

Applications for Emergency Medical Services

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ABSTRACT

Today, despite the obvious need, pre-hospital providers cannot send real-time electronic patient care information from the field to a receiving hospital. This lack of field awareness and inability to plan for the arrival--or anticipate the needs--of seriously ill or injured patients can lead to the misdirection of patients and the loss of valuable time in the early phases of resuscitation. We believe, however, that current technology can address these shortcomings and that is the focus of our research efforts. This paper discusses how several countries, including Israel, Sweden, Britain and the United States, are addressing the need to better triage patients from the field to an appropriate hospital or trauma center. It also introduces a potential solution, called iRevive, which uses emerging technology such as sensors, wireless WAN data transport, web services, artificial intelligence, and mobile devices to meet the dynamic needs of first responders and the hospitals they serve.

Keywords

Emergency medical services (EMS), mobile computing, wireless sensors, patient care.

INTRODUCTION

Emerging technologies such as sensors, mobile computing devices, and ubiquitous WAN data transport have the potential to greatly improve the ability of first responders to cope with uncertain, dynamic, large-scale events. Large scale disasters are difficult to manage, especially when traditional lines of communication are broken, resources are limited, and lives are at stake. A central problem is the large number of casualties and how to both monitor and deal with them. A Dynamic Data Driven Application System (DDDAS) for field triage and patient care [Gaynor 2005] could mitigate the discrepancy between patient load and available resources. It would identify those patients who will do well with minimal care and those who will die despite maximal care, so that focus can be directed to those who will benefit most from optimal trauma care and rapid surgical intervention. It is in this latter group that careful planning and coordination can make the biggest difference. . Triage in the field is therefore an interactive process: by continuously feeding field information to a decision support system, the out-of-

hospital caseload is coordinated with the availability of critical, hospital-based trauma facilities and resources.

This paper presents background information on emergency medical services and examines current applications in several countries, such as Israel, Sweden, Britain and United States. Next, it describes the development of a distributed, dynamic system for real-time patient triage. This system, called iRevive, consists of: 1) a wireless sensor network infrastructure, integrated with a mobile patient care application, for monitoring and documenting patient information; 2) a web based infrastructure for processing and delivering the above, real-time data to command centers and hospital locations; and 3) a distributed decision support system to assist pre-hospital and hospital-based personnel in triage.

Emergency Medical Services and Mass Casualty Events

In the United States, Emergency Medical Services (EMS) organizations provide first response emergency pre-hospital care in urban, suburban, and rural areas. These services are overseen at the national level by the Federal Emergency Management Agency (FEMA), the National Highway Traffic Safety Administration (NHTSA), and by each state's Office of EMS. They are provided by public and private ambulance companies. Nationwide, there are 21,000 EMS services with an average of 2.5 ambulances per service. EMS services log nearly 1 million requests for transport per month in the United States. Critically ill and injured patients who are unstable, or potentially unstable, and require long distance transport to a tertiary or quaternary healthcare center may be transported by air.

Most patient transport is for one or two patients. When six or more patients must be transported from a motor vehicle crash or single accident site, one is dealing with a mass casualty incident (MCI). Mass casualty incidents generally require more formal coordination of patient transport to multiple hospitals, especially if two or more patients are severely injured. This is because two severely injured patients can quickly consume the emergency resources of any well staffed trauma center. Mass casualty event (MCE), on the other hand, are sudden, unexpected situations in which, over a short period of time, large numbers of casualties are generated and organized community support mechanisms are either crippled or destroyed [ACS 1998]. A central problem is the need to coordinate the deployment of personnel and resources, in order to quickly identify, monitor, triage, and transport the 10-15% of survivors who are severely injured in a typical disaster [Mallo 1996, Stein 1999, Frykb 1989]. The deployment of resources may be hampered if the communication infrastructure is damaged and roads are blocked. Stratifying severely injured patients from amongst the less severely injured poses another set of challenges. Monitoring these patients is also troublesome and typically intermittent, as current equipment is bulky, wired, and may be in short supply. If the injured and severely injured cannot be triaged and transported to area hospitals in a rapid and coordinated manner, their large numbers can prevent emergency field personnel and hospital staff from providing quality trauma care [Frykb 1988].

