A Campus-Wide Mobile EMS Information Management System

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***Abstract*—Efficient information management is crucial for the timely administration of Emergency Medical Services (EMS). In this paper, we describe a project to design and implement an automatic incident reporting and patient information management system for use by the EMS department at WPI, a small technological university. The EMS personnel are equipped with PDAs to access the system over a wireless LAN. Challenges faced in designing the system included compliance with new medical information regulations, provision of adequate security, interaction on small PDA screens, thin client software design, wireless networking and usability issues.**

***Index Terms*—ubiquitous healthcare, mobile computing, wireless networking, information management.**

I. Introduction

EMERGENCY medical services (EMS) are vital for the survival of most communities, especially university campuses that have a high percentage of young adults that are prone to accidents. Managing information flow is crucial for the efficient delivery of EMS services. Automatic reporting of incidents and statistical analysis allow patterns to be discovered early so that potential epidemics can be avoided. Ability to retrieve patient records (subject to new government regulations) can be useful when administering help to patients who have pre-existing medical conditions or well-documented allergic reactions to certain medication.

Prior to this project, the Worcester Polytechnic Institute (WPI) EMS services employed a manual system in which paper incident reports were filled out as incidents occurred. These paper incident forms were then entered into a standalone database monthly.

In this paper, we describe a project to design and implement an information management system for use by the WPI EMS unit. The system is being implemented in phases and this paper describes the initial phase that supports automatic incident reporting across an 802.11 wireless LAN by EMS personnel that have been equipped with PDAs running our new system. Plans for future phases for querying a patient's medical records at incident sites, support for multimedia, patient signatures, on-site preliminary diagnosis and new wireless security standards are also described.

II. BACKGROUND

A. WPI Emergency medical services

Worcester Polytechnic Institute (WPI) is a technological university with about 2500 students. Currently, WPI's EMS group is one of the approximately two hundred campus-based EMS groups [SMIT01]. The WPI EMS group is responsible for first-response medical service on the WPI campus. EMS is managed by the WPI Campus Police Department and employs students as technicians. Each technician is certified at the Massachusetts First Responder level, and is trained to handle most medical emergencies. Each incident report such information as the patient's status upon the technician's arrival, a brief medical history, present medications, allergies, and measurements taken at the site of the incident, and the responder(s) to the incident.

B. Medical Information Regulations

In the interests of protecting patient privacy, the federal government has developed guidelines for the handling of medical information. These standards are relevant to this project in regards to the manner in which information is entered, transmitted, and stored.

The Health Insurance Portability and Accountability Act of 1996 (also known as HIPAA) contained new provisions intended to protect medical information. There are multiple facets of the HIPAA that health care organizations have to address. The portions of the HIPAA regulations that affect this project are those relating to security. For instance, the HIPPA laws require that each party involved in using medical information can view only "minimally necessary information" to perform the required tasks [KIBB01b]. The laws also require that health care providers create plans for data backup, disaster recovery, and emergency operations [STAN02] and that any data sent over open networks is required to be encrypted, or have other access controls.

C. WPI Wireless Network

Worcester Polytechnic Institute (WPI) has an extensive data network that consists of various computers in labs, offices, dormitories and fraternities, and also other devices such as file and print servers and network printers. The WPI Wireless LAN currently has approximately 60 Access Points throughout campus, with the number soon expected to reach about 160. The WPI Wireless LAN uses the 802.11b

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standard. The WPI Wireless LAN covers most buildings on WPI's main campus. Worcester Polytechnic Institute's wireless network is based on the 802.11g wireless transmissions standard that extends WPI's wired LAN and can achieve maximum transmission speed of 54 Mbps (TANE03).

III. SYSTEM DESIGN CHALLENGES

In this section, we shall summarize the key challenges that we faced in developing our system.

- *Small User Interface:* Due to the size limitations of PDAs, designing an effective user interface (UI) is an important and challenging task because restrictions exist on the amount of information and controls that can be displayed.

- *Compliance with medical information guidelines:* The new HIPAA guidelines outlined in section II.B establish certain requirements and constraints to our system design.

