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Vital Signs Monitoring and Patient Tracking Over a Wireless Network

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Abstract— **Patients at a disaster scene can greatly benefit from technologies that continuously monitor their vital status and track their locations until they are admitted to the hospital. We have designed and developed a real-time patient monitoring system that integrates vital signs sensors, location sensors, ad-hoc networking, electronic patient records, and web portal technology to allow remote monitoring of patient status. This system shall facilitate communication between providers at the disaster scene, medical professionals at local hospitals, and specialists available for consultation from distant facilities.**

Keywords – emergency, vital signs, sensors, mote, triage

I. Introduction

Steady advances in wireless networking, medical sensors, and interoperability software create exciting possibilities for improving the way we provide emergency care. The Advanced Health and Disaster Aid Network (AID-N), being developed at The Johns Hopkins University Applied Physics Laboratory, explores and showcases how these advances in technology can be employed to assist victims and responders in times of emergency. The scope of this paper covers a subset of the technologies in AID-N.

We have developed a system that facilitates collaborative and time-critical patient care in the emergency response community. During a mass casualty disaster, one of the most urgent problems at the scene is the overwhelming number of patients that must be monitored and tracked by each first responder. The ability to automate these tasks could greatly relieve the workload for each responder, increase the quality and quantity of patient care, and more efficiently deliver patients to the hospital. Our system accomplishes this through the following technologies:

- Wearable sensors to sense and record vital signs into an electronic patient record database. This dramatically improves the current time-consuming process of manually recording vital signs onto hardcopy pre-hospital care reports and then converting the reports into electronic format.
- Pre-hospital patient care software with algorithms to continuously monitor patients' vital signs and alert the first responders of critical changes.
- A secure web portal that allows authenticated users to collaborate and share real-time patient information.

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II. Methodology

During health emergencies, when time is of the essence, there is little tolerance for system errors and poor usability designs. Through the use of standards-based software and best-of-breed hardware, our goal is to deliver a system which is scalable, reliable, and user-friendly.

Our patient monitoring and tracking system extends upon the CodeBlue project from Harvard University [1]. CodeBlue is a distributed wireless sensor network for sensing and transmitting vital signs and geolocation data. Figure 1 illustrates our current prototypes. A wearable computer attached to the patient's wrist, commonly known as smart dust or a mote, forms an ad hoc wireless network with a portable tablet PC. We've integrated several peripheral devices with the mote, including location sensors for both indoor and outdoor use, a pulse oximeter, a blood pressure sensor, and an electronic triage tag. The electronic triage tag allows the medic to set the triage color (red/yellow/green) of the patient at the push of a button. It replaces the paper triage tags that are commonly used by medics today. The mote also has onboard memory for storing the patient medical record.

As in Fig. 1, the mote continuously transmits patient information to the first responder's tablet device. The transmission uses the TinyOS Active Messages protocol, which is based on the IEEE 802.15.4 standard [2]. The mote was originally developed at the University of California Berkeley in the late 1990's. Since then, it has gained significant interest from academia and industry for its ability to provide low-power, cost-effective, reliable wireless networks for monitoring applications. Our mote prototype uses the MICAZ platform from Crossbow Technology. It is powered by 2 AA batteries and consumes roughly 20 mA when active, resulting in a battery lifetime of 5–6 days of continuous operation. It uses a single-chip radio, with a maximum data rate of 76.8 kbps and practical indoor range of approximately 20–30 m.

The system is designed to require little setup time. A medic carries many mote packages and distributes them to the patients. Each mote is pre-attached with a paper triage tag, which acts as backup if the electronic triage tag fails.

When the patient is first triaged, the medic straps the mote wristband on the patient, places the finger sensor on the patient's finger, and sets the electronic triage tag to the patient's triage category. The blood pressure sensor is an optional module, and the medic may put it on select patients who need the additional level of monitoring. The mote automatically starts transmitting data to the medic's tablet PC. The tablet PC is harnessed to the first responder in a weatherproof and anti-glare casing.

We integrated these wearable sensors with a pre-hospital patient care software package (MICHAELS) created by the OPTIMUS Corporation. MICHAELS runs on the first responder's tablet PC. We modified MICHAELS to automatically record and analyze the patients' vital signs and alert the first responder of abnormal changes. MICHAELS also transmits patient information in real time to a central server that hosts the medical record database.