The triage process occurs at several locations including both in-field and hospital gate (typically at the ED entrance). In field triage determines treatment, transportation order, and destination. Triage at the ED involves a trusted emergency physician or surgeon experienced in trauma care using one or more triage tools to stratify patients based on mechanism of injury, physiologic criteria, injury site and severity, age, pre-existing disease, and/or expectation for

survival [Bond 1997, Cook 2001]. Experience has shown, however, that overtriage rates of 50-60% are common [Frykb 1988]. This is a major problem from the perspective of providing optimal trauma care, because overtriage ties up valuable resources that could otherwise be used for more severely injured patients. To better allocate trauma resources, it would be useful to decide as early as possible which patients will benefit most from transport to a dedicated trauma center and, conversely, which patients can be safely excluded or delayed entry into the system.

Emergency medical service (EMS) providers, local municipalities, and regional government agencies have an obligation to cooperate and support a sound emergency services infrastructure that scales to large events with many injured victims. This goal can only be accomplished if there is open communication and extensive data sharing among these different agencies. Current EMS and disaster management systems manage large amounts of data; however, none have a sophisticated, dynamic, sensor-based infrastructure that is scaleable and fault tolerant. This paper seeks to describe new technologies for data collection, integration, and response, to address this pressing need.

Potential Impact

Applying advanced technologies to the management of emergency resources has the potential for major impact on society, in terms of a more effective means of disaster response and the saving of lives. We are currently working with multiple emergency services groups in the Boston area to develop prototypes and experiment with these technologies for future testing in rescue and response drills. The range of service groups includes: Boston MedFlight (our regional aero-medical critical care transport service); Cataldo Ambulance (the second largest ambulance service in Massachusetts); and a Level 1 trauma center (Boston Medical Center). We also have a working relationship with the Washington, D.C.-based Capital Wireless Integrated Network (CAPWIN) team. These existing relationships will allow us to deploy and test our prototypes in local and regional disaster-response drills.

CURRENT APPLICATION OF INFORMATION TECHNOLOGY IN EMERGENCY MEDICAL SITUATIONS

Emerging technologies such as mobile connected devices are beginning to be applied to emergency medical situations because countries such as Israel and Britain have long histories of terror on the local population. Other countries such as the U.S., which has recently become aware of its vulnerability, and forward thinking countries, such as Sweden, just want to be prepared. Most of the current efforts use wireless LAN (802.11), and wireless WAN (2nd and 3rd generation cellular) technology to transfer data in real-time from the event site to several locations including hospitals and emergency command centers. Below are several examples that include both international and domestic projects.

In Israel, one effort uses advanced technologies to arrive faster at the site of the accident. Magen David Adom, the Israeli medical services, is now implementing a "supervision and control system" developed by Ness Technologies. This system is used by the regional and national dispatching centers and in the regular ambulances and Intensive Care Units. The system can help reduce response time by providing real time data location. The dispatching centers' team locates the ambulance that is closest to the emergency scene and the ambulance driver follows the shortest route to the emergency scene on his vehicle computerized map. The system has already proved to be life saving [artman].

Sweden is using an advanced system linking the hospital to paramedics on site. This system in pilot testing enabled better care of victims at accident sites by leveraging multiple types of wireless data communications between hospitals and accident sites. The system includes mobile computing devices, wireless LANs, wireless WANs and GPS. At the accident scene the paramedics use the Symbol 1740 device to collect the patient's measurements like pulse and blood pressure. The paramedic enters the vital information which is stored in the SPT 1740 and transmitted to the ambulance. Then it is transmitted in real time to doctors and the patient database in the hospital. Doctors analyze the information and respond to the paramedic with instruction. The SPT 1740 can also record the medications given to the patients and thus provides accurate information for further treatment [wireless].

