access information on the chip by placing a mobile device next to it (see Figure 2).

Fig. 2. Reading REPTs with the mobile RFID reader

2.1 System Design

In order to capture the advantages of both PBPTs and RBPTs without duplicating their disadvantages, appropriate trade-offs have to be made when to store information digitally and when to continue using pens. Data entry must be fast and convenient and inconsistencies between data on paper and on chip must be avoided. These can occur, if relief workers sometimes enter information digitally and sometimes by pen. To this end, we separate information with respect to use (see Table 2): data needed for treating the patient and data needed for obtaining an overview of the disaster site. Both are provided by relief teams during their interaction with a patient - yet, they are entered and viewed very differently.

Patient Data Patient data is most urgently needed whenever a paramedic team is at the patient. At that point in time, relief workers need to be able to

Table 2. Data presentation scheme

	on Paper	on RFID
Patient ID	fixed	fixed
Category	initialized, modifiable	initialized, modifiable
Surname	text field	-
Name	text field	-
Gender	select box	-
Medication	accumulated list	-
Team ID	-	accumulated list
Location	-	accumulated list
Time	-	accumulated list

see and add to the medication record without delay. Paper-based presentation is the most direct solution. Relief workers can use their pen to make proper annotations according to current work procedure. Also patient data or such medical annotations can be detailed and would be laborious to enter on a mobile device

Disaster Control Data Information to support an overview of the disaster site is closely related to temporal and spatial aspects. Such information can be sampled whenever a support team makes contact with a patient. When the relief worker places the mobile device close to the paper tag and presses a button, a time stamp and the id of the relief team can be transmitted to the RFID chip. Using a location tracking system, such as GPS, location information can be also provided by the mobile device completely automatically. All information plus the patient id and the current classification can also be stored on the mobile device and transmitted to the incident commanders whenever wireless network access is available. Should the network be inaccessible, the data is automatically sent at a later point in time when the network can be reached.

Overarching Data The unique patient id and the patient classification are data items that are critical both for the patient data on the PBPT and for the disaster control data on the RBPT. The id is permanently set when the card is created. But the patient classification cannot be guaranteed to be always consistent since a relief worker might reassess a patient's degree of injury and change the color label without updating the RFID (e.g. because no mobile device is at hand or because the relief worker was interrupted). We suggest giving top priority to the paper based classification because of backward compatibility.

2.2 System Implementation

We have developed a mobile hand-held system for relief workers who triage and medicate patients. The mobile RFID system was implemented using the .Net

Compact Framework on Dell X51 hand-held computers with touch screens and SD-card RFID readers from SDiD. Since the RFID reader has to be carried to the patient and not vice versa, we decided to use HF readers as these readers are amongst the most compact ones, as shown in Figure 2.

Ambient storage Applications may not assume the permanent availability of a wireless network, due to the fact that in unstable and unpredictable MCI scenarios an existing or manually built up communication system can break down for many reasons. As a consequence, relevant electronic patient related information has to be stored directly on these object that embodies ambient intelligence. Thus our proposed solution for MCIs differs significantly from common ubiquitous patient tagging concepts.

RFID technology in general provides in addition to the mandatory ID only few freely usable bytes of storage per tag. This is especially true for passive, low-cost tags, but more expensive alternatives are not applicable in these environments. For an overview of RFID technology see for example [4]. Therefore the patient related information has to be stored efficiently and in a compact way. Using our encoding, all disaster control data can be stored on an RFID card with only 48 bytes of non-volatile memory, e.g. on a Mifare Ultralight RFID card [12].

Flexibility The RFID based solution must offer the same flexibility as a sheet of paper. As a consequence, the complete reading and writing of the REPTs has to be under the user's control. The relief worker decides, whether a tag has to be read and displayed on his mobile device. The reader may not perform read or write operations without the paramedic's explicit request. Due to the unstable environment, all operations which have been initiated by the user have to be interruptible at anytime.

As long as no tag is within the reach of the reader, the reader continues scanning for tags and searching for wireless networks. As soon as a tag is found the information on the tag is read and showed to the user and the user can continue with the documentation of triage, medication, registration and transport. In the background the data from the REPT is extended by information from the local database. Afterward, the local database is extended by the data from the REPT. When no data but the id is available on the REPT, local data is directly received and displayed to the user.

Backward compatibility Since, for whatever reason, some relief teams may exist who do not have a mobile device that is capable of reading and setting the triage category digitally, the paper based color bar must remain the foremost indication of triage results. That way, categories are also readable from some distance.