MICHAELS has the capability of writing the patient medical record onto the mote. This allows the patient medical record to be stored locally with the patient. When a patient boards the ambulance, the medic onboard can load the information from the patient's mote back to the MICHAELS software.

The tablet PC requires a network connection to communicate with the central server. In our implementation, we take advantage of Verizon's EVDO coverage in the Washington, D.C., Metropolitan Area. Our tablet PCs use EVDO wireless cards to attain high speed network connectivity from anywhere in the greater Washington area.

Fig. 1. Patient information flow.

We've built a web portal to connect with the patient record database and make the real-time patient information accessible to users from Internet browsers. This web portal will be used by different participants in the emergency response team, such as the emergency department personnel who need this information to prepare for the incoming patient.

Effective healthcare requires access to patient data that are generally stored on heterogeneous database systems. Integration of patient data is a significant challenge faced by the healthcare community. In our implementation, we are able to connect two disparate systems, that is, the patient record database and the web portal, through the use of well defined web services. Patient information is transmitted over SOAP, a secure and encrypted form of XML. The WSDL (Web Service Definition Language) for these web services is published to a community of authorized users. This web service-based approach for intersystem communication gives our software the flexibility to interoperate with third-party software in the future.

III. Implementation

A. Wearable Sensors

The wearable sensors provide four functionalities: vital signs monitoring, location tracking, medical record storage, and triage status tracking.

We integrated two types of non-invasive vital signs sensors – a pulse oximeter and a blood pressure sensor. The pulse oximeter attaches to the patient's finger and measures heart rate (HR) and blood oxygenation level (SpO_2). A cuff pressure sensor on the patient's upper arm measures systolic and diastolic blood pressure.

We also integrated two types of location sensing capabilities – a GPS to provide geolocation, and indoor location detection system to provide location where the GPS signal cannot be reached. The GPS sensor allows medics to track patients who are outdoors, e.g. at the scene of the emergency, with accuracy of 3 meters (CEP). The indoor location system, based on the MoteTrack project developed at Harvard University, requires the installation of location beacons [3]. Indoor location beacons are being installed at a designated auxiliary care center near Washington DC. Patients are admitted to an auxiliary care center if nearby hospitals have reached their occupancy capacities and cannot admit more patients. At an auxiliary care center, which can often be short on staff and overfilled with patients, the patients vital signs will continue to be monitored by our system. The ability to track the location of the patients indoors will be a very useful feature for helping medics quickly locate a specific patient whose conditions have deteriorated.

With all the peripheral devices turned on, the pulse and oxygenation reported every second, the GPS location reported every 5 minutes, and the blood pressure reported every 15 minutes, and the battery lifetime of the overall system is approximately 6 hours. The blood pressure sensor is the most power hungry peripheral, and when it is not used, the battery life of the overall device increases to 1-2 days.

B. Vital Sign Monitor Algorithm

Software on the tablet device receives real-time patient data from the mote and processes them to detect anomalies. If the patient has a medical record that has been previously entered, information from the medical record is used in the alert detection algorithm. Table I shows a partial list of physiological conditions that cause alerts. The algorithm uses additional information such as patient age and height to adjust its thresholds. If additional information is not available, the algorithm uses a set of default values.

C. Pre-hospital Patient Care Software

MICHAELS is integrated with an electronic medical record database hosted at OPTIMUS Corporation. The tablet PC regularly transmits patient data (vital signs, location, triage color) and alerts for multiple patients to the database via a wireless network. If network connectivity is unavailable, the patient monitor and alert system on the tablet PC continue to operate.

When an anomaly is detected in the patient vital signs, the medic's software application generates an alert in the user interface. Figure 2 shows an alert in the software application. The medic can locate the patient by selecting to view a map of the disaster scene marked with the GPS location of each patient. The medic can also select a "sound alert" feature that will sound a buzzer and blink an LED on the mote. All alerts are listed inside a side panel, making multiple alerts easier to manage.