Another example is London where the ambulances seamlessly switch between wide area (GPRS) and wireless local area (Wi-Fi) networks. The ambulance service is testing a technology from Broadbeam to switch between five different networks according to priority using it to download maps in order to get to the patient as well as to transmit vital patient data back to the hospital reducing the time to get the critical data. According to the deputy director of technology at London ambulance, it used to take approximately one minute to pass the details to the ambulance crew by voice and then the crew needed to look for the destination in the map, now this takes two seconds [mobility].

In the United States, the trend toward broadening ITS (Intelligent Transportation Systems) deployments that include EMS includes the public safety community recognizes the need for greater coordination of multiple agencies on the scene of the incident, clearance and recovery operations to enhance public safety, security and health. Toward those ends, the USDOT formed the ITS Public Safety Program in 2000. For EMS the benefits of the ITS include improved patients care. Some of the examples of the usage of ITS are: deployments in San Antonio, Texas and Seattle, Washington of real time voice and video links between ambulance crews and emergency physicians or deployments of location sensors and mobile voice and data communications equipment on transit and maintenance fleet. In some cities such as Dallas Texas, transponders on some emergency vehicles tell traffic signals to give green light priority to the emergency vehicle [itsa].

Other systems such as Artemis use web services for interoperability or WIISARD uses real-time sensors for in-field triage, but do not provide a end-to-end EMS application such as iRevive. The Artemis initiative stores healthcare documents in an ebXML registry/repository to facilitate their sharing by enabling the interoperability of medical information systems through semantic Web services. [srdc]. The Wireless Internet System for Medical Response in Disasters, or WIISARD [ucsd] provides in-field triage. The goal of this project is to provide emergency personnel and disaster command centers with medical data to track and monitor the condition of hundreds to thousands of victims over a period of days at the disaster site. It will also enhance the communication among emergency team members.

Current Weaknesses

Currently many hospitals and EMS service providers track patients by using paper tags around the wrist or the neck serving as a means of documentation and information while transferring patients from the field to the hospital. However, those tags have limitations since they can be torn off, must be read line-of-site, they can be destroyed, and are not weather resistant. Recent advances in tagging have improved on the use of bar coding and mobile wireless data acquisition

to identify and track the victims. Technologies such as “Triage Tracker” (Disaster Management Systems, Pomona, CA) extend this concept by giving each individual a unique identifier and linking that identifier with triage status. The registration system developed in Utrecht and the Netherlands has linked patient identification and registration data with out-of-hospital and in-hospital medical data. By scanning patient wristbands at various locations, such as at the disaster site and at the hospital, the system can track and provide the approximate location of patients.

1. One disadvantage of the bar coding is that it requires the presence of providers with scanning devices that must have line-of-site reading of tags. One possible solution is including the using of radio frequency identification tags to carry the data from the site to the hospitals. These systems allow real time patient tracking as well as mobile data acquisition to create portable medical record. Tracking methods using the mobile LAN and 802.11 have been tested.

2. Another problem is logistics. Many problems are not caused by shortages of medical resources but rather by failures to coordinate their distribution. Real time data acquisition regarding patient’s needs, the location of rescue personnel and resources available on site, are critical to the overall coordination. Currently, documentation of needs and resources is maintained manually on written boards at the incident. Such written boards have the potential of errors and inaccuracy. “Electronic Command Board” recording real time data on the status of patients, personnel and resources can be a solution. In addition, those systems can use the internet thus allowing access to multiple users. Such systems to locate ambulances are currently being tested [aemj].

The following recommendation is based on the study in Minnesota which found that:

- Access Critical Coverage Gaps and Implications for service. The EMS service is dependent on mobile coverage. Yet, adequate coverage in rural areas continues to be problematic. In this case it could result in not allowing adequate result.
- Integrate EMS Planning into Information Technology (IT) Planning and funding the communication and system elements to provide an important cornerstone for EMS management. Such systems need to be integrated into the transportation planning process as this is the means by which state and local funds are often allocated [ISF].

