# A Next Generation Electronic Triage to Aid Mass Casualty Emergency Medical Response

Tia Gao and David White

**Abstract— For years, emergency medical response communities have relied upon paper triage tags, clipboards of notes, and voice communications to share information during medical emergencies. This workflow, however, has proven labor intensive, time consuming, and prone to human error [1]. In collaboration with three EMS groups in the Washington, DC Metropolitan area, we have developed a next generation triage system to improve the effectiveness of emergency response. This system includes: 1) electronic triage tags, 2) wearable vital sign sensors, 3) base stations laptops to monitor and manage patients, 4) pervasive tracking software to locate patients at all stages of the disaster response process, and 5) PDAs to support documentation and communication. Our system has evolved through three iterations of rapid-development, field-studies, usability reviews, and focus-group interview. This paper summarizes engineering considerations for technologies that must operate under constraints of medical emergencies. It is our hope that the lessons reported in this paper will help technologists in developing future emergency response systems.**

## I. Introduction

Medical emergencies, where the responders must collaborate effectively to care for and track an often overwhelming number of casualties, pose numerous challenges. In mass-casualty emergencies, the rapid and accurate triage (counting and sorting) of patients is a critical early step of the response process, and triggers a chain of events in the medical and resource coordination. For years, responders performed these critical tasks with paper triage tags, clipboards of notes, and voice communications (over telephones and hand-held radios). This workflow, however, has proven labor intensive, time consuming, and prone to human error.

Responders conduct initial triage by attaching red, yellow, green or black colored paper triage tags to patients based upon assessed priority. The medics then call their EMS officers using their handheld radios, and verbally report the patient count. The officer manually tallies the patient counts on clipboards and, again, verbally reports the patient count to transportation coordinators and requests for the necessary number of ambulances.

Manuscript received June 10, 2006. This work was supported by the U.S. National Library of Medicine under Grant N01-LM-3-3516.

T. Gao is with the Johns Hopkins University Applied Physics Lab, Laurel, MD 20723 USA (phone: 240-228-3475; fax: 301-762-8230; e-mail: tia.gao@jhuapl.edu).

D. White is with the Johns Hopkins University Applied Physics Lab, Laurel, MD 20723 USA (e-mail: david.white@jhuapl.edu).

After initial triage, patients wait at the scene until their ambulance arrives. With a resource limited response team, patients often wait for an extended period of time before transport. During this waiting period, patient conditions may deteriorate. Secondary injuries such as hypoxemia, hypotension, and cardiac tamponade become life-threatening if not treated immediately. To address these problems, current emergency response protocols require responders to periodically re-triage patients [2]. During a mass casualty emergency, however, this important protocol is often neglected by the overwhelmed responders [3]. In addition, patients with minor injuries often depart the scene without notifying the response team, thus creating an organizational headache for EMS officers who are responsible for tracking the whereabouts of each patient.

The problems listed above point towards a growing necessity to alleviate the overwhelmed responders through automation. Unfortunately, there are no systems available for automated mass casualty monitoring and tracking. Monitoring packs used by responders during routine ambulance runs can only track the vitals sign trends of a single patient, and multi-patient bedside monitoring systems require mainframe computing systems that are not suitable for field use [4][5][6]. It is with these considerations in mind that we have developed a next generation electronic triage system that facilitates collaborative and time-critical patient care in multiple levels of the medical response community. Recent events in global terrorism, military conflicts, and natural disasters raised international concern on casualty care and suggest the growing need for efficient emergency medical response solutions in the future [7].

## II. Previous Research

In a previous publication, we described the development of wearable patient sensors that communicate, over a wireless ad-hoc mesh network, with patient monitoring laptops at the scene [8]. The ad-hoc mesh network, developed by the Harvard University CodeBlue project and based upon the IEEE 802.15.4 standard, has rerouting and meshing capabilities to ensure reliability in mass casualty environments [9][10]. Base station laptops receive data from tags and continuously monitor patient vital signs and location in both indoor and outdoor environments. The base station laptop also forwards the patient information in real time to remote patient record databases for storage and transmission to receiving hospitals. Base stations use Verizon EVDO wireless cards to attain high speed network connectivity for communication with the remote server. We integrated our system with a pre-hospital patient care software system currently used on all ambulances in Arlington County, VA.