TABLE I
ALERT DETECTION PARAMETERS [4, 5, 6, 7]

Alert Type	Detection Parameter
low SpO_2	SpO_2 < 90% *
bradycardia	HR < 40 bpm *
tachycardia	HR > 150bpm *
HR change	$\lvert \Delta HR / 5\,\text{min} \rvert > 19\%$
HR stability	max HR variability from past 4 readings > 10%
BP change	systolic or diastolic change > ±11%

* These are defaults values, they are adjusted based on additional input from the patient medical record.

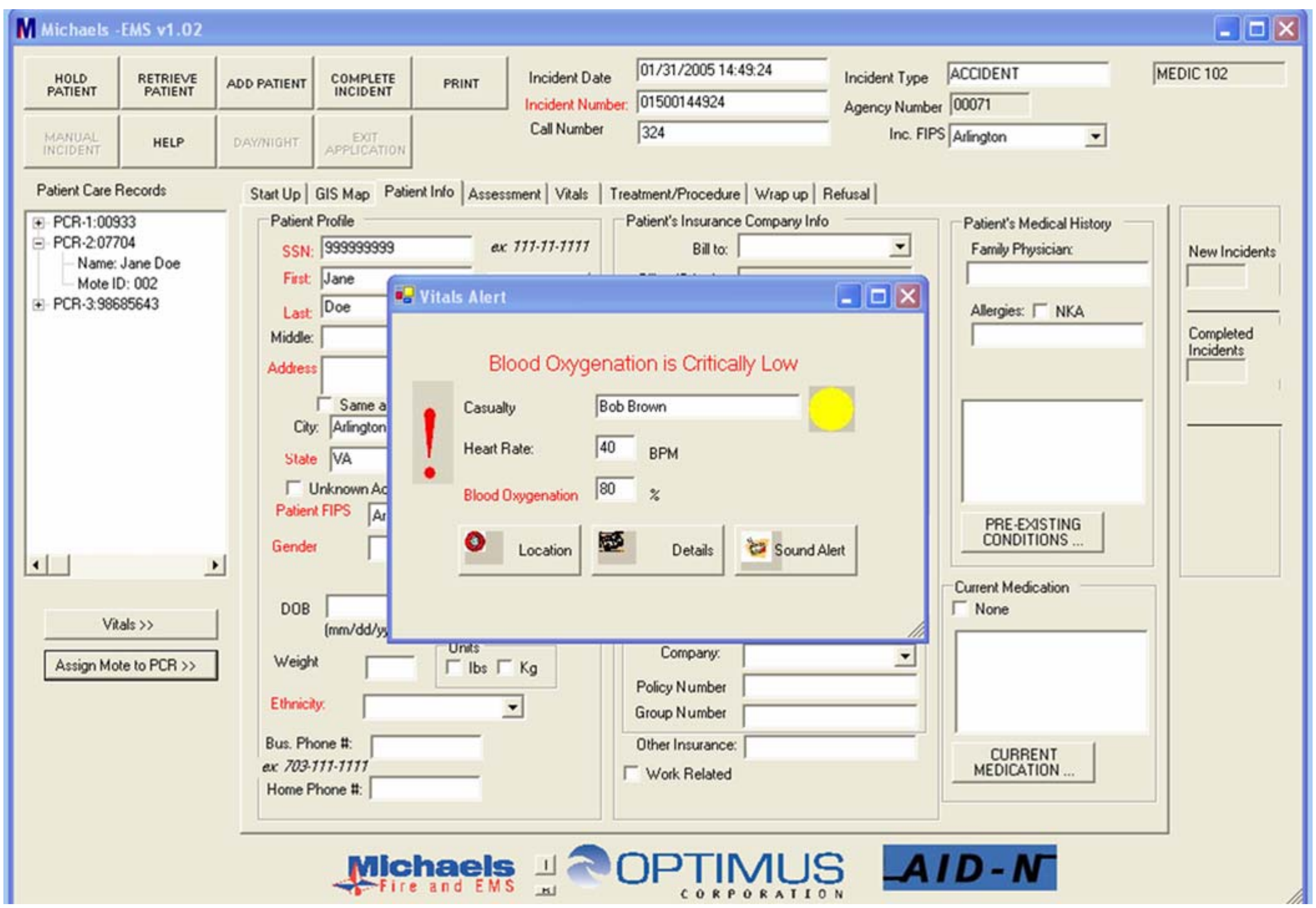

Fig. 2. MICHAELS shows an alert when the patient's blood oxygen level is critically low.