THE CASE FOR IREVIVE

The development of a dynamic communications and decision support infrastructure for use by multiple emergency services would greatly improve the ability to effectively respond to mass casualty events. Our proposed approach, called iRevive, is intended to coordinate the deployment of field personnel, and the large-scale triage¹ of victims. Using iRevive, hospitals and first responders would tap into a real-time communications infrastructure that provides a global view of the evolving disaster response scenario. Individual patients would be continuously monitored using tiny, wireless sensors to provide real-time patient location and vital sign information. A decision support system (DSS) would use this information along with

¹ The current triage algorithm used in iRevive is very simple – it does a static table lookup. In future versions a dynamic triage algorithm that combines patient vital signs with medic observations and treatments will be implemented.

individual patient's data and ambulance location information to determine how to best allocate and utilize limited medical resources.

Our vision raises two specific challenges that we are addressing through this project:

- (1) Extending medical decision support systems (DSS) to large-scale, multi-patient triage: Existing medical decision support systems (a) guide physicians to treat individual patients or (b) guide decision makers on how to define healthcare guidelines and policies that result in the highest societal benefit. An example of (a) is a DSS that assists physicians in the diagnosis and treatment of anaphylaxis [JTFF 2005]. This type of system usually assumes few constraints on human and material resources. An example of (b) is a guideline derived from a cost-effectiveness analysis of radio frequency ablation for the treatment of supraventricular tachycardia [Chen 2001]. This type of system takes into account fixed resource limitations, utilities, and probabilities and is not easily modifiable in a dynamic environment. Making accurate triage decisions in the face of a large number of victims requires that we significantly extend these types of decision support systems to handle a massive caseload of varying degrees of stability and injury severity, with a realistic adjustable dynamic model of resource utilization.
- (2) Integration of real-time vital sign sensors into disaster response: Wireless sensor networks have the potential to provide the real-time vital sign data from multiple patients that will enable multi-patient decision support. The potential value of medical sensor data is obvious, however many challenges remain in terms of scalability, robustness, and integration of real-time data into patient records and decision support systems.

iRevive Architecture

Figure 1 illustrates how the *iRevive* application [Gaynor 2004,2005] would be used to provide emergency medical and evacuation services for injured military personal. The arriving medic places wireless vital sign sensors on one or more patients. Each medic is equipped with ruggedized tablet PC that captures and displays the real-time sensor data and allows the documentation of observations and treatments. Data capture is automated for vital sign data. Data on observations and treatments is manually entered by the medics. This data entry is guided by a set of rules that enforce consistent and complete capture of data. All of the data captured is subsequently used for billing and other management functions besides serving as an input for further research. Local medics are linked to the transport aircraft via an 802.11 wireless infrastructure that enables situational awareness of the aircraft crew so they can prepare for any additional medical interventions that may be required. Each transport vehicle is equipped with a base station that links both to local technicians, command centers, and destination hospitals. This WAN linkage enables global allocation of resources, and increased awareness of the condition of incoming patients at the destination hospital. During patient transport, *iRevive* continues to capture both sensor data and data recorded by medical personnel. The *iRevive* application enables the creation and transfer an electronic patient care record that combines automated capture of vital signs with manually entered data on observations and interventions performed.

A detailed conceptual architecture of *iRevive* is shown in Figure 2. It illustrates how data is transferred between components of the *iRevive* application system. Central to the architecture is a sensor gateway that aggregates data from multiple sensory devices. The aggregated data is available for consumption by different applications including the documentation component of *iRevive*. The data is delivered from the gateway to applications by a set of web services. These

services permit exchange of data in a manner that is compliant with HL7v3, the emerging standard for the exchange of clinical data. Patient care data from the documentation component is transferred to the organizational data repository using web services compliant with HL7v3 standards. The standards based infrastructure of *iRevive* promotes interoperability with a wide variety of IT systems at receiving hospitals. It also offers the flexibility to choose from a set of best of breed components because it permits plug-and-play integration of sensors and supports interoperability as it uses web services and HL7v3.