Figure 1: The Sony Clié PEG-NX60 [SONY03]

- *Data translation*: While the final patient and incident records must be stored in a relational database, transmission using the Extensible Markup Language (XML) (W3D05) was more convenient. Hence, XML to an RDBMS format translation had to be done. XML allows the creation of descriptive data documents that can be read on any platform. The use of a non-platform-specific data format is important to eliminate dependence on a specific back-end operating system or hardware configuration, thus promoting flexibility and ease of development.

- *Security:* Security is a major issue when sending medical information over a network. Security becomes even more of an issue when dealing with information sent over a wireless network. Since the data is being sent through the air, it is susceptible to anyone within range if there is no security mechanism provided to protect it. In this project, all transmitted data was encrypted to provide security for the medical information that is sent across WPI's wireless medium. Data was encrypted using WEP, which provides a level of security similar to that of a wired LAN and the Secure Sockets Layer (SSL) encryption.

IV. SYSTEM OVERVIEW

Based on our vision of the system, the EMS system was broken into three main parts, namely 1) Client-side data entry and interaction by the EMS staff 2) Medical information transmission and 3) Server-side processing. We shall now describe each of these system components and specific issues pertaining to them.

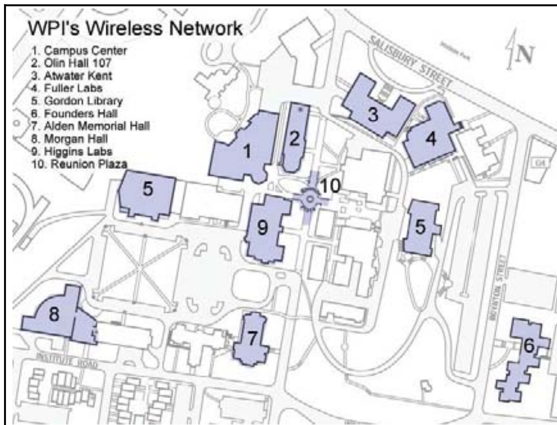

Figure 2 WPI's Wireless Network

A. Hardware Configuration

The EMS personnel were equipped with Sony Clie PEG-NX60 PDAs with WL100 802.11g network cards that supports 128-bit WEP wireless encryption. These devices ran the Palm 5 operating system and communicated over the WPI Wireless network with the server at the EMS office on campus.

B. Client-Side Interaction

Most of the client side interaction on the PDA was through sequences of forms that supported desirable features such as automatic reporting, and the querying of patient records. The forms designed included components, such as text fields, command buttons, and drop down menus.

On Palm, a user may perform input using a stylus, to interact with the device's touch-sensitive screen. Text may be entered through a built in, or attached keyboard, but is most often entered through Graffiti®. Graffiti® is a proprietary method for entering characters through pre-defined strokes. Additionally, an on-screen keyboard is available for use.

The Palm OS is single-threaded, and its applications must wait for one thread to complete before starting another. This makes it essential for operations to be extremely fast, or for a dialog to inform the user of status. This has particular implications for network access, as the user must wait for all network operations to be finished before continuing.

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C. *Networking and Data transmission*

Incident reports and patient records were stored on a remote server at the EMS office. The client PDAs could connect and hence communicate with the EMS server in two ways 1) Direct Serial Access and 2) Wireless communication from the incident location.

1) *Direct serial access:* During direct serial access, the PDA is placed in a cradle that is connected to a desktop computer or server. At this point, the HotSync manager can run conduits that synchronize data between the PDA and a desktop machine.

2) *Wireless transmission:* A WLAN connection is usually made from a PDA or laptop to a wireless Local Area Network (LAN) access point. Mobile device can then communicate over the wireless network at high speeds even while the EMS personnel are in motion. Wireless coverage can be a major issue.

A TCP/IP network stack was used for both modes of communication. All data was encrypted in two ways, namely, using the Wired Equivalent Protocol (WEP) and Secure Socket Layer (SSL).

D. *Server Side processing*

Although many features are planned for the current EMS system, the initial prototype supported mostly incident reporting. Based on new requirements imposed by this project, a new mySQL database was selected. Once the server has received the data from the handheld client, it translates the data into a database-loadable format and loads it into a database. Specific issues that came up regarding server side processing were data translation, and database design.

1) *Data translation:* XML does not have a relational design and XML documents must be translated to be useful to a relational database. As Server Query Language (SQL) is the predominant relational database manipulation language, any successful translation would need to convert XML to SQL. A variety of methods exists for this translation; however, most of the existing tools for accomplishing this are database management system (DBMS)-specific.

