November 14, 2010

Dr. Andrew Rawicz
School of Engineering
Science Simon Fraser University
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Re: ENSC 440 Project Design Specification for the Remote Diagnostic System

Dear Dr. Rawicz:

This document provides a set of technical design details with regards to our product; Remote Diagnostic System (RDS). RDS is a product designed for paramedics and the emergency department in a hospital to use. The goal is to reduce triage time and promote efficient resource allocation by providing patient information ahead of time.

In the design specification document, we will include the features in the production design and not the enhancement model. The final enhancement design will be treated as a future improvement and will only be implemented if time permits in the development cycle.

If you have any questions regarding the design specifications, please feel free to contact me at your leisure. I can be reach by e-mail at cca16@sfu.ca or by phone at 778.898.3889.

Sincerely,

Danny Chieh-Yao Cheng
President and CEO
MediCare Solutions

 Enclosure: *Design Specification for a Remote Diagnostic System*

Medi✛Care

Solutions

Design Specification for a

Remote Diagnostic System

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Executive Summary

The design specification for the Remote Diagnostic System (RDS) is a detailed technical document that outlines the design of our product and the justifications behind our design. This document contains the design features outlined in the *Functional Specification for a Remote Diagnostic System* [1], but only the production specifications are emphasized – functional requirements marked I or II or III. The enhancement design (requirement IV) will be briefly discussed in the design consideration, but will not be emphasized.

The RDS has two main components: the server and the handheld tablet. The server will be running in a Windows environment for compatibility with the existing systems. The handheld tablet however, will be running Linux as it is one of the most stable embedded operating system. The server has two intended functions, storing patient information in the SQL database, and displaying the patient's status on an electronic whiteboard display. For the current production design, the database and the whiteboard will be integrated into one machine. Also, the nurses will have the ability to add entries to the server from their computers as well. The handheld tablet will be operated using a touch screen with user friendly graphical user interface. The handheld tablet will also be put in a rigid case that can fit onto a vehicle stand inside the ambulance. A more detailed design aspect is provided in the document.

Included in the document is the system flow chart both in general and in detail. Also, for ensuring the product is marketable, we included our test design and test cases that we will use to ensure user friendliness and system stability.

Currently, the project is still on course for completion by December 15, 2010. The definition of project completion will be to cover all the functional aspects listed in the prototype level. The design specification does talk about production level design, but for the purpose of the course just the prototype design will be presented. The project milestones are continuously monitored to ensure that the time allocated is reasonable, and to ensure project will be ready for execution on the pre-established completion date.

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Glossary

ER	Emergency Room
EMS	Emergency Medical Service
GUI	Graphical User Interface
UI	User Interface
Handheld Tablet	A portable touch screen computer
Server	A computer **Server** that stores all information about patients and hospitals
RDBMS	Relational Database Management System
WAN	Wide Area Network
3G	3rd Generation
GPS	Global Positioning System
ER	Emergency Room
WiFi	Wireless Fidelity
RDS	Remote Diagnostic System
TS	Touch Screen
GPRS	General Packet Radio Service
UMTS	Universal Mobile Telecommunication System
GSM	Global System for Mobile Communications
EDGE	Enhanced Data Rates for GSM Evolution
WCDMA	Wideband Code-Division Multiple Access
HSPDA	High-Speed Packet Access
EVDO	Evolution Data Maximized
PHY	Physical Layer
MAC	Medium Access Layer
RLC	Radio Link Layer
RRC	Radio Resource Layer
Kbps	Kilobits Per Second
Mbps	Megabits Per Second
WLAN	Wireless Local Area Network
LAN	Local Area Network
TCP	Transmission Control Protocol
DC	Direct Current
AC	Alternating Current
V	Voltage
A	Ampere

1. Introduction

Remote Diagnostic System is an emergency health services (EHS) tool that will provide EHS professionals with a more efficient working environment by delivering patient information to the hospital prior to their arrival in an autonomous process. The current acceptable standard emergency room (ER) wait time that is established by the BC provincial government is 10 hours while the average wait time at a hospital is 1 to 3 hours. The wait time is defined as the time from admittance to discharge or admittance to a hospital bed. In comparison, hospitals in Quebec are averaging 11.2 hours for complicated patients, and 4.4 hours for mildly injured patients [2]. If we can decrease the length of stay and wait time by 1 hour, it could save money for patients using the acute beds, which could potentially save another patient's life by providing timely treatment. This design specification outlines the technical details of the RDS that will represent how we will achieve this goal.

1.1 Scope

This document outlines how the functional specifications drafted in the *Functional Specification for a Remote Diagnostic System* will be achieved. The design specification will focus on achieving the functions specified in the production model – functions marked I or II or III. If the time permits, an enhancement model will be built. The enhancement product design specification is, however, discussed as a future improvement possibility. The design specification also includes several figures to help cover ideas that may be conveyed more easily through images.

1.2 Intended Audience

This document is intended for the employees of MediCare Solutions that are involved in the project, specifically, the engineers assigned to this project. The document will be used as a guideline to fulfill every functional requirements set out by the *Functional Specification for a Remote Diagnostic System* [1]. On top of fulfilling the functions, this document will also be used to create test cases that will quality assure the product before a full scale production can begin.

2. System Specification

Applicable system requirements for the Remote Diagnostic System are presented in this section.

The overall Remote Diagnostic System is described by the flow chart shown in Figure 1.
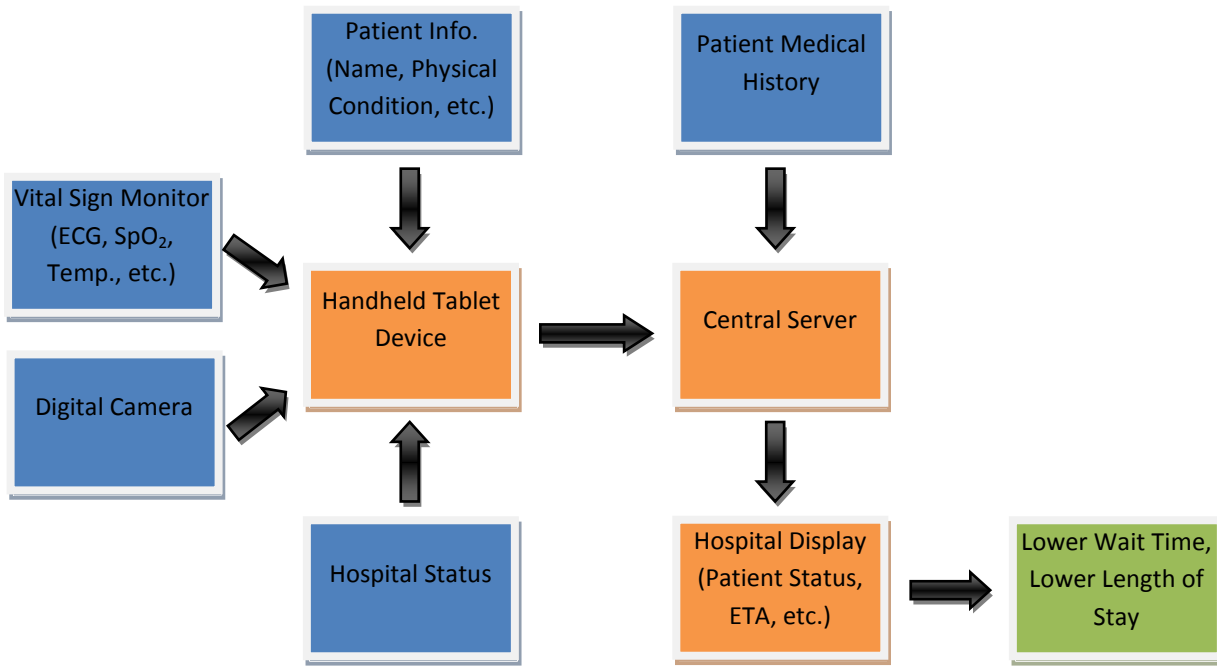
Figure 1 - System Overview Flow Chart

