An Intelligent 802.11 Triage Tag For Medical Response to Disasters

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When medical care is initiated at a mass casualty event, the first activity is the triage of victims, which is the grouping by victims severity of injury. Paper triage tags are often used to mark victims' triage status and to record information on injuries and treatments administered in the field. In this paper we describe the design and development of an"Intelligent Triage Tag" (ITT), an electronic device to coordinate patient field care. ITTs combine the basic functionality of a paper triage tag with sensors, nonvolatile memory, a microprocessor and 802.11 wireless transmission capabilities. ITTs not only display victims' triage status but also signal alerts, and mark patients for transport or immediate medical attention. ITTs record medical data for later access offsite and help organize care by relaying information on the location of the victims during field treatment. ITTs are a part of the Wireless Information System for Medical Response in Disasters (WIISARD) architecture.

INTRODUCTION

The initial activity of medical first responders at a disaster site or large natural catastrophe with large numbers of casualties is triage(1). Triage is the process of rapidly sorting patients into categories based on the urgency of need for care and the resources available. Simplified triage systems have been developed to allow the rapid determination of priorities for patients, taking into account both the victim's condition and logistical realities.(1,2) Based on these algorithms many localities use paper triage tags (either around the wrist or neck) to identify patients according to triage category to aid in the processing of victims.(3) Triage categories are *Immediate*, *Delayed*, *Walking Wounded*, and *Comfort-Care or Deceased*. Categories are color coded (red for *Immediate*, yellow for *Delayed*, green for *Walking Wounded* and black for *Comfort Care*) to aid in sorting, treatment and transport operations. Tags usual have tear-off tabs for injury category (4) to further improve clarity. Figure 1 is an example of a typical triage tag.

In additional to recording the severity of injury, triage tags serve as the equivalent of hospital identification bracelets and are numbered (and now often have bar codes) to provide a unique identifier for the individual.(3) Triage tags also have space for writing medical information and serve as the as the primary means of documentation of field care, communication and information transfer between the field and hospital. However, tags have well-known limitations. The space for recording medical data is limited. The "tear off" format of tags only allows unidirectional changes in patient condition (worsening). The tags are not weather resistant, and are easily marred or destroyed.

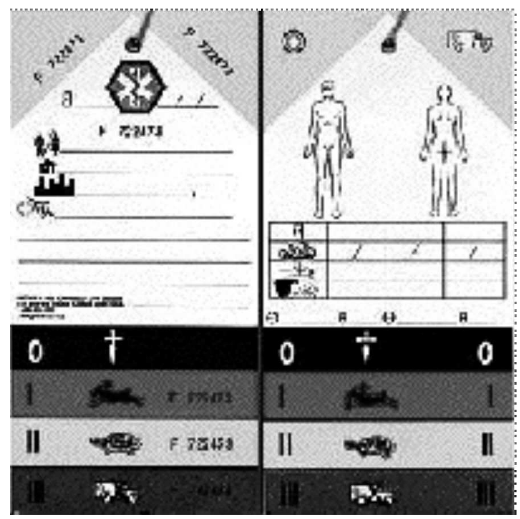

Figure 1. Example of a triage tag.

Moreover, the tag is a static and disconnected information repository. Real-time information regarding victims and their status is critical to the overall management of field medical care. Medical command must coordinate timely information on the number of casualties and their needs with the known availability of resources, such as on-scene providers, ambulance locations, and area hospital capacities. Real-time information is also critical to determining the appropriate patient destination, depending on the type of injuries and the capabilities of the receiving facilities.(5, 6)

This "sequential interdependence" highlights the importance of transfer of that information in the disaster setting. Actions in the field (such as triage, transport and treatment of victims) ultimately impact hospital resources and capabilities. Real-time information on hospital and health care resources has an important impact on disaster response management and field care of victims. Yet this information is often not available and is hampered by the lack of a comprehensive communication and information system at the disaster scene. Poor information can result in the transportation of victims to inappropriate hospitals that lack both critical facilities and staff and may be further from the scene than hospitals with those resources. (7, 8)

Figure 2. PDA "triage tag" in use during a mass casualty drill in May 2004.