2) *Database design:* An important component of the project is to store the information that is entered into the handheld application and sent to the server. Previously, incident reporting was done manually. EMS filled out paper forms at the incident site and then used a Microsoft Access database to store the information that is entered by hand from their run sheets. This information was entered monthly, from run sheets that were stored until entered into the database. The existing database used by WPI EMS had a relational design consisting of three tables: call information, call type, and member information. The existing database did not fully account for responder information and tie it to the incident records, so that was a necessary addition to the new system. Medical privacy requirements dictated special considerations in the database design as well. For instance, law prohibits searching for incidents by patient name.

V. System design and implementation

Based on the information obtained from preliminary studies, certain technologies were chosen to implement the system with an eye toward the WPI EMS group's requirements. A high-level approach overview of the system is now given.

A client application runs on the Palm OS 5 operating system and resides on the handheld device. This application is responsible for collecting user input through the various forms it presents to its user. It is then responsible for storing the input from the user in a database that is created on the device. The user has the option of transmitting each incident report (record in the database) to the EMS Server via the direct serial access (HotSync) method or by way of wireless transmission. Once the server receives the data, it is then parsed and inserted into the EMS database. The overall design breaks down into three major components, the Client-side Application, Data Transmission component, and the Server-side processing component. Each component of the system is comprised of their own sub-components with specific logic and code that is discussed in the following sections. See Figure 5 is a flowchart detailing the flow of data within the system.

This project defines five databases, one to hold each of the following types of information: incidents, medications, allergies, vital measurements and responders.

Input form layout: The group of forms used to input and edit data, known herein as "input forms", share many components Standardization was necessary for quick visual recognition of components, providing for a faster data entry. See Figure 8: An Input Form for an example.

Encryption: Two layers of encryption are available to ensure the data is sent safely to the database. WEP encryption is needed to secure the transmission as it travels across the wireless medium. SSL encryption is needed in two cases; either the data reaches the wireless access point, or the HotSync is used to upload data to the server via a serial connection.

For the NX60, WEP encryption is enabled when a user selects which type of connection they wish to make to their wireless LAN. In this project the highest level of WEP encryption that the NX60 would support, 128-bit, was used. SSL encryption acts as a second layer of encryption to protect the data being sent from the wireless access point to the database server and from the HotSync to the database server.

Although SSL encryption was considered initially, it was not implemented in this project because was not applicable for two reasons. One of the major requirements of this project is to have incident report information sent to an appropriate EMS contact via email once it has been stored in the EMS database. Since WPI does not have an SSL enabled SMTP email server, there is no point in enabling SSL because once the email is in transit, it is vulnerable to any type of interception.