Each ambulance will be equipped with a handheld tablet device allowing paramedics to enter valuable information of the patient at the scene or during transportation. Information will be transmitted to the central server located at hospital emergency room. Nurses will allocate resources based on the received information. System must provide real-time data transmission to allow quick adjustments on the resource allocation at hospital. A well-established system network will provide hospital status to each tablet device to allow fast ambulance transportation routing adjustment.

3. Overall System Design

This section provides a high-level of system design overview. Detailed design decision about individual component can be found in the corresponding subsections.

A data transmission path for the Remote Diagnostic System is presented in Figure 2. In the overall system setup, multiple tablet devices will be connected to a single server computer, and multiple server computers will construct a network that allow tablet to communicate with different server to plan out the most efficient path for paramedics to save the patients.

Input

GPS
Module

3G
Module

Paramedic
Input

Touch
Screen

Tablet
Device

Software
Encryption
Decryption

Transmission
Module

Vital Sign
Signal

Image
Video
Input

Camera
Module

Network

Transmission
Module

Software
Encryption
Decryption

**Server
Computer**

Database

Whiteboard
Display

Output
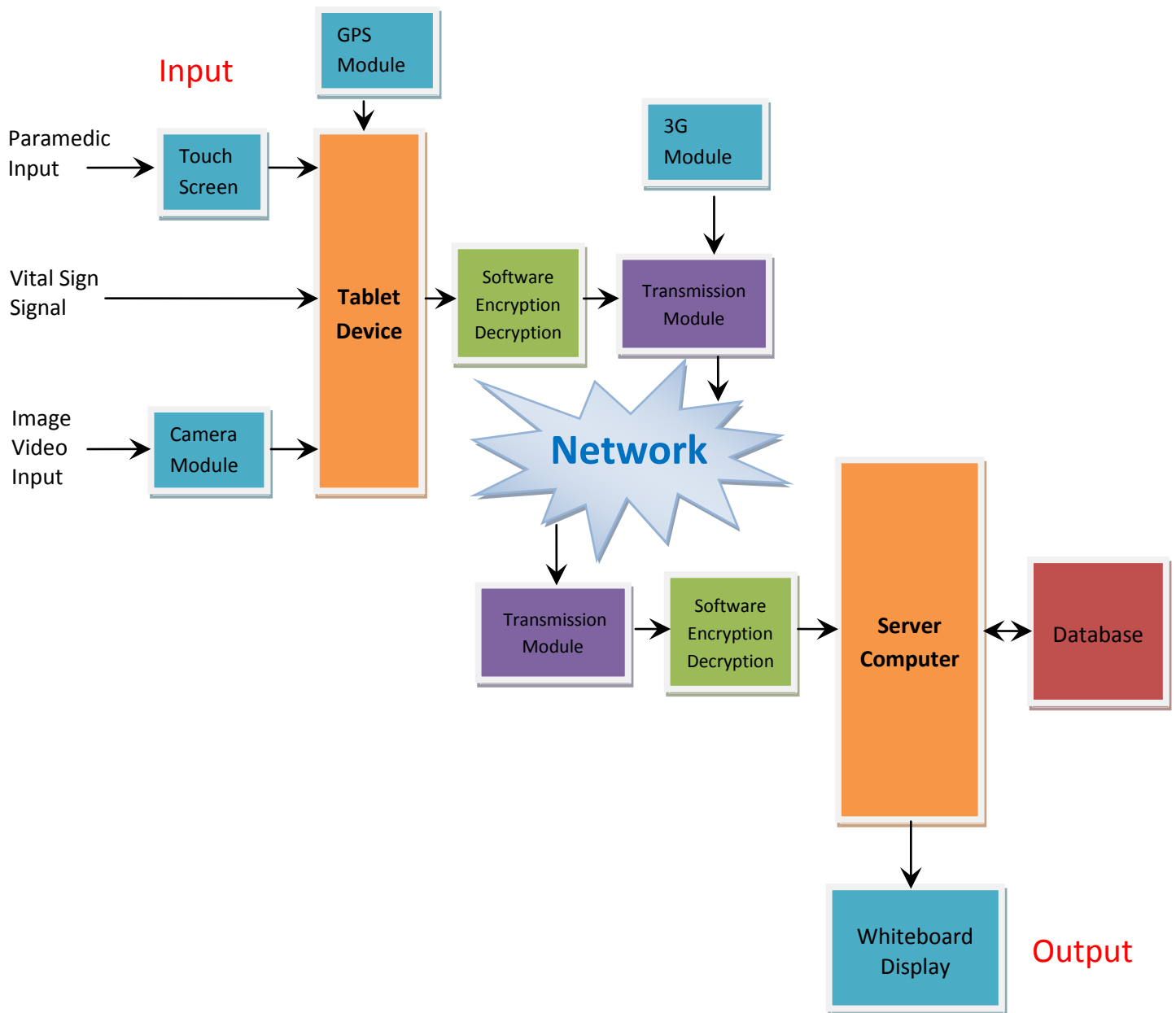
Figure 2 - Remote Diagnostic System data transmission path

The tablet device acts as the client and allows user to interact with it to gather input data. The server computer is the server which process the data transmitted from the clients. One server computer might be connected to multiple tablet devices.

3.1 System Overview

Our system utilizes a specifically designed handheld tablet device with extra modules to allow paramedics to electronically fill out the forms required by the hospital while they are treating patients on site. The forms will be transmitted to the hospital along with wound images and real-time vital sign

information to prepare the hospital for incoming emergencies, thereby improving the efficiency of emergency room (ER) treatments. Also, it will enhance the communication between paramedics and nurses during patient transportation.

Two main components of the RDS are handheld tablet carried by paramedics and server located at hospital emergency room.

