ARTEMIS Personal Area Networks for Emergency Remote Triage and Information Management

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ABSTRACT

The Automated Remote Triage and Emergency Management Information System (ARTEMIS) project seeks to provide situational awareness to all level of commands in order to increase patient survival rate during emergencies. By moving the burden of triage off of the medic and into an automated system, more time will be able to be spent on casualty care rather than assessment. Continual monitoring of responders and casualties will alert medics of critical changes in a patient's health that might normally have gone undetected after a patient is initially triaged. ARTEMIS employs a network of embedded sensors worn by responders and casualties to gather the data required for greater situational awareness and to relay the data back to appropriate levels of command both on the field and in remote locations.

Keywords

embedded sensors, situational awareness, emergency response

INTRODUCTION

Increasing patient survivability by moving information and resources closer to casualties in the field is a major objective of automated remote triage. Survivability of emergency responders and casualties can be improved by expanding the flow of medical information on the field and throughout the chain of command. The goal of the Automated Remote Triage and Emergency Management Information System (ARTEMIS) project is to provide medical situational awareness at all levels of command through network centric medical response.

The most critical stage of this process begins by monitoring individual first responders and casualties and providing relevant information to the medics, who are the first line of care. In addition to improving the outcomes of injured responders and civilian casualties, we believe that a more effective flow of medical information will help to prevent injuries and to assist tactical decisions. In the military domain, for instance, of all of the casualties medics attempt to rescue, 25% of them are already dead before the medic arrives, and the process of accessing the soldier puts the medic at risk (Pearce, 2002). Ten percent of casualties in the battlefield are injured while attempting to rescue a previously injured comrade, and if a medic is part of that 10%, the soldiers he is responsible for and their mission are likely to be jeopardized. While some casualties are unavoidable, we believe that these specific types of injuries can be reduced and outcomes improved with a more effective analysis and distribution of medical information on the battlefield. Realizing this vision requires a combination of technologies capable of: (1) extracting physiological information from the soldier with simple non-invasive sensors, (2) analyzing sensor data to transform raw data into clinically useful information, and (3) efficient network architecture and protocols for data exchange.

ARTEMIS equips responders and casualties on the field with wearable embedded sensor "tags" that process, store, and analyze physiological data collected from the subject. Medical algorithms determine state information about the subject, giving a concise summary of the large amounts of data being collected.

In the field, data is passed to medics via ad hoc networking between individual sensor systems. Each medic's device displays a list of all tagged subjects with their triage state. Detailed information about individuals is also available, as well as functionality that allows medics to enter additional information about the subject. This information is passed back to the subject's tag where the medical algorithm updates its assessment based on the new data.

Data from the field is sent back to the command post using a publish/subscribe middleware layer than can be adapted to whatever network might be available (existing infrastructure, deployed satellite systems, etc). The publish/subscribe model allows arbitrary sensor types on the field to publish data to the network. Various roles in

the command center can then subscribe only to the data they need. This creates a very flexible architecture that balances a wealth of data rich content without causing individual users of the data to become overwhelmed with too much information.

Additionally, the sensor tags can continue to publish data over the network while in transit to treatment centers if the vehicle is equipped with mobile communication technology such as satellite or cellular systems. Hospitals then get advance information of incoming casualties with recorded details of patient's medical history since the tag was first applied.