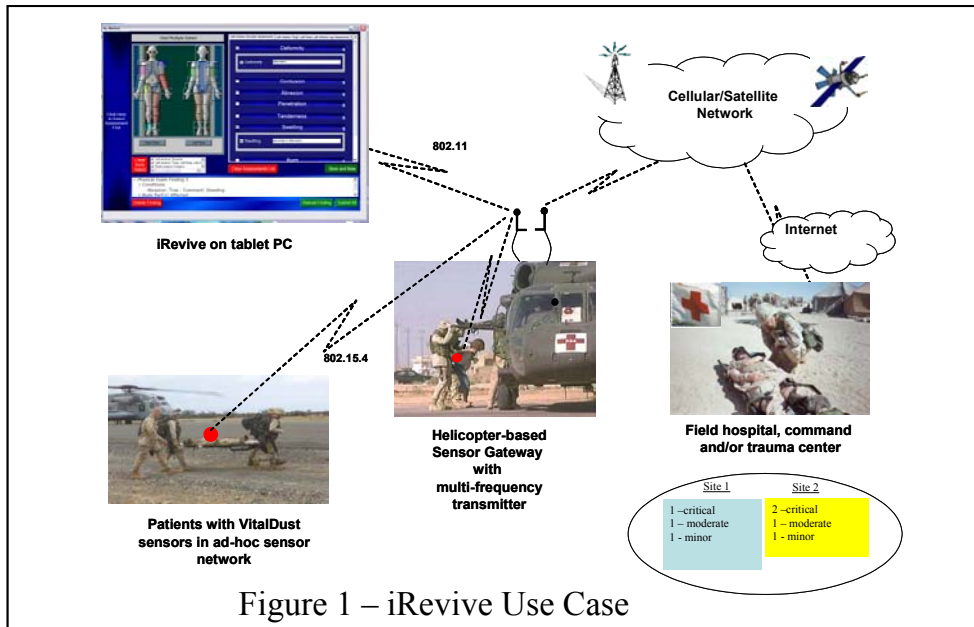


Figure 1 – iRevive Use Case

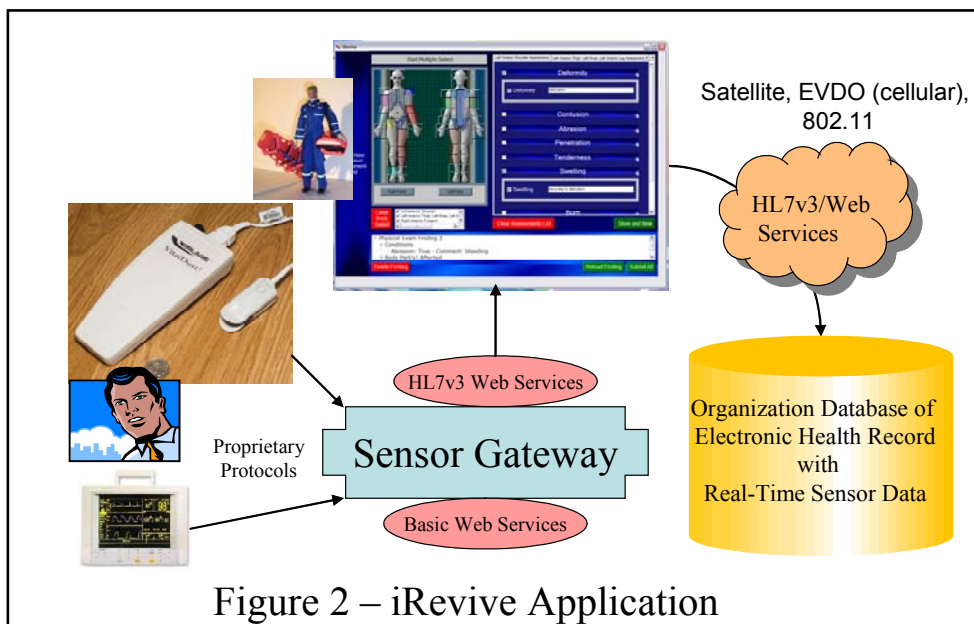


Figure 2 – iRevive Application

We have adopted the sensor gateway architecture because it provides the flexibility to manage the uncertainty of not knowing what protocols and standards medical sensors may adopt in the