As shown in the high level data transmission block diagram, Figure 2, 3G network will be the main method of data transmission, however a WiFi adapter in compliance of IEEE 802.11 standard will also be provided to improve the quality of transmission path. A 7 inch Capacitive Touch Screen (TS) is provided on the tablet device to allow paramedics to enter their assessment information. Graphical User Interface (GUI) will be specially designed for the paramedics to input information quickly and efficiently. The GUI will take the information fields from the actual form that is currently being used by the paramedics as seen in Appendix A. A high resolution digital camera will provide the ability to take images of the wound area for hospital to have a pre-assessment of the nature of the injury. GPS module will allow the tablet to estimate the time of arrival to hospital so they can prepare for the incoming patient.

On the server side, a database will store the incoming patient information so that a record of the communication between the paramedics and hospital will be kept in case of service assessments. A specialized application will be running on the server to allow hospital to view and edit information of the patient currently in the ER and those that are currently on the way. A very detailed display will be dedicated to the patient during transportation, so that nurses will be able to observe the real-time status of the patient along with images of the wound area.

The design decision of each component in the system will be discussed in detail in the following sections, server details are in section 4 and tablet details are in section 5.

3.1 Transmission Method

In our system, the accuracy and speed of the data transmission between the tablet device and server is very critical. Without a proper transmission channel, the system will not be able to increase the efficiency of the communication between paramedics and nurses, which is the one of the main goal in the design of RDS.

Upon our research, 3G network with its wide transmission range and low location limitation is a promising solution for our application, see Appendix B for examples of mobile network classification. The current 3G and 3.5G networks provide a transmission data rate of 2Mbit/s for stationary user, and 384Kbit/s in moving vehicle according to IMT-2000 standards [3]. With a careful compression of the transmitted data, this bandwidth is sufficient to provide a real-time data from a moving ambulance to hospital. The 4G network is currently under development and it will provide an even larger bandwidth capacity. By choosing to use 3G network now, it will also be easier for our system to adapt to higher level of mobile network in the future. At the same time, 3G networks in Canada is operating at radio frequency of 1900 MHz and 850 MHz, where 1900 MHz is mainly used in urban areas and 850MHz is used in rural areas [4]. Those frequencies are reserved for Global System for Mobile Communications

(GSM) frequencies used by mobile carriers in Canada. Equipment interference is not one of the concerns with using such high frequency as the ambulances are not equipped with frequency sensitive medical devices, such as apnea monitors or magnetic resonance imaging system [5].

One concern with 3G network is the lack of prioritization between different devices. When too many devices are trying to use 3G network around the same location, devices will start to lose their connectivity. In order to overcome this, we need to negotiate with service provider to reserve frequency bands, or use the hospital frequencies to ensure the availability of the transmission path [6].

WiFi transmission will still be provided, to enhance the transmission reliability through the hotspots. However, due to the lack of regulation, it is possible to lose confidential information during transmission. In order to counteract any possible packet sniffing, a software encryption method will be included in the overall system design. The encryption method will be further discussed in section 3.3.

3.2 Data Transmission Flow

As indicated in Figure 2, there are three different types of data that need to be transmitted from the tablet to the server; form input data, vital sign data, and image data. Each type of data will need to be transmitted using a slightly different transmission protocol in both 3G and WiFi network conditions. In 3G network, the transmission standards are very limited: General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE) are two widely used 2G/3G protocols in North America. Other ones like, Evolution Data Maximized (EVDO) and Universal Mobile Telecommunication System (UMTS) with its two most popular implementations, Wideband Code-Division Multiple Access (WCDMA), High-Speed Packet Access (HSPA), are more frequently used in other parts of the world [7].

The following table lists some widely used 2G/3G network technologies:

Name	Class	Usage Location
EDGE	2G / 3G	Worldwide, except Japan and South Korea
GPRS	2G / 3G	Worldwide
UMTS - WCDMA	3G / 4G	Europe, Japan, China
UMTS - HSPA	3G / 4G	Asia, Europe, North America
EVDO	3G	Americas, Asia

Table 1 - Widely used 2G/3G network technologies [8]

In mobile networks, UTMS becomes the top choice for our application. UTMS is considered to be a 3G radio technology and is part of the International Telecommunication Union's (ITU) 3G definition [9]. Currently Rogers Wireless, a local provider at Vancouver, supports 3G network through UTMS. However, there will be additional infrastructure built for UTMS through HSPA. The theoretical transmission bandwidth through UTMS 3G networks is up to 42Mbps in downlink and 11Mbps in uplink connection [10]. Figure 3 shows Rogers Wireless 3G coverage near urban areas of Vancouver.
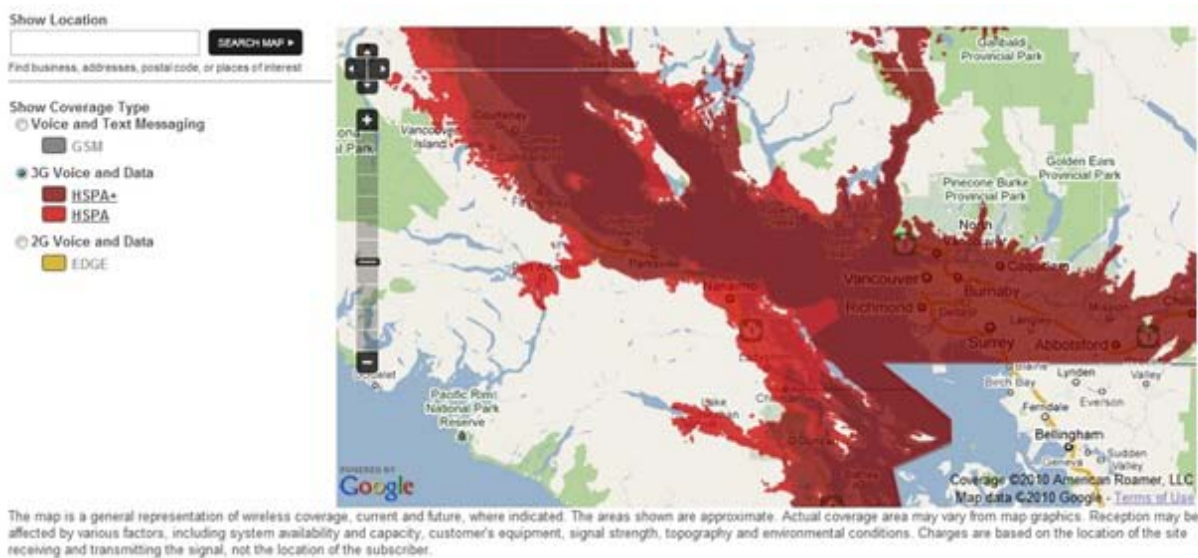
Figure 3 - Rogers Wireless 3G network coverage [11]

In order to guarantee the correctness of the transmitted data, we also need to enable the two-way communication between the server and tablet to perform error checking and error control. A general 3G network technology contains four different layers from bottom to top: physical layer (PHY), medium access layer (MAC), the radio link layer (RLC), and the radio resource layer (RRC) [12]. Please refer to Appendix C for a list of functions provided by each layer during a transmission. The RLC layer will enforce data error checking and flow control. If data packets are missed during the transmission, it will request for transmission of that packet again. Through this error checking, we can ensure that data is correctly transmitted by using 3G network, UMTS - HSPA in this application.