We have since developed significant enhancements to [6] in order to accommodate the constraints of mass casualty disasters. The patient sensors were enhanced to minimize false alarms and provide new modes of operation. Functionalities were added to the base station to provide greater assistance in responders' workflows. A PDA application was developed to provide a portable medium for documentation and communication. By allowing accurate and simultaneous monitoring of mass casualties, this system could greatly relieve responders' workload and facilitates the proper allocation of resources to fit the evolving needs of patients during the ongoing emergency.

Related research improves upon the paper triage tags through the use of barcodes, tag readers, passive RFID tags, hand-held computers, and geolocation to collect data about the mass casualty events [11][12][13][14][15][16]. Our tags provide similar functionality as [13] and [14], but are more robust due to their decentralized communication architecture, integrated vital sign and location monitoring capabilities, and an ultra-low power embedded hardware.

## III. IMPLEMENTATION

Our wireless devices were implemented on the MicaZ and TmoteSky motes from Crossbow Technology and MoteIV corporation, respectively [17][18]. The MicaZ mote has a maximum data rate of 76.8 kbps and a practical indoor range of 20–30m. TmoteSky has a maximum data rate of 250 kbps and a practical indoor range of 50m. They are constructed to be inexpensive and light weight, and with MEMS manufacturing, we envision these motes to become single-use disposable devices. Software developed for the motes enable decentralized communication that is highly fault tolerant. [7]. The following sections describe four areas of our triage system: 1) electronic triage tag, 2) wearable sensors, 3) vital signs monitoring and reducing false alarms, 4) pervasive patient tracking, and 5) documentation PDA.

### *1. Electronic triage tags*

Our wireless triage tag provides five functionalities: triage, status display, vital sign monitoring, location tracking, information display, and alarm signaling. Four colored LEDs (red, yellow, green, blue) on the tag are used to designate triage colors (red, yellow, green, black). An amber-colored LED designates contaminated patients during hazmat emergencies. The triage color is set by insertion of a colored card. As shown in Fig. 1, the insertion of a red card causes the red LED to light up. Data of the triage color is wirelessly transmitted to a remote base station. The tag's modes of operation, shown in Table I, can be controlled directly on the device or remotely from a computer station. The tag operates on two AAA batteries.

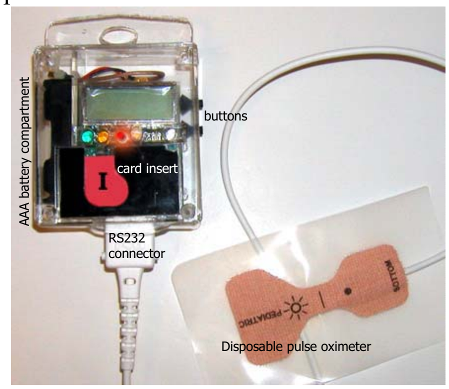


**Fig. 1 Electronic triage tag.**

### *2. Wearable Sensors*

To effectively measure patients' physiological conditions, we developed multiple types of vital sign sensors. A low-power pulse oximeter was developed as the primary sensor for the electronic tag. A wireless non-invasive blood pressure cuff (NIBP) and 2-lead EKG were developed as separate modules that could be applied to patients who required the additonal level of monitoring. We designed each device with the following usability principles: 1) exhibit a modular design with standard connectors, 2) incorporate common commercially-available batteries, and 3) allow easy access to the battery compartment.

The electronic triage tag is modular such that multiple form factors of pulse oximeter sensors can be connected via a standard serial port. An assortment of disposable and reusable oximeter sensors are available, including ear clips, finger clips, and foot wraps for infants, and are used in different environmental conditions.