future. Similar to the layered Internet architecture that enables Internet applications to work over any type of LAN, the sensor gateway enables applications to consume sensor data from a group of heterogeneous medical sensors with a common interface. This gateway supports drivers for multiple different sensors, ranging from sensors developed by established vendors such as Welch Allyn to sensors developed in non-commercial research environments such as Vitaldust². This gateway approach decouples sensors from applications, thus providing flexibility in sensor choice and the ability of applications to evolve independently of the sensors that provide data to the applications.

Our research team has built a simple sensor shown in Figure 2 based on a commercial pulse oximeter sensor for OEM products. Our unit is called Vitaldust [Gaynor 2004]. It streams a patient's pulse rate and level of blood oxygen saturation over a wireless link. Vitaldust is based on small, low-power nodes (often called motes, or smartdust) consisting of simple embedded micro controllers and low-bandwidth radios operating in the microwave (2.4GHz) spectrum range, which are known as IEEE 802.15.4 [IEEE 2005] and Zigbee [Zigbe 2005] standards. This emerging wireless sensor

A unique feature of *iRevive* is the integration of fine-grained real-time vital sign data with manually recorded human observations and interventions. As sensor data streams into *iRevive* it is correlated with medic entered data to create a patient time-line of observations and treatments that is a time-synchronized view of vital signs, observed changes in patient conditions, and treatments/interventions performed. It will hence enhance the ability of researchers to gauge the effectiveness of in field medical intervention in the context of long term patient outcomes.

The logical system architecture for *iRevive* has three layers: the Graphical User Interface (GUI), the Data Processing (DP) layer, and the database (DB) layer. The bottom layer is the database layer that includes a repository in which the rules that guide data capture are formally represented and stored, a data repository for the patient care data, and a metadata repository that helps reorganize the captured data for auditing, billing, and mining. The middle layer is a data processing layer that has two main modules: the Semantic Interpretation (SI) component that evaluates rules in the context of input data along with the Data Display/Capture module that pulls and pushes data between the underlying database(s) and GUI. The top layer GUI is what the medic interacts with to enter clinical data for documenting the patient's care and changing conditions. It is also the interface in which data such as vital signs are displayed. This layered structure is motivated by the medical industry and its evolving standards for patient care, as well as the ever changing set of requirements for medicolegal documentation. Each layer is examined in more detail next.

Database Layer

The data layer in the *iRevive* architecture has three main components: (1) a metadata repository that contains metadata on the forms used for reporting and data capture, the set of fields in each form (form-fields), and the association between each form-field with its corresponding (patient-data) database field(s). The metadata is stored in a set of tables that richly define and express the

² Vitaldust is a wireless pulse oximeter built from off the self hardware at Harvard University by Matt Welch and his research group.

data. In addition the tables can be formatted to meet requirements for any clinical care organization documentation and reporting needs. (2) Patient's data is captured in a relational database management system. It includes not only the description of the patient, his or her injuries or condition, treatments and procedures administered, but also detailed clinical and administrative documentation (e.g. specific data points defining the physical exam, qualitative and quantitative descriptors for medications and interventions) that must be associated with the more structured patient data. This database is also capable of storing the real-time sensor data collected by the sensor gateway and pulled in using web service requests. The fields in the metadata repository index the patient data containing clinical or administrative documentation. (3) A rule-base that captures the rules defined for data capture and validation. These rules represent the complex inter-dependencies between the data. For instance, depending on the value entered in a specific field, the rules identify if the data is within range, what other data must be captured, determine the data entry forms that contain the form-fields corresponding to this data, and define the sequence in which the identified data-entry forms must be displayed and the sequence in which the data must be captured. These three layers interact to ensure consistent and complete data capture. The rules are currently represented using XML data encoding and are processed in the Data Processing Layer.