In the prototyping stage, the concept of data transmission will be demonstrated through a Wireless Local Area Network (WLAN) through a WiFi module because WiFi networks does not require any licensing fee to operate in. A simple wireless router will be used to simulate the access point that provides wireless network services to both the tablet device and server computer. Figure 4 shows the setup of the prototype system. In the actual system deployment, multiple server computers and tablet devices connected through 3G network with WiFi enhancement will be the ideal system structure.

For the WiFi Internet protocol, Transmission Control Protocol (TCP) is chosen to be used in the prototyping stage. TCP is a well-developed protocol, and it will ensure successful transmission of data from the client to server. As a sacrifice for guaranteeing successful transmission, TCP is slower at data communication because it will re-transmit any lost packets. However this transmission rate is not part of the consideration for the prototype device where only a proof-of-concept system is constructed.
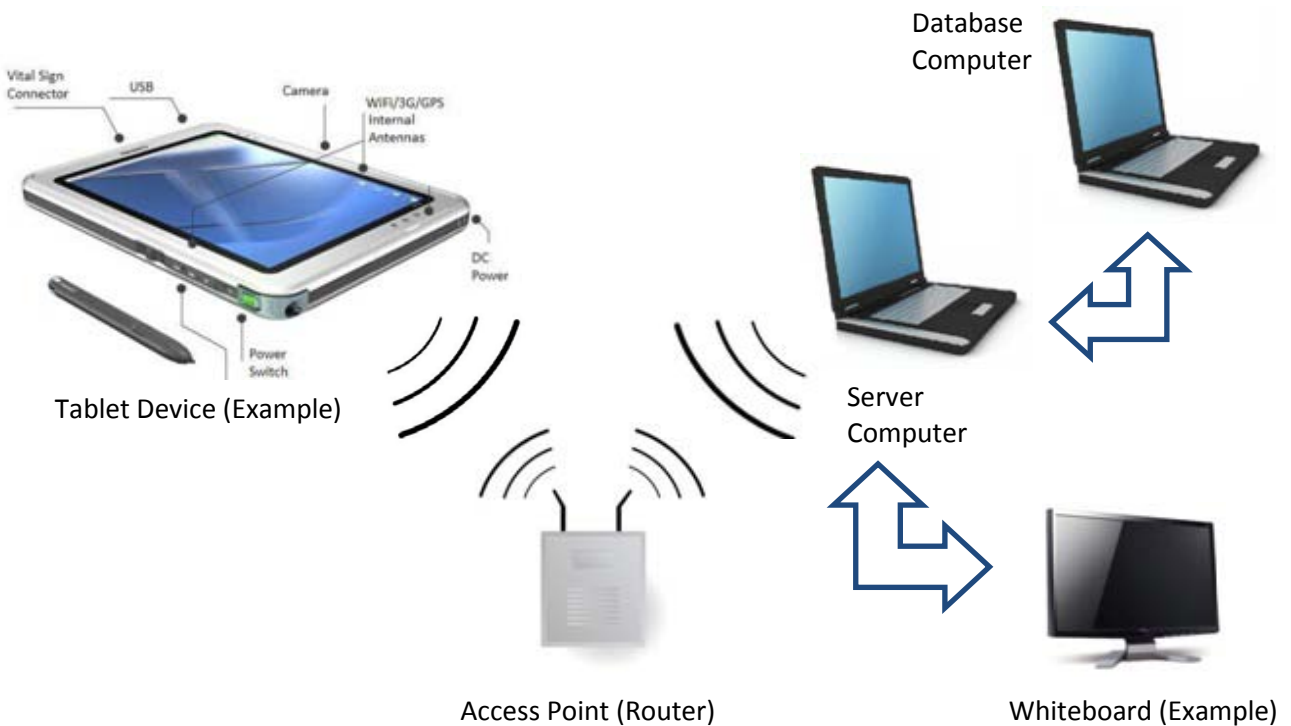
Figure 4 - Communication within prototype system

3.2.1 Paramedic Form Input Data

The first set of data that RDS need to transmit is the information about the patients filled into our electronic form by the paramedics. This information includes all the basic inspections, such as name, sex, initial condition, treatment performed, and etc. that can be seen in Appendix A. This form will illustrate patient related information to the nurses and doctors at hospital. This portion of data consists of mainly text characters and the data only need to be transmitted once. Moreover, there is no need to provide real-time update to it.

Data will be truncated by each section of the form, and data in each section will be transmitted separately by a blank area. Each section will be terminated by a special character, and the content in each blank area will be transmitted in a continual transmission session. Each transmitted data trunk will have its own checksum. Upon successful transmission, the server will echo back this checksum to ensure data correctness.

3.2.2 Vital Sign Data

Next set of data will be the input from the vital sign monitor. This section of data is the real-time information that needs to be transmitted at a regular interval to ensure that the server side is updated in real time. The transmission will take the highest priority once it is present in the system. The vital sign monitor provides a sequence of data entries of heartbeats and blood pressure at a regular interval. Once the vital sign monitor is connected, the tablet device will pull the data from the vital sign monitor serial

bus at 1 second intervals and transmit the data at 5 second intervals once the packetization is completed. The 5 second interval is chosen because heartbeats and blood pressure would not change at a rapid rate and this sampling interval will provide sufficient data for the hospital ER.

3.2.3 Image/Video Data

The last set of data format is the image and video packets. Image data will be compressed into JPEG format before transmission in the prototype. JPEG format is chosen because of the compression ratio that it provides. Even though the JPEG format will reduce the image quality, it's still acceptable in RDS prototyping stage. We do not expect the nurses to perform inspection from the images that are provided through our system. The image is just for ER nurses to have a good understanding of the wound area and the severity of the injuries so that they are able to have the preparation done before the patient's arrival. Images will be stored on the tablet device and transmitted along with the paramedics form data. In the final product, a loss-minimum or lossless compression such as PNG or BMP will be adapted to improve the image qualities.

Video streaming is also desirable in the process to provide the nurses an enhanced understanding of the inspection done by the paramedics. Video data can be transmitted in either synchronized or asynchronized method, depending on the requirement of the actual scenario. Tablet device will have the abilities to record video clips or streaming directly to the server. Video clip data is the least important data that is needed by the server side, thus it will have the lowest priorities. Video streaming functionalities will not be provided in the prototyping device.