The NIBP device is an integrated BP cuff controller and wireless transceiver. The cuff automatically inflates at customizable time intervals to acquire pressure readings and transmit the data over the wireless mesh network. This device builds upon the NIBP module from SunTech

TABLE I
ELECTRONIC TRIAGE TAG MODES OF OPERATION

| Operation | Component | Description |
|---|---|---|
| User Input | password button | A lockout feature to prevent misuse of the other button. |
| | synchronize button | Synchronizes triage tag ID with other sensors on patient (BP, EKG) |
| | Card insert | Insert card set the triage color |
| Triage Color | red LED | Priority I – Critically injured (High) |
| | yellow LED | Priority II – Seriously injured (Medium) |
| | green LED | Priority III – Injured (Low) |
| | blue LED | Priority IV – Decreased (Lowest) |
| Decontami-nation Status | amber LED | Contaminated (blinking) Decontaminated (solid) |
| Alert | buzzing | Audible sound to locate patient |
| Information Display | LCD panel | Displays the patient's vital statistics, number of medications received, and receiving facility. |

Medical, known as the Advantage Mini [19]. When acquiring BP readings every 5 minutes, the device operates for 10 hours on a four-cell battery pack of 9V lithium batteries. Again, this is a modular system such that various sizes and styles of commercially available cuffs can be connected to the device.

The wireless 2-lead EKG sensor detects R-wave intervals from the sensed EKG morphology and transmits the extracted data over the wireless mesh network. This device, based upon the sensor board developed by Harvard University, operates on 2 AAA batteries [20]. Various types of commercially available EKG leads and electrodes can be attached to this module [21][22]. Our R-wave detection algorithm produces reliable results while operating under considerable environmental and human noise, such as noise due to muscle activity and respiration. Furthermore, the algorithm is resilient to common usage errors such as reversing the polarity of the leads and variations in lead placement (e.g. leads placed on the wrist, chest, or abdomen). These features make it practical to deploy these EKG devices for a broad range of care providers, patients, and environments.

### 3. *Vital Sign Monitoring and Reducing False Alert*

The base station laptop's vital signs analysis algorithms are based upon: 1) published detection methods implemented by existing patient monitoring products and 2) feedback from paramedics and physicians [23][24]. Table II shows a list of the monitored patient conditions. Fig. 2 shows a screenshot of the base station's graphic interface. Detection parameters are customized to each patient using several novel techniques.

- If the patient has a medical record that was previously entered, information from the record is used to adjust the detection thresholds.
- Thresholds are adjusted upon environmental factors (e.g. altitude and temperature) reported from standalone sensors at the scene.
- Thresholds are programmatically adjusted upon patients' baseline readings.
- Paramedics can adjust thresholds on a per patient basis by manually updating thresholds.

Patients' thresholds are transmitted to the remote patient record database for later retrieval. If there is no network connectivity to the remote server, thresholds are stored locally on the electronic triage tag.

### 4. *Pervasive Patient Tracking*

Previously, we developed two methods for tracking patients: 1) GPS and 2) MoteTrack, an indoor tracking system to determine location in areas where the GPS signal strength is too low [25][26]. We have since updated our GPS module with a smaller antenna (ceramic patch) and a new low-power receiver (SiRFstar III) [27]. This GPS module acquires signals down to -159dBm, thus making patient tracking possible in diverse environments including indoor environments and urban canyons. With a .1 second reacquisition time and location updates every 1 minute, our triage tag has an operational battery life of 17 hours. An option on the base station graphical interface allows users to turn off remote triage tags' GPS or adjust their GPS reacquisition interval.

In addition, we use a low-power alternative to localize patients to general localities of a particular area of the disaster scene (such as treatment or decontamination area), an ambulance while being transported, or an admitting care facility. Tag locations are calculated by their proximity to: base stations laptops installed inside ambulances, at care facilities, and at designated areas of the disaster site. Mobile laptops are equipped with SiRFstar III GPS receivers to detect its location, while stationery laptops allow users to manually specify the location from an options menu. Hence, the medic can track the general locality of the patient based upon the base station the triage tag is reporting to.