Figure 1 depicts information flow during emergency medical situations using the ARTEMIS system. Responders' and casualties' physiology and location are continually monitored in the field by sensors worn on each person's body. Sensor data is consumed by field medics and command personnel. Data exchange occurs in the field via reliable ad hoc networking. Information flows to the command levels and treatment centers via ad hoc satellite proxies. In the event that medical personal determine a casualty must be evacuated, data begins to flow to the hospital or medical treatment facility before transportation arrives. During transit, vehicular-based satellite or cellular systems continue to forward data to the medical facility that will be receiving the casualty. This model provides end-to-end monitoring of casualty health.
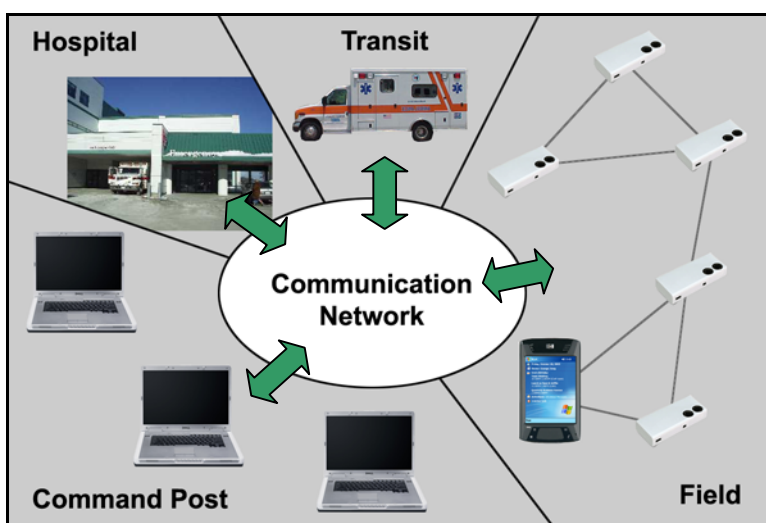

Figure 1. ARTEMIS Components and Communication

AUTOMATED REMOTE TRIAGE

The medical algorithm used in ARTEMIS is based on a simple and effective triage protocol designed by NATO called START (Simple Triage And Rapid Treatment) (DeLorenzo and Porter, 1999). This protocol classifies injured subjects based on the location, type, and severity of the injury; the ABCs of triage (airway, breathing, and circulation); as well as the subject's cognitive and ambulatory state. The resulting classification falls into one of several categories:

- Minimal: Subject is able to self-treat and walk to a casualty collection point

- Delayed: Subject is able to self-treat but not able to walk

- Immediate: Subject has serious injuries and requires immediate treatment

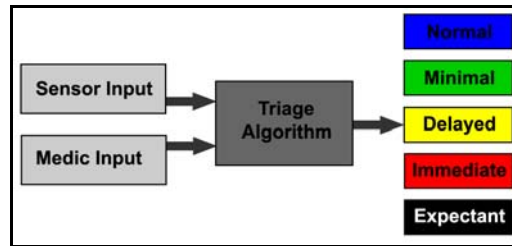- Expectant: Subject has serious injuries and death is imminent

Figure 2. Automated triage algorithm uses sensor data and medic input to determine the subject's triage state.

ARTEMIS seeks to derive as much information as possible from sensors to feed into the triage algorithm with the end goal of fully automated triage that only requires a responder to apply the ARTEMIS tag. Automating the information gathering process leaves more time for medics to do treatment rather than assessment. Furthermore, detecting status changes after the initial triage assessment is more accurate when there is more input available.

SYSTEM ARCHITECTURE

Table 1 shows the requirements for a deployable system to be used by emergency responders:

Inexpensive	Systems should be on the order of 100s or fewer of dollars
Easy to deploy	Time should not be taken away from response to set up the system
Wearable	The system should not be cumbersome or interfere with responder's operations
Rugged	Must be able to withstand environmental factors like rain and dust, as well as being dropped or bumped
No reliance on pre-existing infrastructure	Must be able to deploy its own network if one is not available
Reliable	The communication protocol must be fault tolerant

Table 1. System Requirements

ARTEMIS tags are built using commercial off-the-shelf components to reduce development time and cost. All systems can be configured once and be ready for deployment regardless of the type of emergency. Bluetooth enabled sensors replace wires that can become tangled and unwieldy. The tags can be stored in commercial off-the-shelf, ruggedized, wearable cases. Ad hoc wireless networking ensures that communication can occur on the field regardless of pre-existing infrastructure, and reliably adapts to dynamically changing network structures.