3.2.4 Transmission Priority

Figure 5 shows the bandwidth allocation of the three different types of data transmitted by RDS.
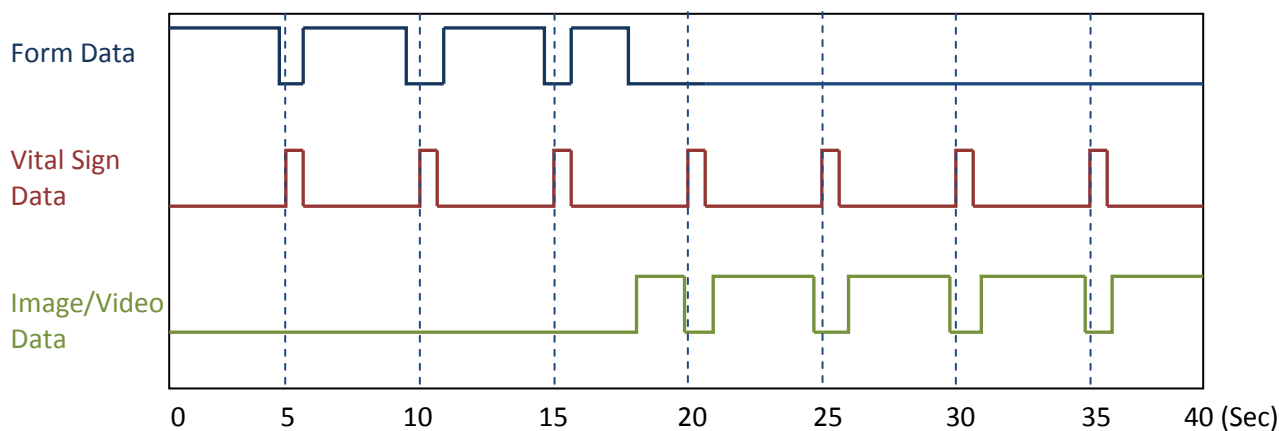

Figure 5 - Bandwidth allocation for RDS

All three types of data will share the same connection channel, thus the bandwidth has to be allocated depending on the priority of the data. Vital Sign Data is of the highest priority, followed by the form data, and the least important is image/video data. The above diagram shows a rough estimate of the bandwidth allocation in a 40 second transmission period. The figure assumes that all three types of data

are present all together at time zero, and vital sign data is extracted every 5 second. Form data is completely transmitted within 17~18 seconds. When the vital sign data is ready for transmission, tablet will prioritize it to the start of the queue, and transmit it first.

3.3 System Encryption Method

In order to avoid loss of confidential information, an encryption method must be implemented in order to protect all the data. A Virtual Private Network (VPN) with symmetric-key encryption method is a solution to the data security [13]. Before any transmission starts, tablet will establish a VPN channel to the server with the pre-established authentication password, and data will be encrypted with a key. This provides two-fold of securities to the transmission process. Even if the authenticated session is compromised, without the key, sniffer will not be able to decipher the content of the transmitted content. Figure 6 shows a sample symmetric key encryption concept:
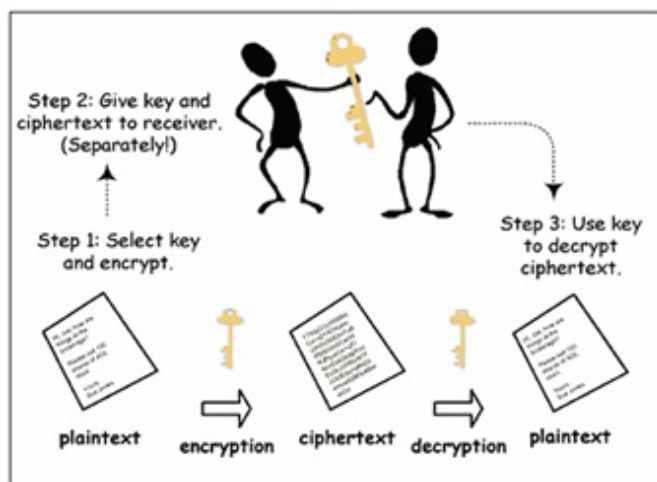

Figure 6 - Illustration of symmetric key encryption concept [14]

Symmetric key encryption is easy to implement, and it provides enough protection to the confidential data in paramedic services. There is readily available symmetric key algorithm for us to adapt. For further improvement, a more sophisticated encryption method might be required to provide a better protection. In the prototyping stage, encryption method will not be implemented as this software module could be added easily to the system later on.

3.4 System Deployment

In the final deployment stage of Remote Diagnostic System, we would setup a network that connects all paramedics' services from different hospital. Figure 7 shows the system network that will be constructed once the system is fully deployed to the field.
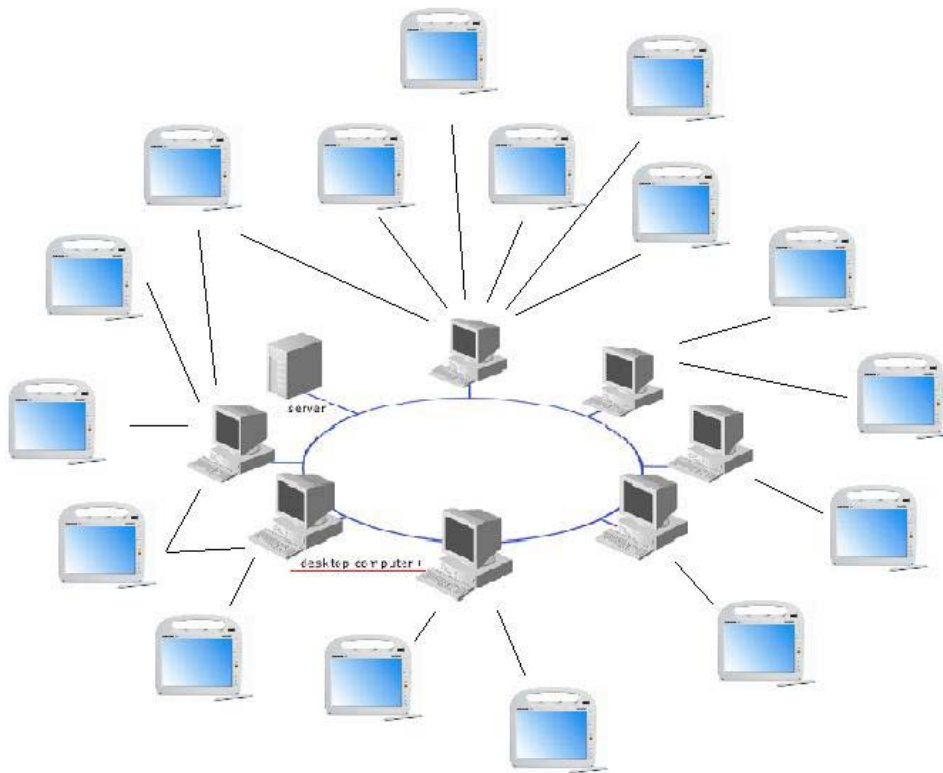
Figure 7 - Deployment system network

Multiple Server computers will be inter-connected to share the information from the tablet devices; this will improve the response time for ER and allocate resources accordingly. Tablet device might even be able to connect to different server computers and allow an efficient resource management for the emergency services.

4. Server

In Remote Diagnostic System, the server is acting as a data receiver and information management system; it will be accomplished by utilization of relational database management system (RDBMS) and GUI-based application. When the paramedic in the ambulance completes the electronic forms on the handheld tablet, the patient data will be transferred to the server application, and stored into the database. At the same time, hospital personnel can also use the GUI application to look for detailed information (eg. patient history, paramedic examination result, etc), where those information are retrieved from the same database.