TABLE II
ALERTS RAISED BY VITAL SIGNS ANALYSIS ALGORITHM

| Category | Alert |
|---|---|
| Cardiac | No pulse |
| | Bradycardia |
| | Tachycardia |
| | Onset of change |
| | Stability |
| Respiratory | Low oxygen saturation |
| | Onset of change |
| Blood Pressure | Systolic pressure |
| | Diastolic pressure |
| | Widening pulse pressure |
| | Narrowing pulse pressure |
| | Mean arterial pressure |
| | Change |

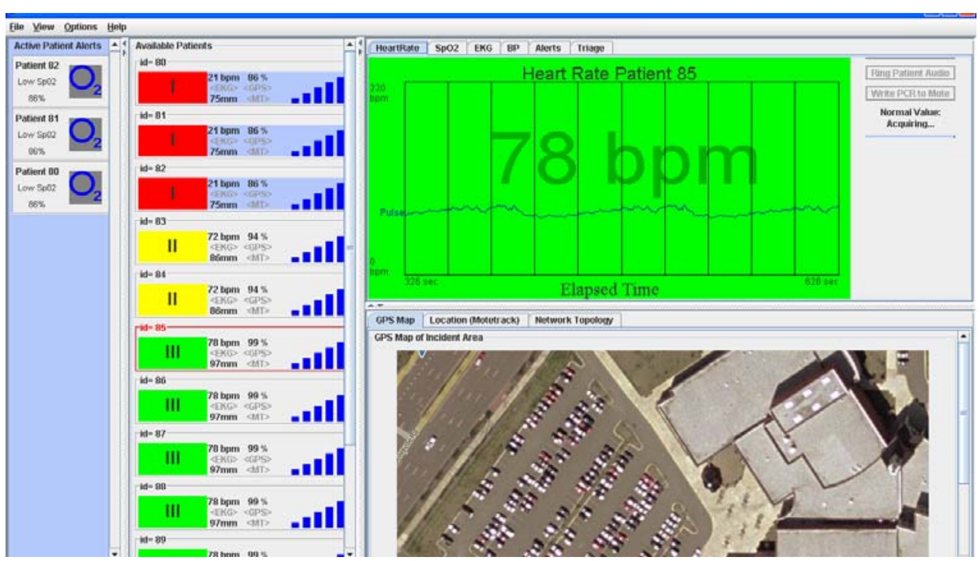

**Fig. 2: Graphical user interface of mass casualty patient monitoring station.**

*5. Incident Documentation PDA*

The PDA, Fig. 3, is developed to facilitate incident information documentation and communication. As a light-weight alternative to the laptop, the PDA provides a portable means of viewing real-time sensor readings of patients. Furthermore, it includes a camera, a Bluetooth barcode scanner, and a Bluetooth SiRF III GPS to facilitate rapid data capture. It improves the process of reassessing and matching patients to resources by allowing responders to quickly record patient identification information, triage details, treatments, photographs, and locations. The inputted data is immediately transmitted to a remote server for further dissemination. The barcode scanner improves the process of manually recording patient identification details by allowing responders to scan the 2D barcode on patients' driver's licenses. Data from the barcode is parsed with the PDF417 encoding standard.


**Fig. 3 PDA shows screens for inputting chief complaint (left) and for capturing patient photo (right)**

## IV. Future Work

In collaboration with Montgomery County Department of Homeland Security, we are testing our system in a simulated MCI exercise to take place in August 2006. During this exercise, comparisons between the effectiveness of current disaster response methodologies and our technologies will be conducted.

## Acknowledgment

We would like to thank Matt Welsh and his students at Harvard University for their technical guidance; staff at Suburban Hospital for their clinical expertise; and EMS personnel in Baltimore and Montgomery County, MD and Arlington, VA for insight into first responders' line of work.

## References

[1] Branas CC, Sing RF, Perron AD: A case series analysis of mass casualty incidents. *Prehosp Emerg Care* 2000;4:299–304.

[2] FEMA Medical Team Training Manual; Available at http://www.fema.gov.

[3] Interviews with Polk, D., MSW, NREMT-P, Paramedic Program Instructor at the University of Maryland Baltimore County Department of Emergency Health Services, January 2006.

[4] Mobile Acuity LT Central Monitoring Station; Welch Allyn; Available at http://www.monitoring.welchallyn.com/products/.