This paper describes the design of an Intelligent Triage Tag (ITT) developed as part of the Wireless Internet Information System for Medical Response in Disasters (WIISARD) project. The focus of this project is on the use of 802.11 (WiFi) wireless-based technologies to coordinate and enhance care of mass casualties in a terrorist attack or natural disaster. WIISARD is funded by the National Library of Medicine's Internet II Research Program. WIISARD will provide emergency personnel and disaster command centers with medical data to track and monitor the condition of hundreds to thousands of victims on a moment-to-moment basis, over a period of hours to days at the disaster site.

WIISARD System Components

The key components of the WIISARD system inlcude:

1) Electronic Wireless Patient Tagging and Monitoring devices – These include intelligent tags, blood-pulse oximeters and other sensors.
2) Tracking and Data Relay Units (TDRUs) – These are hand deployed wireless access points with integrated GPS, mesh and/or ad hoc networking that create the communications infrastructure for the site.
3) First Responder Devices – These include equipment tags, handheld data entry and retrieval devices, portable IT terminals, and VoIP voice devices.
4) Integrated Software Systems – Operating concurrently through all layers in all the various devices, the software serves to enhance the situational awareness of first responders, recording of medical data, aid in the monitoring of severely ill patients, and communication of medical data to hospitals.

This paper describes our design and initial research to develop triage tags for an integrated and fully wirelessly connected disaster care environment. Design specifications are based on extensive interviews with first responders on operations. Initial concepts for an ITT were tested using 802.11 personal digital assistant (PDA) devices during a mass casualty drill with the San Diego Metropolitan Medical Response System team in May 2004. These tag simulators were incorporated into a full scale exercise involving hundreds of first responders. Twenty simulated victims were tagged with these devices. The PDA simulator tested geolocation reporting and positioning concepts using 802.11. A picture of the PDA "tag" in use during the drill is shown in Figure 2. Results from use of PDA's aided in refinement of design specifications of the ITT.

DESIGN CONSIDERATIONS

ITTs are designed for use in a mass casualty scenario resulting from a weapon of mass destruction, natural disaster or industrial/commercial accident. The event could have as many as several thousand victims in various conditions from walking-wounded through deceased. Because of transportation bottlenecks or contamination issues, the best possible care would have to be afforded to the victims at the scene or nearby.

Scenario of use

Upon arriving in a Mobile Command Post at the scene, TDRUs would be deployed throughout the site to place a communications bubble over the area. First responders would move throughout the site carrying a satchel full of patient tags, a responder tag and a single data entry device (PDA). Each victim would receive a patient tag and would be "logged into the system" via the PDA. Triage status, condition, identification, treatment and other indications would be entered into the system via the PDA. Triage status would be registered on the tag itself with indicator lights, and the internal memory would record all treatment data as a local data repository. Patient tags would commence listening for directed data and would issue periodic broadcasts of information such as AP signal strengths (for geolocation), battery life, acceleration for movement, temperature and orientation. The data is routed via the TDRUs to the Mobile Command Post where it is processed, stored, relayed to the Internet, and moved back to devices on the field.

Critical functions for the ITT are to report its location, display triage status, signal providers, and to locally store clinical information. Location tracking is central to WIISARD. It allows the command post to monitor victims to prevent them wandering off or entering hazardous areas. The most practical approach is an active Radio Frequency Identification Device (RFID) system that reports position using observed radio signal strength. A barcode scanning and passive RFID were considered geolocation, but these systems can only monitor the last point of contact of a victim . But, because of the limited accuracy of practical location finding methods, position alone will not be sufficient to find victims at a crowded casualty collection point. Tags need to be able to signal providers which specific victim, among many victims in the immediate vicinty, needs attention. In addition to acting as a tracking and signalling device, it would be useful if tags could store and facilitate the retrieval of field care data when victims arrive at the hospital.