4.1 Database Management System

In order to deal with massive quantities of patient data and ER reports, we chose to manage the information through a RDBMS. Our choice of RDBMS is Microsoft SQL Server 2008 due to compatibility, since most of computer in hospital are running in Windows environment.

By using RDBMS, we can easily solve the following potential concerns:

1. Security/Privacy: Patient's background information and medical reports are two main category of data stored in the database. Due to privacy issues, not every hospital personnel should be granted access to that information. With RDBMS, different accounts can be created and assigned to different people working in hospital. Only the medical personnel who have access to specific portion of database can view and modify patient data.

2. Scalability/Data Migration: With large amount of incoming data from emergency service each day, the size of database will be expanding rapidly. The server will require regular hardware maintenance and upgrade, and moving stored data from one machine to another may be a frequent task. Using RDBMS, we can detach the data and re-attach them in another machine easily without having to make much modification to the Server application.

3. Concurrent Access of Data: The database used by system like RDS and hospital will most likely have high access rate; therefore data consistency and concurrent access will be a concern. By accessing and storing data through RDBMS, it ensures the conflict of different user modifying same piece of data does not arise. In addition, RDBMS allow us to set many constraint to the data (eg. certain field must be filled before storing into database, or format of data, etc…), which adds an extra layer of data control beside the front-end GUI application.

4. Recovery from Crush/Error: As mentioned earlier, RDBMS can set various constraints to prevent user from inputting problematic data into the database. It also has the ability to treat a series of actions as a single transaction; so if an error occurs in the middle of the series of actions or the system crashed for some reason, the RDBMS is be able to recover the database back to the status before the actions are performed. This feature is important for medical related data, which can be highly sensitive and life critical.

4.2 Detail Database Design

Due to the fact that our RDBMS intend to store and retrieve information from various sources, the ability to allocate information to different tables is necessary to ensure ease of access. Therefore, we have created 12 different tables as shown in the schema diagram of the database in Figure 8. The schema diagram displays existing fields in each table including a unique field at each table where it is symbolized with a yellow key-shaped object beside the field's name. This is often known as a "primary key". The purpose of the primary key is to allow searching of the desired piece of information. Our RDBMS currently stores 4 main categories of information: patient's personal information, ER whiteboard information, paramedic's assessment report and triage nurse's assessment report.
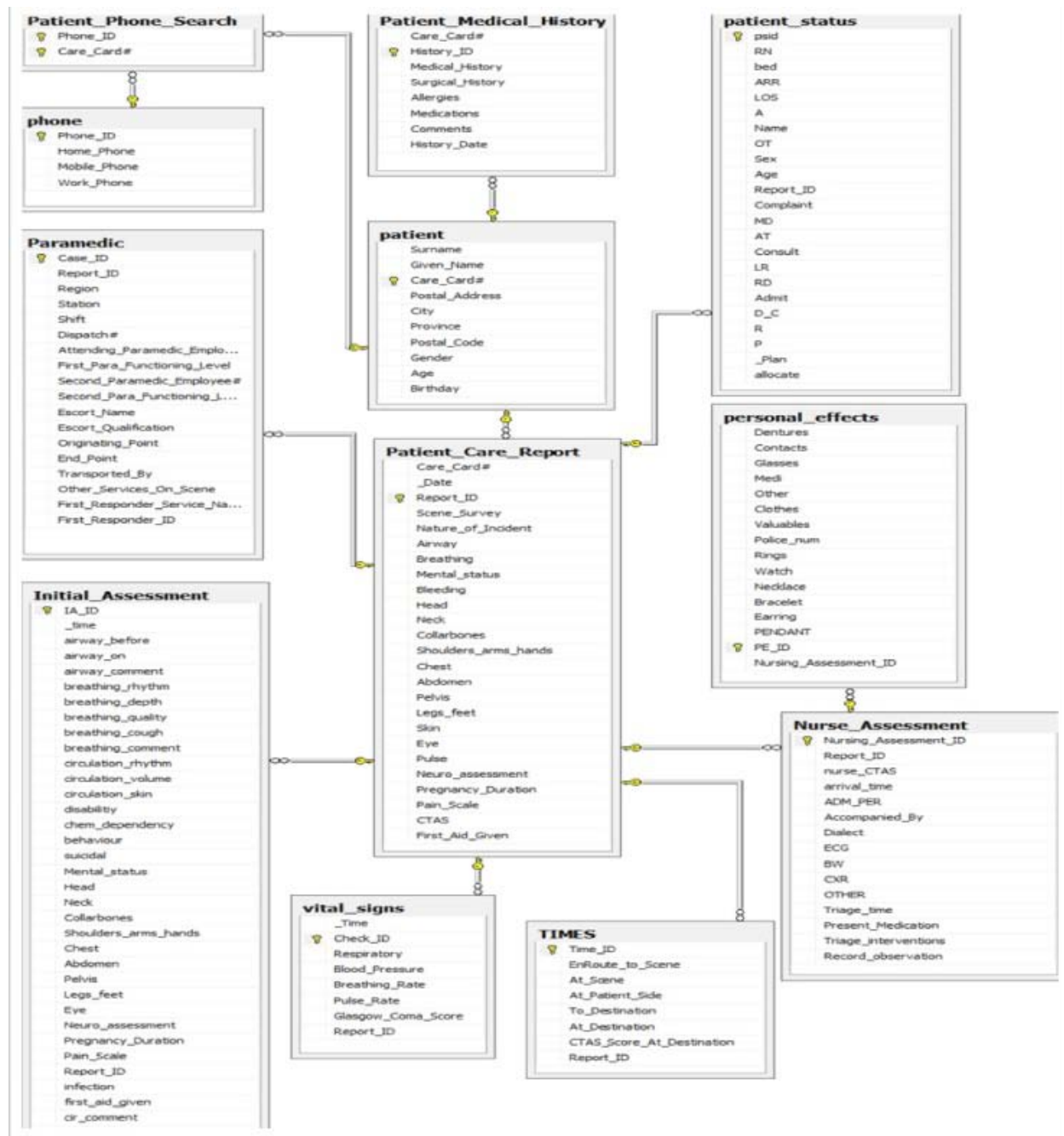
Figure 8 - RDBMS Schematic Diagram

4.2.1 Personal Information

Existing personal information such as name, address, phone numbers, medical history etc… will be stored under the "patient", "patient_medical_history" and "phone" tables. Since each patient's care card number is unique, care card number will be used as the primary key to extract and display patient's personal information on the graphical user interface that can be triggered from the whiteboard. Such information can also be displayed by our tablet device to give paramedics some background information

on the patient's medical history to assist with their treatment. Similarly, using care card number as the primary key will allow authorized personnel to update existing or insert new pieces of information to our RDBMS.