Data Processing Layer

The Data Processing Layer (DPL) contains the semantic interpretation (SI) function that evaluates and interprets the rules and the Data Display and Capture (DDC) module that displays information to the medic including real-time vital signs and processes data input. The DDC queries the SI, requesting it to contextually validate incoming data in the context of data that was entered earlier. The DDC also consults the SI to ensure that the data entered is complete in the context of the current event that is being monitored or documented. This interaction is very dynamic because as information about the patient is entered, the relevant applicable rules change, for example:

1. **Validation for the correctness of the individual field.** This is both a qualitative and quantitative check of the field. For example, an adult over 200kg must be administered some drug (say, *lidocaine*) at a higher dosage, but within a certain range, whereas a child with the same condition has a different set of constraints for the same drug.
2. **Fulfillment of mandatory data/documentation:** Certain fields and situations trigger the need for additional information. For example, cardiac patients require aspirin. The DDC tells the SI that the patient has a cardiac condition (as specified by the medic) and queries the rules to discover the mandatory data entry form needed for documenting the administration of aspirin for this particular case.

User Interface

The GUI of *iRevive* is designed to meet the needs of mobile medical technicians. The particular fields on each screen, and the order of forms to fill out is dynamic, and determined as each unique emergency transport unfolds. Our GUI strategy is to allow flexibility in choice of platforms, and the ability to evolve in the context of adding new fields and forms. Above in Figure 3 is an example of what a medic views. The GUI allows both high level views of the entire body, or a zoomed in display for a particular body region. It includes pull down menus appropriate for the current view.

MULTI LAYER MANAGEMENT OF EMERGENCY EVENTS

Our emergency medical application is a Multi-Layer Dynamic Data-Driven Decision Support System. It provides decision support at three important layers: at the site of the incident, at local command centers, and at a central point of coordination. These three points form a hierarchical layering with on-site care at the bottom and central coordination at the top. At each layer, data is aggregated from layers below (similar to the different time variant hierarchical structure of Chaturvedi [Chatu]). Each layer presents data aggregated from a dynamic set of real-time sensors and mobile Emergency Medical Technicians (EMTs). By linking real-time sensor data, procedural data, and geographic data to specific points in time, iRevive enables rapid decision support that considers actual EMT intervention and patient outcomes, as they occur to determine optimal future action.