[5] LifePak 12 Monitoring System; Medtronic Inc; Available at http://www.medtronic.com.

[6] Visicu eICU Solutions, Visicu, http://www.visicu.com.

[7] E. N. Brandt, W. N. Mayer, Mason, J. O., Brown, D. E. Jr., Mahoney, L. E.. "Designing a National Disaster Medical System," *Public Health Reports*, 1985, 100(5), 455-461.

[8] T. Gao, D. Greenspan, M. Welsh, Vital Signs Monitoring and Patient Tracking Over a Wireless Network, Proc IEEE EMBS Annual International Conference 2005.

[9] K. Lorincz et al., "Sensor Networks for Emergency Response: Challenges and Opportunities," *IEEE Pervasive Computing*, IEEE Press, pp. 16-23, October-December 2004.

[10] J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler, K. Pister. System Architecture Directions for Networked Sensors, *In Proceeding of 9th Int'l Conf. Architectural Support for Programming Languages and Operating Systems (ASPLOS 2000)*, ACM Press, 2000, 93–104.

[11] J. Bouman, R. Schouwerwou, K. Van der Eijk, A. van Leusden, and T. Savelkoul. Computerization of Patient Tracking and Tracing During Mass Casualty Incidents. Eur J Emerg Med 2000; 7(3):211-6.

[12] P. Chang, Y. Hsu, Y. Tzeng, Y. Sang, I. Hou, and W. Kao. The Development of Intelligent, Triage-Based Mass-Gathering Emergency Medical Service PDA Support Systems. J Nurs Res 2004; 12(3):227.

[13] J. Hamilton. Automated MCI Patient Tracking: Managing Mass Casualty Chaos Via the Internet. Jems 2003;28(4):52-6.

[14] C. Lauraent, and L. Beaucourt. Instant Electronic Patient Data Input During Emergency Response in Major Disaster Setting. Stud Health Technol Inform 2005; 111:290-3.

[15] L. Lenert, D. Palmar, T. Chan, and R. Rao. An Intelligent 802.11Triage Tag for Medical Response to Disasters. *AMIA 2005 Symposium*. 2005.

[16] S. McGrath, E. Grigg, S. Wendelken, G. Blike, M. De Rosa, A. Fiske, and R. Gray. ARTEMIS: A Vision for Remote Triage and Emergency Management Information Integration. Dartmouth University. Novermber 2003.

[17] Crossbow Technology Inc. MicaZ Datasheet. Available at http://www.xbow.com.

[18] Moteiv Corporation. TmoteSky Datasheet. Available at http://www.moteiv.com.

[19] SunTech Medical, Advantage OEM, Available at http://www.suntechmed.com/HTML/Advantage.htm.

[20] T. Fulford-Jones, G. Wei, M. Welsh, "A Portable, Low-Power, Wireless Two-Lead EKG System," In *Proc. of* the 26th IEEE EMBS Annual International Conference, IEEE, September 2004

[21] Rochester Electro-Medical Inc, Disposable Electrodes, Available at http://www.rochestermed.com/ElectrodesFrame.htm#DElect.

[22] Hawaii Medical, LifeGuard Pre-wired Electrodes, Available at http://www.hawaiimedical.com.

[23] Cardiac Arrest Associated With Trauma, Circulation. Circulation. 2005;112(24): IV 146 - IV 149.

[24] Schwartz GR, Principles and Practice of Emergency Medicine. King of Prussia, PA: Rittenhouse Book Distributors, 1999.

[25] W. Tollefsen, M. Pepe, D. Myung, M. Gaynor, M. Welsh, and S. Moulton. iRevive, a Pre-hospital Mobile Database for Emergency Medical Services. *In International Journal of Healthcare Technology and Management (IJHTM),* Summer 2004.

[26] K. Lorincz and M. Welsh. MoteTrack: A Robust, Decentralized Approach to RF-Based Location Tracking. *In Proceedings of Personal and Ubiquitous Computing, Special Issue on Location and Context-Awareness*, Springer-Verlag, 2006.

[27] SiRF Technology. SiRFstar III GPS receiver chipset. Available at http://www.sirf.com/products-ss3.html.