When digital access exists, both the RFID and the physical color bar and the RFID entry must be changed together. In case of inconsistencies, paper based

triage category overrides the category on the RFID chip as mentioned above. The paper based triage category cannot get lost, even if all mobile devices run out of power.

Backward compatibility in our case means that exactly the same information is available as before. Additionally the action of all emergency teams with mobile devices is logged and available to all succeeding teams.

Maintenance of electronic consistency Guaranteeing a consistent global system state at any point in time although the environment is unstable and changing rapidly is not possible when realizing the highly distributed approach. Since a continuous wireless communication between all systems cannot be guaranteed, all redundant copies of a specific patient dataset can not be changed simultaneously if a relief units writes, deletes or overwrites parts of the patient dataset. Due to the fact that the REPT always contains the most recent information it is possible to establish a consistent state in a downstream step. The dataset with the most recent information on a specific REPT overrides other versions of this electronic dataset.

Security considerations In order to guarantee retraceability in addition to the timestamps the initiator of the modification has to be stored on the mobile RFID readers. Furthermore it must be assured, that these log files can neither be deleted nor be modified by the relief units during or after the mass casualty incident. At present, in MCIs all patients are labeled with PBPT which can be read, modified or deleted by all persons who are located in the MCI scenario. The access of patient related information by third parties can not be prohibited efficiently. By storing patient related information on mobile devides and on REPTs the reading and writing of information is more difficult for third parties and at the same time not less secure than the paper based approach. Opposed to a central solution in which all information is stored in a central database the decentral approach is more insecure. It is problematic to increase security and manipulation resistance of REPTs (e.g. by using encryption), as long as other problems of patient tags remain. For instance, patient tags are not robust against mischievous interchanging or deleting. Nevertheless security is not the major issue when developing mobile assistance systems for relief workers in mass casualty incidents. For a sound functionality of the overall system it is more critical to grant access to all authorized persons instead of refusing access to unauthorized persons.

User interface design In order to make the most common interactions as simple as possible, the mobile user-interface logs the current task of the emergency team.

When an emergency team is performing a triage, the mobile user interface works in the triage mode. Due to the fact that preconfigured REPTs[1] are used,

[1] Triage teams currently carry a collection of preconfigured PBPT of each category to speed up the assignment process.

the RFID chip is already preconfigured as well. As long as the paramedic does not change the colored bar, he only has to move the preconfigured card along the reader without any interaction on the mobile device. The mobile device reads and shows the preconfigured category and writes the team identifier and timestamp on the card. This read / write process takes about 1 second. In the rare case that no preconfigured REPT in desired category is left and the preconfigured paper-based category has to be changed manually, the paramedic can tap on the screen and change the electronic category accordingly and write it back to the tag by moving the tag along the reader for a second time.

When an emergency team is doing re-triage, the mobile user interface is set to the re-triage mode. The REPT is already hung around the patient's neck, in order to get all electronic information, the paramedic moves the reader over the tag. The paramedic gets the electronically stored current triage category of the patient. This electronic category is inconsistent to the manual one, when 1) the triage team had no mobile device AND changed the preconfigured paper-based category or 2) the triage team had a mobile device AND changed the preconfigured paper-based category AND did not write to the tag for second time. In all other cases the electronic category is correct and the device enables the paramedic to change the patient's category after the completion of the re-triage. In the case that the re-triaging emergency team has no mobile device, they just change the paper-based colored bar.

3 Conclusion and future work

The data storage concept fulfills the requirements regarding availability, distribution and usability. The solution contains concepts to enable the use of the system in unstable and unpredictable environments. The proposed solution shows how RFID technology can help relief workers in MCI scenarios to perform the necessary documentation more quickly. Since information can be duplicated automatically, the relief workers have more time for medication and transport of the injured. This application shows that RFID technology can not only be used for straight-forward identification; a powerful distributed database results from the sum of all REPTs in the field.

The presented concept is promising, therefore we are in the progress of determining its suitability for practical use. Besides the improvement and extension of the existing application, the evaluation in the context of a disaster control exercise will be our next step in the future. We are aware of the fact that disaster control exercises are laborious and time consuming because it involves the participation of relief workers, incident commanders and actors [11]. Thus such evaluations have to be extremely well planned and can only be conducted in the scope of existing disaster control exercises which are irregularly organized by the fire brigades.

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