D. Web Portal

An effective emergency response information system should support the need for multiple parties to share information about patients' status and locations. Our web-based information portal allows different types of users to access the patient information in real-time. When a user logs in, the information displayed to that particular user is managed by group-level permissions. The portal has three groups of users:

1) Emergency department personnel login to the portal to retrieve information about the patients who are being transported to their hospital. Figure 3 shows a page in the portal for this group of users.
2) Incident commanders login to the portal to see summaries of patients at particular disaster scenes. Since patients are tracked by the electronic triage tags, the incident commanders can review the number of patients for each triage color. This allows them to make informed requests for additional medical supplies and personnel and to properly allocate available resources.
3) Medical specialists, often located at distant facilities, may be called on to give treatment instructions to the medics at the scene. They log in to view real-time medical data of the patient being treated. They can also review the triage colors of patients at the scene to verify that the patients have been triaged correctly.

IV. Conclusion and Future Work

The AID-N system has great potential in improving problems in today's emergency response system, especially in plans to deal with mass casualty disasters. While designing our system, our team collaborated extensively with medical professionals to identify their greatest needs. The key activities which could be improved using technology are: patient monitoring, patient record generation and remote patient record review. AID-N has constructed hardware and software prototypes to address these needs, and shows promise in improving the efficiency of emergency personnel for these activities.

All technologies have limitations, and cannot provide their benefits under all circumstances. When new technology is introduced into the emergency response arena, it is important to note its limitations as well as its capabilities. Due to the chaotic nature of emergencies, our system faces the difficulty of operating in situations that challenge instrumentation designed for use in the controlled environment of a clinical situation. For example, the pulse oximeter sensor used by AID-N cannot function on patients with finger nail polish or nail fungus. Furthermore, in cold temperatures and/or high altitudes, the body responds through vasoconstriction in the peripherals; in this case, blood flow to the fingers is restricted and does not register accurately on the pulse oximeter.

The patient monitoring feature will not be useful in all situations. In a mass casualty disaster, when the medics must triage many casualties quickly, they will not have time to respond to alerts until all patients have been triaged. Medics expect the monitoring system to be most useful for patients who have been triaged and are waiting for ambulances. They can then use our system to prioritize the patients who need to be transported by ambulance.

Pilot exercises are being conducted at Suburban Hospital, Johns Hopkins Pediatric Trauma Center, and an auxiliary care center. Lessons learned from these trials will be used to improve the next version of our system.

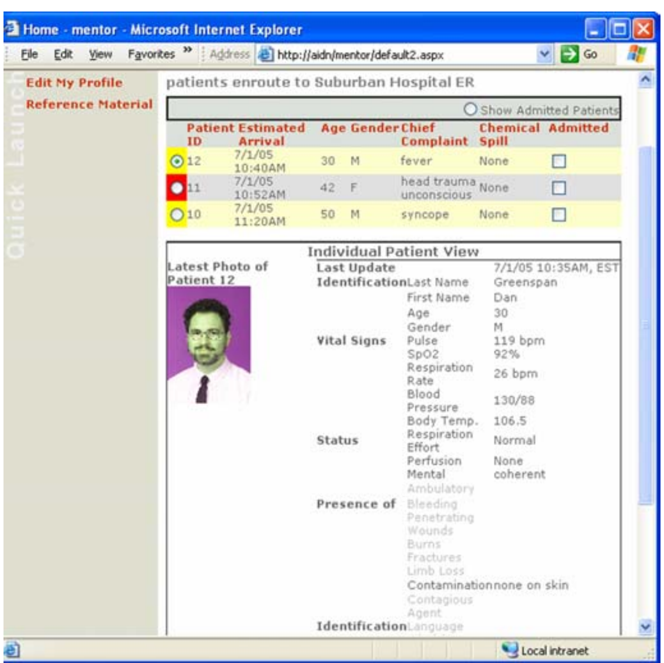

Fig. 3. Web portal for emergency room personnel, listing the patients en route to the hospital and their triage color, ID, estimate arrival time, age, sex, chief complaint, and chemical agent exposure.

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