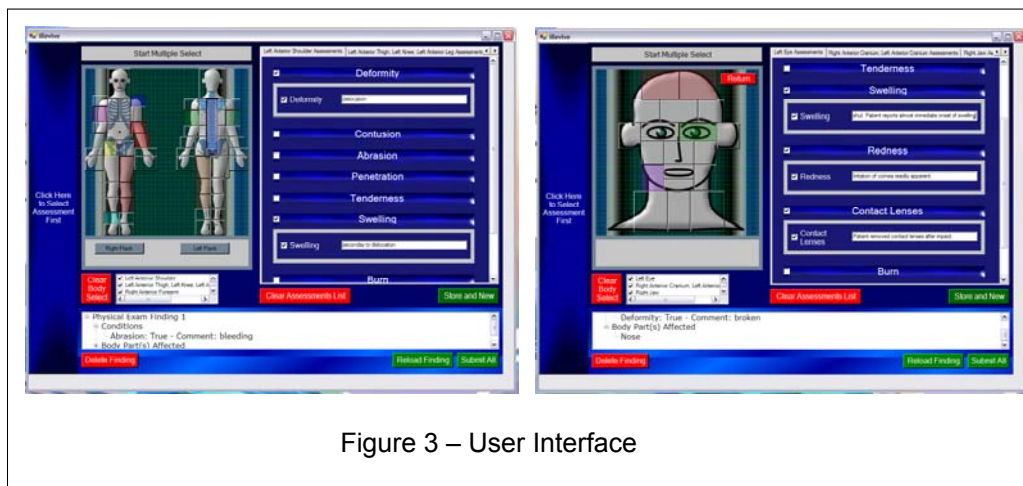
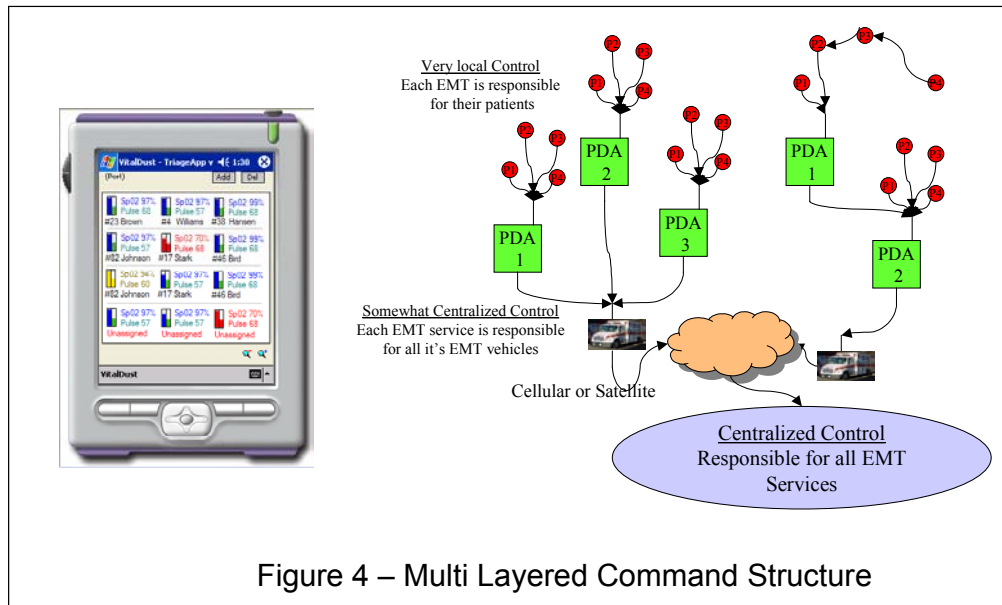


Figure 3 – User Interface

Figure 4 illustrates the three layers of decision-making that drive the iRevive decision support system: at the edge EMTs have situational awareness with sensor data and data from the local command center. The local command center receives both sensor data and procedural data from EMTs. At the highest layer the central command receives aggregated data from each local site and can also send real-time information to the local command centers.



Edge Layer

The edge of an incident is where the EMTs and patients are physically located. Each EMT needs continuous access to real time sensor data of each patient to determine the triage order of all patients assigned to them. This is accomplished by sending each EMT a continuous stream of vital sign data from each patient under the EMT's control. The primary concern in a crisis situation is that each EMT has situational awareness of their assigned patients based upon real time data. Information also flows from the local command center to each EMT, which might include data about a particular patient, treatment suggestions, or general instructions to the EMT. Providing real-time data to the EMT allows for situational awareness of their immediate time-critical responsibilities.

Local Command Center Layer

Data flows from each sensor network and is aggregated at the local command site along with data from each EMT. The local command center provides a view of all patients and EMTs at the local site allowing effective management of local resources. Each local command center receives data from the central command center for effective coordination of global resources. The local command site enables a view of all local resources combined with data from the central command center.

Centralized Coordination Layer

The top layer is the central command center that receives data aggregated from each local command site and includes real-time sensor as well as data input by each EMT about the care of each patient. This data enables resources to be managed across a broad region with many emergency events. The overall architecture of iRevive enables data to flow between central and local command sites.

CONCLUSION

This paper looks at emergency medical response systems from several countries such as Israel, Britain, Sweden, and the US. It then explores some of the shortcomings of these systems, and proposes a new architecture called iRevive. iRevive addresses weaknesses of other systems by adopting emerging technologies such as wireless sensors, WAN data transport, and mobile computing devices. We discuss how iRevive enables edge based management with centralized coordination of global resources.

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