There are three primary components in the ARTEMIS tag system used in the field: the embedding platforms containing the processor unit, the sensors, and the communication network. The embedded platforms are Bluetooth enabled and have serial and Compact FLASH (CF) ports that are available for connecting to sensors. Data is sent between ARTEMIS tags using 802.11 wireless connections. Data is stored on the processor in non-volatile FLASH memory so that if the tag is temporarily disconnected from the network or loses power, no data is loss.
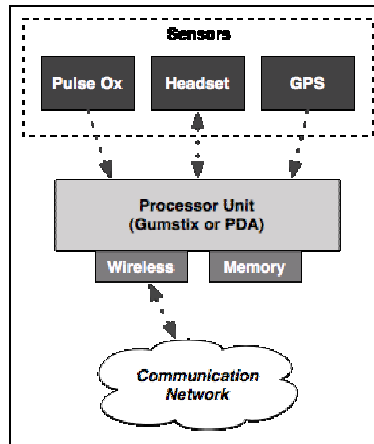
Figure 3. ARTEMIS Tag Modular Hardware Design

Embedded Platform

ARTEMIS uses two different embedded platforms in the field. Responders and casualties wear eTriage-Casualty units to collect sensor data and relay information across the network. Medics use eTriage-Medic which has the same functionality of the eTriage-Casualty system, plus additional features that allow medics to view medical data and issue treatment protocols. Both systems consist of an embedded computer; GPS unit; and a single, multifunctional, non-invasive sensor that effectively measures physiological parameters in emergency situations. The embedded computer collects, analyzes, and interprets physiological data in a meaningful way. This data is then relayed to all medics in the field via ad hoc networks between units and is also sent back to the command and control center for higher level monitoring.

Both devices are designed to be wearable and unobtrusive. This means, that there can be no wires hanging across the user's body, and the device should be lightweight and compact. Both units must also be able to withstand environmental factors present in emergency situations such as water, dust, or heat. While responders and casualties will wear their device but not interact with it, the medic must be able to move their device around: putting in his hand when viewing or entering data, and putting it out of the way when not in use. Wires tethering stationary components such as the pulse oximeter and headset to the CPU are especially impractical for the medic. Bluetooth-enabled sensors are particularly useful for eliminating wires that might get in the medic's way.

The requirements for eTriage-Medic and eTriage-Casualty also differ in that the medic requires a graphical display in order to view data from all the other devices on the network (both medics and casualties) and enter new, qualitative assessments. The casualty device needs only to collect data and transmit and receive messages on the network; a graphical display beyond a few LEDs is neither necessary nor useful. For eTriage-Casualty, we use the Gumstix embedded Linux platform. For eTriage-Medic, we use handhelds running Windows Mobile. The Gumstix is a more desirable embedded platform than similar platforms such as Berkeley Motes because they have a variety of commercially available add-on hardware modules that provide extra functionality such Bluetooth and wifi, which integrate easily with our sensors and network architecture. Windows Mobile handhelds were chosen for eTriage-Medic because they are widely available and supported, and are also available with integrated Bluetooth and wifi.

Sensors

The system was designed with a modular approach, so sensors can be removed, added, exchanged from the embedded platform. The current system two sensors: a pulse oximeter to collect physiological data and a GPS unit to track the subject's location. We are in the process of integrating a headset for voice recognition and in order to assess cognitive state.

Pulse Oximeter

We are using Nonin pulse oximeters, a commercial sensor developed for physiological monitoring that has been used in the medical domain for two decades. Commercial pulse oximeters collect physiological data, including saturation of oxygen in the blood stream (SpO2), perfusion index, and pulse rate. These parameters are key

diagnostic indicators of patient health. Oxygenation is an indication of how well the lungs are providing oxygen to the blood. Perfusion is the circulation of blood through the vascular bed of tissue and is an indicator of circulatory function. Pulse oximetry relies on the different spectral properties of oxygenated hemoglobin (HbO2) and reduced hemoglobin (Hb) to measure oxygen saturation (SpO2). SpO2 is derived in standard pulse oximeters from the relative absorption of light from a red and an infrared LED. The photoplethysmogram, commonly referred to as the "pleth waveform," is usually only derived from one of these two signals, and is an indirect measurement of blood volume under the sensor. The temporal behavior of this signal is influenced by the cardiac and respiratory cycle.