4.2.2 ER Whiteboard Information

The information displayed on the whiteboard will be refreshed periodically, which means the whiteboard application will frequently query for data from database. To ensure the smoothness and minimal usage of computer resource, we create a separate table "patient_status" from all other patient detail tables in the database which holds only the information to be displayed on the whiteboard. By doing so, it does not just speed up the data retrieval time, it also allow us to modify the information to be displayed on the whiteboard without modifying the original patient detail data, which will act as backup records.

4.2.3 Paramedic's Assessment Report

Information from the paramedic's assessment report will be stored in "paramedic", "Patient_Care_Report", "vital_signs" and "TIMES" tables. Information of the paramedic that was responsible for taking the patient from the scene to hospital is stored in "paramedic" table. The paramedic's assessment of the patient's injury is stored in the "Patient_Care_Report" and "vital_signs" tables. Critical times such as time of arrival to the scene are accumulated in the "TIMES" table. Since each report will have all of the above information, a report ID is used as the unique identifier to accurately store and extract information. Moreover, since information can be written to the database prior to ambulance's arrival to the hospital, information can be accessed by the triage nurse in order to have a pre-assessment of the patient's condition.

4.2.4 Triage Nurse Assessment Report

Information from the triage nurse assessment report will be stored in "Nurse_Assessment", "Initial_Assessment" and "Personal Effects" tables. The basic triage information are stored in the "Nurse_Assessment" table while information of an in-depth assessment is stored in the "Initial_Assessment" table. Information of the patient's personal belongings is stored in the "Personal_Effects" table. In order to accurately store and retrieve accurate information, each report has been assigned a unique ID (Nurse_Assessment_ID).

4.3 Server Graphical User Interface

The GUI-based application on the server side can be divided into 3 main parts - whiteboard, patient details, and nurse triage assessment. The GUI application is designed to speed up the process of overall emergency service, so we have tried to keep the number of pop up windows to a minimum and input method as intuitive as possible.

In the case of a medical emergency, timely information is often a crucial factor in saving lives. Therefore, our user interfaces have been designed with readability in mind as well as allowing medical personnel to quickly and efficiently fill out the necessary information electronically. In our GUI design for medical forms, we have implemented top aligned labels for the form fields as much as possible. This will improve the users reading speed by only requiring user to visually move in a single downward direction [16] as

shown in Figure 9. This will greatly reduce the time and effort medical personnel need to spend to read or fill information in a timely yet accurate manner.
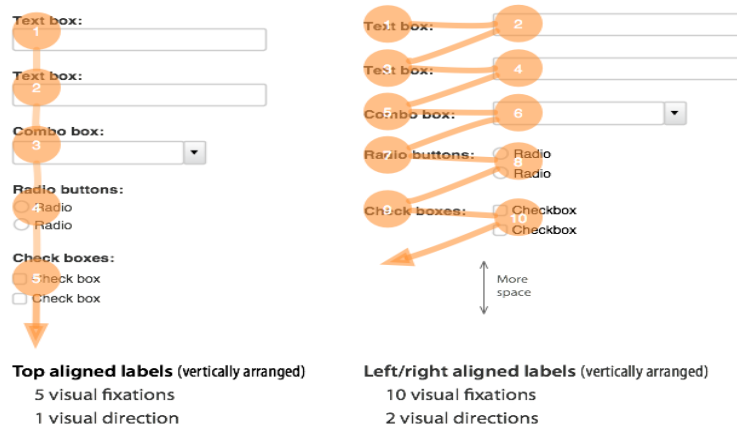

Figure 9 - Top aligned labels vs. Left/right aligned labels [16]

4.3.1 White Board

The whiteboard is designed to provide the current status of patients who are both under treatment in ER as well as patient who are waiting to be allocated to a room, including ones in the ambulance. The information will be projected on a large size monitor simply for displaying purposes, therefore the user who operate the GUI application under the whiteboard display cannot edit any displaying information.

The information being displayed is illustrated in the Figure 10 below, which we have consulted with local hospital personnel and paramedic. We also used Figure 11 as a sample template from for the whiteboard display layout. Since our system is designed to be integrated with hospitals in BC, Canada, some fields shown in Figure 11 are changed to fit our requirement more closely.

Figure 10 - RDS White Board GUI

Figure 11 - White Board sample [15]

As shown in Figure 10, patient records are grouped into two tables - *In Treatment* patients (yellow table) and *Unallocated* patients (pink table). *In Treatment* patients refers to ones that have gone through triage assessment process and have been assigned to proper medical crew and room for treatment, whereas *Unallocated* refers to those still pending for assessment or assignment of medical resources. Once the proper triage assessment is completed (more details in section "4.3.3 Nurse Triage Assessment"), the patient record will be moved from *Unallocated* table to *In Treatment* table.

Since the whiteboard does not allow any navigation, the information of patient will be automatically refreshed every 3 second. If the information are updated from the handheld tablet or through nurse GUI application in edit mode, the new information will be retrieved and reflect on the whiteboard within 3 seconds interval.

4.3.2 Paramedic Assessment Report Display GUI

By double-clicking on a patient's name that appears on the whiteboard, a popup window will emerge to display information taken from the paramedic's assessment report of the patient. As one of our main goal of our device is to allow triage nurse to have a pre-assessment of the patients prior to their arrival to the hospital in order to shorten ER wait time, this report will be accessible as soon as it is received and written onto our RDBMS. A sample of the GUI to display the paramedic's assessment report is illustrated in Figure 12 below. Since MediCare Solutions plan to establish our system in British Columbia initially, the report will follow closely with the existing form that is currently being employed by the British Columbia Ambulance Service (BCAS) as shown in Appendix A.
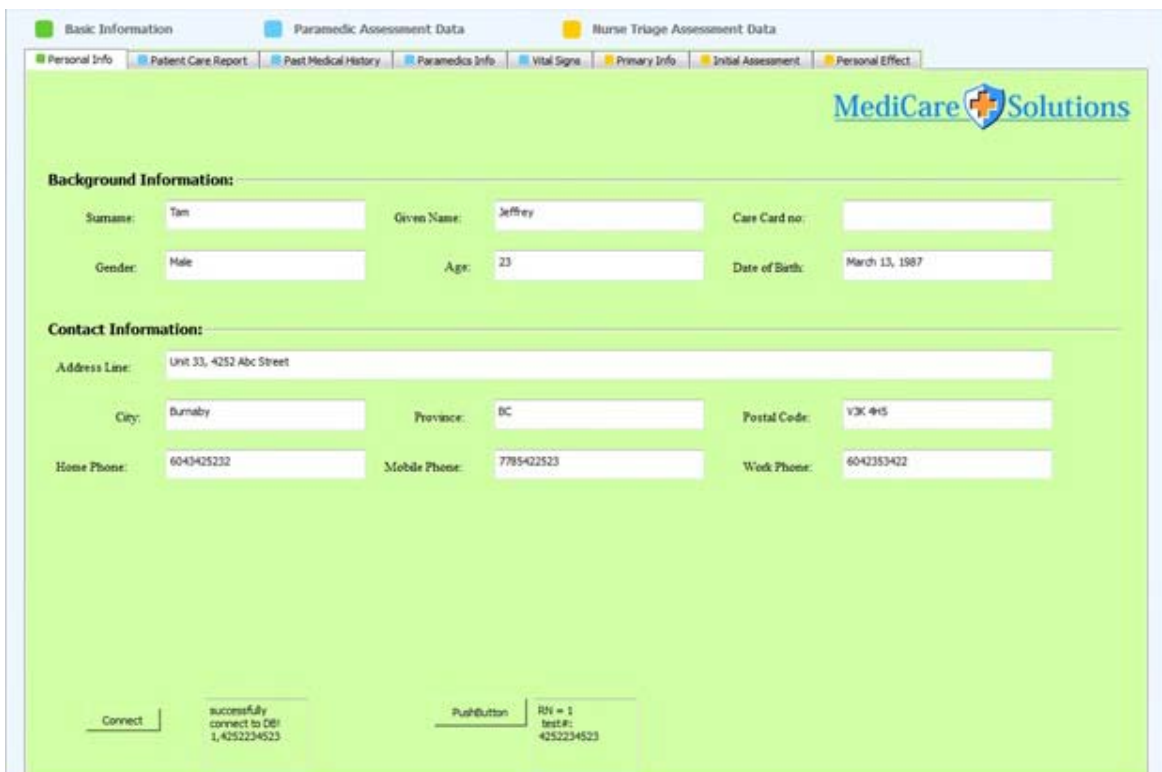