To achieve this aim we developed specifications for the physical construction of the ITT and for software functionality. These include:

- 8-12 hours battery life;
- "1 button" operation for first responders;
- rugged, reliable, idiot proof, water-resistance (can go through decontamination procedures);
- displays triage status and alarm conditions visible in daylight at 5m or greater distance;
- geoaware using 802.11 signal strength methods and dead reconning;
- secure data communications via Internet protocols;
- wake-up/sleep power management;
- can form an ad hoc network with 802.11-equipped computers and act as a web server;
- self-diagnosing and remote software upgrading;
- low-cost of manufacture (< $100).

Functional exchanges of information

Information flow is bidirectional between tags and the WIISARD system. Flow from ITT to servers includes:

- RF received energy from all visible TDRUs,
- link status and SSID of associated TDRU,
- battery status
- shutdown alert
- ACKs for data received

The flow from WIISARD servers to the ITT includes:

- alerts
- current triage status
- medical record data for archival on the tag.

IMPLEMENTATION

Tags are combined software hardware systems that use a low cost 802.11b communications device designed for embedded systems. 802.11b was chosen over other 802.11 protocols for cost considerations. 802.11 was chosen over other standards such as 802.16.2 (Zigbee) to allow deployment of a single network for data communications at a disasters site.

Enclosure

To fit the requirements of small size, ruggedness, and environmental protection, (and to avoid the costs of custom case manufacturing) we have chosen a handheld sized OKW ABS plastic enclosure that incorporates O-ring seals to provide protection against dust, falling dirt, and dripping noncorrosive liquids. (IP65). The dimensions of the test units will be: H: 120mm, W: 65mm, D: 22mm.

Figure 3. 802.11 module

RF Module and Processor

For the 802.11b interface and processor, we have selected the DPAC Airborne for the following features:

- highly integrated 802.11b wireless module with radio, base-band and application processor.
- built-in web server enables drop-in LAN and Internet connectivity.
- integrated RTOS and TCP/IP Stack.
- configurable serial, digital and analog I/O ports including (I2C).
- small, rugged package and hi/lo temp operation.

The Ubicom processor used on the module includes the following features:

- physical layers in software,
- sophisticated power management support
- general-purpose hardware peripherals,
- built-in C programming language and debugging
- software device I/O
- software communications I/O,

Power Controller and Batteries

A Lithium ion battery was chosen as the battery source. It is more complex to charge and operate in terms of electronics but Li+ cells pack the highest energy density and energy to weight ratio of standard cells. The ITTs can consume as much as 2 watts during intense broadcast. In designing for 8-12 hours of battery life, we have chosen two routes: higher watt-hour density Li+ batteries and extended sleep modes for power management. When complete the tag will be programmed to sleep for periods of five seconds or more and wake to address the server for updates. When moving (as tracked by the accelerometer and magnetometer) the unit would report receive RF energies and sensor readings more often.

External Indicators

The ITT is a two-way communications device with the ability to convey specific messages. The design of the device uses LEDs to signal information about hazards, medical alerts and patient management information to first responders at the victim. High brightness LEDs were chosen as visual communication tools. Combinations of colors and rates of pulsation are also used to indicate the urgency of a message, with high pulsation rates (0.1 per second (see Table 1) indicating more urgent messages. The nominal colors of the Triage LEDs were chosen to mimic the standard triage tags (Green, Yellow, Red, and Black) with the blue LED replacing the black. Testing of the ergonomics of proposed design is planned with first responders embedded within the WIISARD team.

Lights	Blink Rate (Hz)	Indication
Red LED	0.5	Immediate
Yellow LED	0.5	Delayed
Green LED	0.5	Minor
Blue LED	0.5	Deceased
White	5	Medical alert
No lights	--	Fault
White	0.1	Low Battery
All	0.5	No RF Link
White+Blue	0.1	Malfunction
Triage White	0.1 0.5	Hazardous area warning
Triage White	0.5 0.1	Decon

Table 1. Design for use of LEDs to convey alert status.

Sensors and Internal Data Bus

Internal sensors and devices in the tag are connected via a standard I^2C data bus. Sensors include an ST Micro LIS3L02DQ 3-axis accelerometer and a Honeywell HMC6352 2-axis magnetometer. These two devices aid the energy reporting scheme and dead-reckoning tag geolocation. An Analog Devices temperature sensor, a time-of-day clock and an ambient light sensor round out the sensorscomplement. The ToD clock allows precise time stamps. An ambient light sensor controls the illumination intensity of the LEDs.