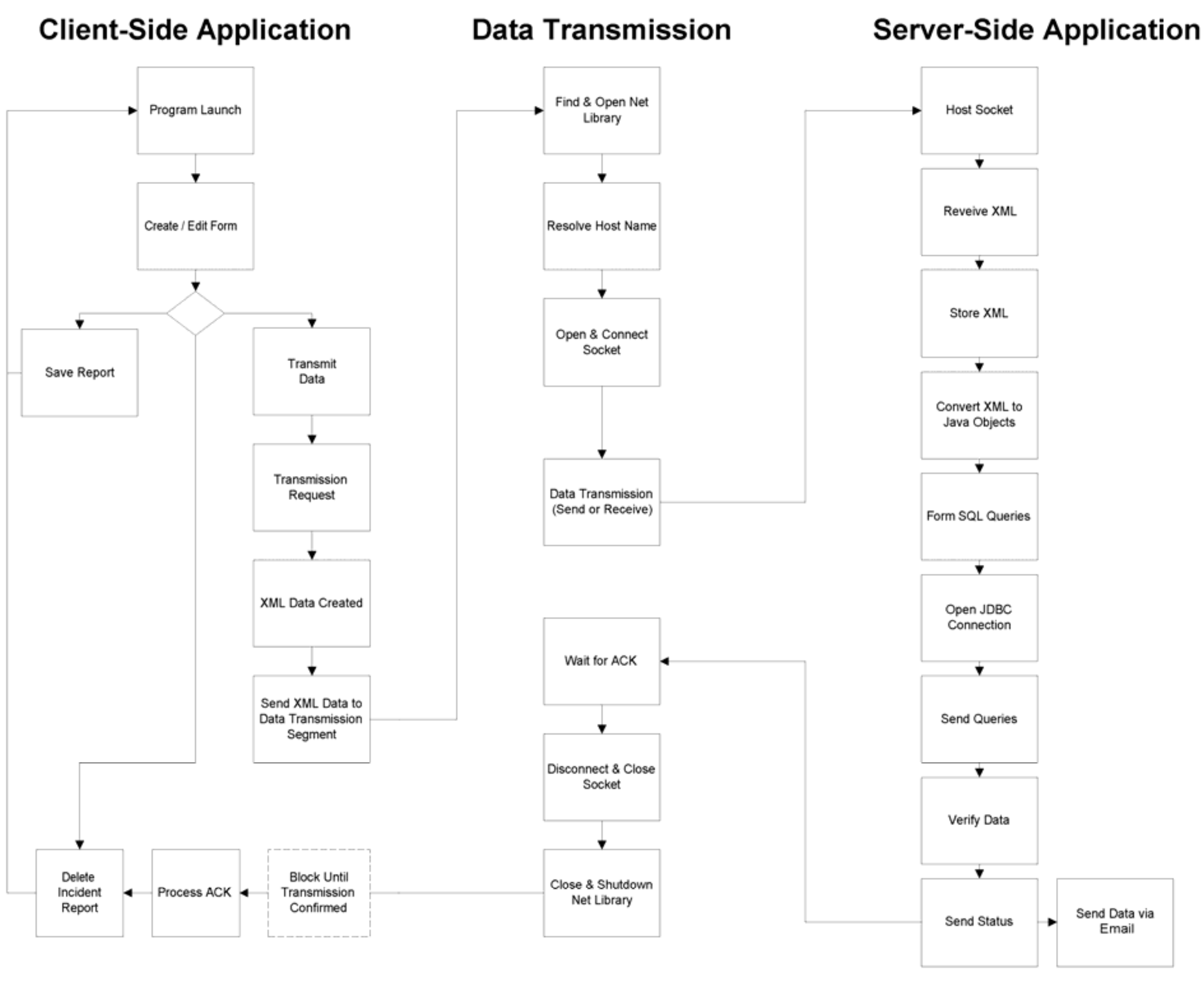

Figure 5: High Level System Flow

VI. SYSTEM TESTING

A variety of testing techniques were employed to ensure proper functionality of the final system. The primary method of testing used a series of test cases that were designed to simulate real-world incidents. The execution of these tests tested the entire system, including the client-side component, the transmission component, and the server-side component.

The secondary method of testing utilized "Gremlins," a testing functionality built into the Palm OS Emulator. Gremlins perform automated actions designed to manipulate every user interface element in the Palm application. This portion of the testing only tested the client-side component.

The next phase of testing was to be field-testing by EMS technicians. However, due to time constraints, this was not possible. In the future, the system will be field tested before deployment. The tests identified several defects that were repaired in the the original implementation. Field-testing shall be conducted to ensure correct operation of the system.

VII. FUTURE WORK

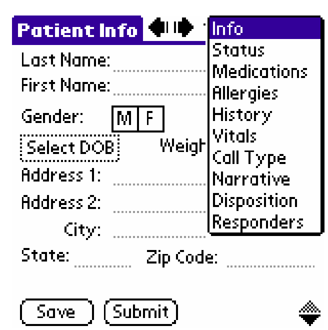

Figure 8: An Input Form

While the EMS Portable Workflow System is operational, its design and implementation, along with the resources Palm OS 5 provides to its users, leaves many options for future work topics. The project was able to achieve mostly automatic reporting features. Future work falls into two categories. First, future work to improve the current reporting system and secondly, future work to add more advanced features. Suggested future work is now discussed.

1) Conduit development: Development of a conduit for the EMS Portable Workflow system would enable data to be sent and received through the HotSync manager, which is invoked when the user presses the button on the cradle the device sits.

2) Adding signature functionality: For a patient to refuse treatment, they must sign a piece of paper to verify that they are in fact refusing the treatment. The EMS technician will still need to carry around a small piece of paper in the event a patient wishes to refuse treatment. The EMS Portable Workflow System could be enhanced to provide the ability to have a patient enter their signature on the device and have it be stored with the corresponding incident report. Associating each signature with the appropriate incident report would be a formidable task. Likewise, creating a canvas on which the patient could sign could also be difficult.