Besides providing the standard measurement of blood oxygen saturation, with further signal processing, the pleth waveform has the potential for measuring several other key physiological parameters, including instantaneous heart rate, heart rate variability, respiratory effort, blood volume change, and sympathetic tone. These measurements could then be used to monitor the ABCs of triage (Airway, Breathing, and Circulation) and detect depressed breathing, airway obstruction and hemorrhage. Therefore, the pulse oximeter can be used to collect physiological data that would otherwise require multiple sensors, thus reducing the size and complexity of the ARTEMIS system.

Nonin pulse oximeters are available with serial and Bluetooth connections. ARTEMIS tags are compatible with either connection.

GPS Unit

GPS units attached to ARTEMIS tags provide continual location tracking of all tagged individuals. This data can be used by the medic to find patients quickly, and is also used by command and control for a bird's eye view of the scene. GPS is limited in that the units need a clear view of the sky, which means it is not suitable for indoor use. However, it is the best commercially available, inexpensive location tracking method available. When better systems become available, they can easily be integrated with the ARTEMIS system.

GPS units are available with serial, Bluetooth, and CF connections that are all compatible with the ARTEMIS tag architecture.

Network Architecture

The ARTEMIS messaging architecture provides the framework for information filtering, information movement, and decision-support capabilities. The ad hoc wireless routing system transports data among computing devices in both urban and open environments over an 802.11 network. If the sensor system worn by a responder or casualty detects abnormalities suggesting an injury, an alert is sent via a wireless connection to the necessary medical personnel (medics, medical evacuation personnel, and medical teams at other echelons). Messaging software routes pertinent information, such as treatment protocols, medical records, reference material, evacuation arrangements, and requests for decision support through the wireless network. Requests and queries can be either one-time or persistent, minimizing the workload on medical personnel using the system. Ad hoc wireless routing protocols ensure reliable and timely delivery of information in limited bandwidth networks.

In a mobile field environment, a wireless communication network provides a convenient means of communication among devices. Because of the potential for constant movement of individual and groups of soldiers in the field, the wireless network must maintain a dynamically updated routing system for transmitting messages. A network routing system with this capability is required for remote triage. The ARTEMIS team has implemented the On-demand Multi-cast Routing Protocol (ODMRP). ODMRP was the top performer during the "Outdoor Experimental Comparison of Four Ad Hoc Routing Algorithms" (Gray, Kotz, Newport, Dubrovsky, Fiske, Liu, Masone, McGrath and Yuan, 2004) conducted in 2004 by researchers at Dartmouth College. ODMRP provides reliable, dynamic packet routing, which is highly adaptable in situations with rapidly changing topologies.

SYSTEM TESTING

Functional testing of the ARTEMIS system was accomplished in 2005. A user jury, comprising testing and review of interfaces, operability, and functional relevance, will be undertaken in the spring of 2006. A field test involving emergency responders and mock casualties, planned for the summer of 2006, will explore networking and additional operational considerations. Modifications to ARTEMIS from these tests will be based on user feedback and quantitative analysis of system performance.

CONCLUSION

Ascertaining physiological state of responders and casualties in mass casualty events is essential for maximizing patient survivability. Triage currently requires much of the medic's time in the field and does not account for a patient's changing physiology over time. Sensor networks such as ARTEMIS can provide an unprecedented degree of medical situational awareness at all levels of the first-responder command hierarchy. Medics will be able to allot more time to treating casualties, hospitals will be better prepared to care for incoming patients, and command and control will be able to monitor their responders and better allocate their resources.

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