Server Integration

The ITT communicates the WIISARD system using a tag manager (TagMon) program as an intermediary. ITTs broadcast their status to TagMon via the UDP protocol (chosen to minimize network load for short messages under conditions of poor quality of service). The frequency and level of detail in broadcases is tailorable to network congestion. TagMon is a Win32 program that runs of a personnal computer connected to the WIISARD wireless LAN. TagMon broadcasts instructions to ITTs by UDP. Both tag and manager repeat repeat broadcasts until message receipt is acknowledged. TagMon, in turn, communicates with the WIISARD database via TCP/IP using a messaging protocol system. TagMon has a user graphical interface for managing messaging, alerts and geolocation of tags. It is designed to work both as a standalone system and as a WIISARD component.

SYSTEM STATUS

WIISARD ITTs are currently under rapid development with prototypes due for fabrication and assembly in July 2005 for deployment in a mass casualty drill in November 2005. "Breadboard" versions of the tag have been completed and are undergoing testing. Capabilities demonstrated using breadboard designs include general network functionality, including the ability to use DHCP to obtain an IP address, the ability to select access points for association based on SSID, the ability to observe 802.11 signal strengths from access points, and the ability to rapidly associate and de-associate with access points in a mobile environment without excessive interruptions of service (more than 7 seconds). The ability of ITTs to receive and send communications has also been tested. Tags are able to transmit access point signal strengths to a web services infrastructure and are able to receive commands from the web services that alter the alert lighting of LEDs. These tests demonstrate proof-in-concept of required functionality for the device. Battery life observations were consistent with planning estimates, with more than two hours of functioning with continuous transmission using standard alkaline nine-volt batteries.

DISCUSSION

The triage tag is the equivalent of the paper chart for hospital care. Existing tags are highly functional and from a human factors perspective, sophisticated recording devices, that have a near optimal user interface for rapid entry of information given limited time and resources at a disaster site. To replace conventional tags, electronic tags have to offer enhanced functionality that compensates for the greater difficulty use.

Paper triage tags are continually evolving works in progress(4), with wide variability between manufacturers in the design and layout of information. Many triage tag manufacturers have begun to add barcodes to tags to help automate data entry and tracking. Use of barcodes to help track patients from a disaster site within hospitals was proposed in 1996 by Noordergraf and colleagues and has subsequently been refined.(9) Raytheon has developed and deployed a system using triage tags with barcodes and tag readers connected by cellular and 802.11 interfaces that is in use with the St. Louis Metropolitan Medical Response System.(10)

The passive RFID technologies are a logical extension of barcoding approaches (RFID tags are generally easier to read than barcodes). The Navy has developed a passive RFID identification system called Tactical Medical Coordination System.(11) This system supports storage and retrieval of medical records data in combat situations on a medical "dog tag" but does not geolocate victims or receive signals from central systems to faciliatte management. Other investigators have developed handheld computers that collect and relay triage data in mass casualty events without integrated triage tag systems.(12, 13)

Perhaps the greatest benefit from use of more advanced tags will come from integration of tagging systems with systems for hospital care. For example, the ITTs developed within WIISARD could be combined with 802.11 hospital systems for tracking patients during disaster response, such as the MASCAL system(14), to provide seemless tracking and transmission of information from a disaster site to tthe hospital emergency room and wards.

The ITTs being developed for WIISARD extend previous approaches to triage tags by making tags both geolocation and communications devices. The tags are beacons announcing the position of victims to the WIISARD system but also communicate the status of patients to first responders as well as displaying alarms and signals. ITTs are not user input devices, and deliberately do not include buttons that would allow someone to set triage status or trigger an alarm. These actions require use of a provider's PDA in order to secure the process and prevent tampering. Our objective is to establish both the feasibility and use of this technology. We are currently building a sizeable quantity of industrial prototypes of IITs and will test use of these devices within actual mass casualty drills in Fall 2005.

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