3) Storing/sending multimedia: As PDA technology continues to grow, the ability to support audio and images would need to be incorporated into each device. The EMS Portable Workflow System could benefit significantly if multimedia assets were to be incorporated into its system.

4) On-site retrieval of medical records of accident victims: As part of the next phase of the project, when an EMS personnel goes to an incident site, it would be useful to be able to retrieve patient records to determine pre-existing conditions and medical history in order to avoid administering drugs or treatments to which the patient may react adversely. To support this feature, patient record retrieval from the PDA would need to be implemented.

5) Change to WPA security: Several authors have criticized WEP as an encryption standard and many organizations including WPI are moving to WPA, a more robust wireless security standard. In the future, the current system will have to be modified to work well with WPA.

VIII. RELATED WORK

Related commercial systems include PDAMedic, MedDataSolutions, Mobile EMS and RescueNet EMS Pro.

IX. CONCLUSION

The goal of this project was to design and implement a new information management system to streamline the incident reporting process for the WPI EMS department and lower administrative overhead. The EMS Portable Workflow system successfully implemented a design based on the client-server model, utilizing personal digital assistant technology to implement the client-side component. Data is transported from clients to the server using wireless technology. The server receives the data from the network and inserts it into a database management system.

Several key research challenges were solved including interaction with small PDA screen sizes, data translation, database design and information security. It is the hope of the authors that the EMS Portable Workflow System provides long and useful service to the WPI EMS department and may someday be expanded to serve other EMS departments.

ACKNOWLEDGMENT

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APPENDIX

Worcester Polytechnic Institute Emergency Medical Services:

Date: ___/___/___ **Patient Priority/Distress:** 1-Severe 2-Moderate 3-Mild **Dispatch Location:** ________
Patient Name: ________ **WPI ID:** ___-___-___ **DOB:** ___/___/___ **Sex:** M F
Age: ___ **WPI Box:** ________ **Dorm Room:** ________ Address (if not WPI): ________
Mechanism of Injury: ________

History/Narrative on present illness/injury (continue on back if necessary):

________ *Check here if continued on back:* [ ]

Past Pertinent History:

Medications:
1____ 2____ 3____ 4____ 5____

Allergies: [ ] NKDA
1____ 2____ 3____ 4____ 5____

Vital Signs: [ ] Unable to obtain [ ] Not attempted

TimeBPHRRR

HR: [ ] Regular [ ] Weak [ ] Bounding [ ] Thready [ ] Irregular
RR: [ ] Clear [ ] Wheezing [ ] Labored [ ] Shallow [ ] Absent
Skin: [ ] Hot [ ] Warm [ ] Cool [ ] Cold [ ] Pale [ ] Flushed [ ] Cyanotic [ ] Normal [ ] Dry
Pupils: R: [ ] PEARL [ ] Unreactive [ ] Dilated [ ] Constricted [ ] Slow
L: [ ] PEARL [ ] Unreactive [ ] Dilated [ ] Constricted [ ] Slow

Emergency Care: [ ] Oxygen: ____ LPM via: NRB NC BVM Blow-by
[ ] Suction [ ] Bandaging [ ] Spinal Immobilization
[ ] Ventilation [ ] Ice / Heat Packs (circle one) [ ] CPR
[ ] Airway insertion [ ] Splinting [ ] Psychological
[ ] Other: ________

Times:
Call: ____ Dispatch: ____ On scene: ____ Clear scene: ____ Est. total time: ____
EA called: ____ EA on scene: ____ EA clear: ____ Transported by: ____ Transported to: ____

WPI EMS: **WPI Police On Scene:**
Name: ________ Signature: ________ Number: ____ Officer Name: ________ Number: ____
Name: ________ Signature: ________ Number: ____ Officer Name: ________ Number: ____

I acknowledge that I was offered medical assistance by the Worcester Polytechnic Institute Emergency Medical Services and that I refuse that care. I understand that I can call WPI EMS at any time in the future if I choose to do so.

Patient Signature: ________ Witness Signature: ________

WPI EMS Attendant Signature: ________

Prehospital Care Report faxed to EMS Coordinator: ____:____ **AM / PM**

Figure A 1 WPI's Existing Call Sheet