Figure 12 - Paramedic assessment report display sample

Due to the complexity and overwhelming amount of information in the report, we have divided information into multiple tabs with intuitive headings to allow efficient access to the required information. Textboxes are employed to display information is a clean and organized manner. Upon request, vital signs information of the patient will also be available in real-time as the patient is being transported to the hospital to give nurses a pre-assessment of the patient's condition.

Another feature that has been implemented onto this GUI is to allow paramedics to obtain existing patient information from the hospital's RDBMS such as personal information and past medical history if the patient's care card number is attainable. This is easily accomplished by entering the patient's care card number to its respected field and click on the "Connect" button displayed on the bottom-left corner of Figure 12. With this feature, paramedics could more accurately predict the cause of injury and provide treatment in a timely manner to increase the patient's chance of survival.

4.3.3 Nurse Triage Assessment Report GUI:

Once the patient arrives at the hospital, he/she will be attended by triage nurse for a second assessment of the injury. This assessment will be more comprehensive than that performed by the paramedics and will also be covered by our system using a separate user interface as displayed in Figure 13. Instead of extracting information from the RDBMS like before, this GUI's main function is to write into the RDBMS. The GUI will act as the electronic version of existing Emergency Nursing Assessment form used by hospitals in BC. Information written in this form, by the triage nurse, will be written to the hospital's RDBMS, which can be access by authorized medical personnel in the future. This user interface will be made available to users by clicking on the "Complete Triage Assessment" button from the whiteboard user interface.

Figure 13 - Nurse triage assessment report sample

Due to the elongated nature of the report, it has been organized using tabs with intuitive headers. Checkboxes and drop-menus were also employed to improve over-all efficiency in filing the report. Moreover, we have implemented an update feature in the user interface to permit accurate update of information in the cases where information was initially missing or mistyped.

4.4 Overall Operating Flowchart

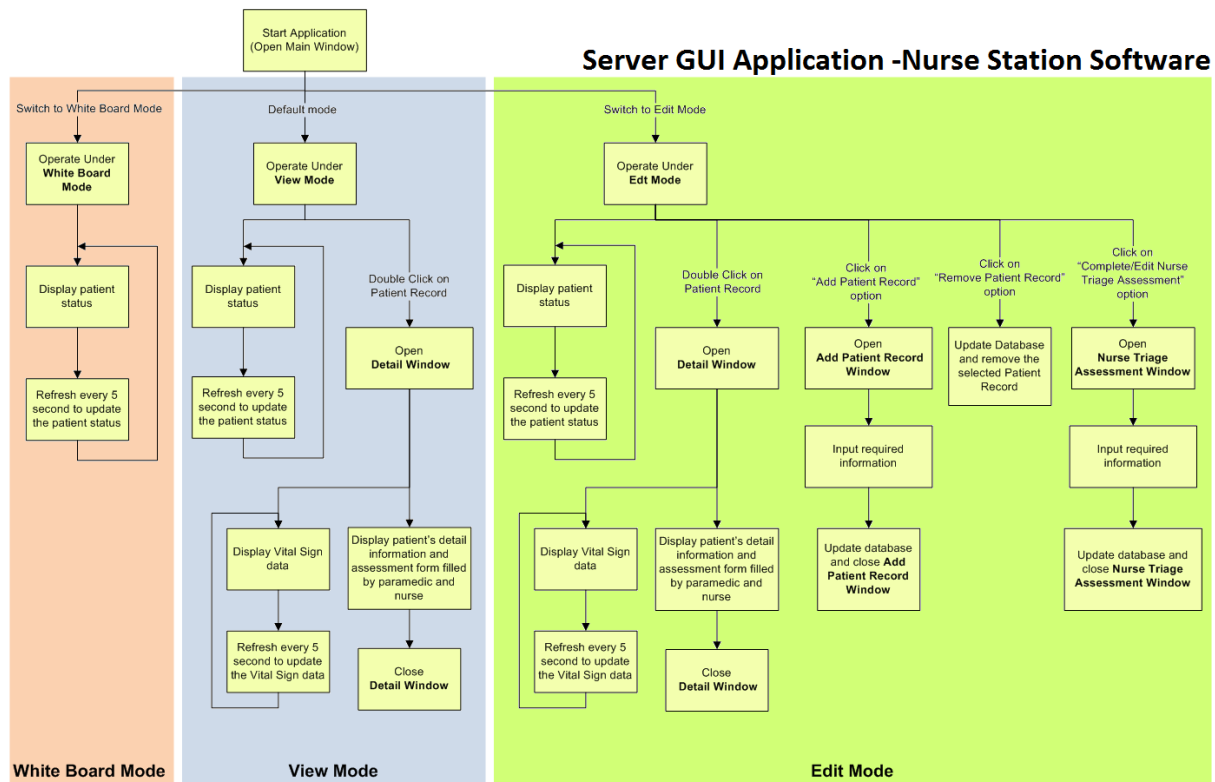In summary, we have produced a flow chart (Figure 14) that will illustrate how the program will be used by a nurse.

Figure 14 - Server GUI application flow chart for the Nurse Station software

5. Handheld Tablet

The handheld tablet is a portable computing device that the paramedics will use to enter patient information. The tablet will be operated through a 7" touch screen module with custom graphical user interface (GUI) for the best user experience possible.

5.1 Handheld Tablet Graphical User Interface

The paramedics will need to operate the tablet through a GUI in order to enter patient information. Since the tablet itself is supposed to be a portable device, there won't be a keyboard or a mouse to operate with on the field. Thus, an intuitive design is utmost important in order to have our product promote an efficient working environment. Figure 15 is a screenshot of the draft of what the tablet GUI would look like.
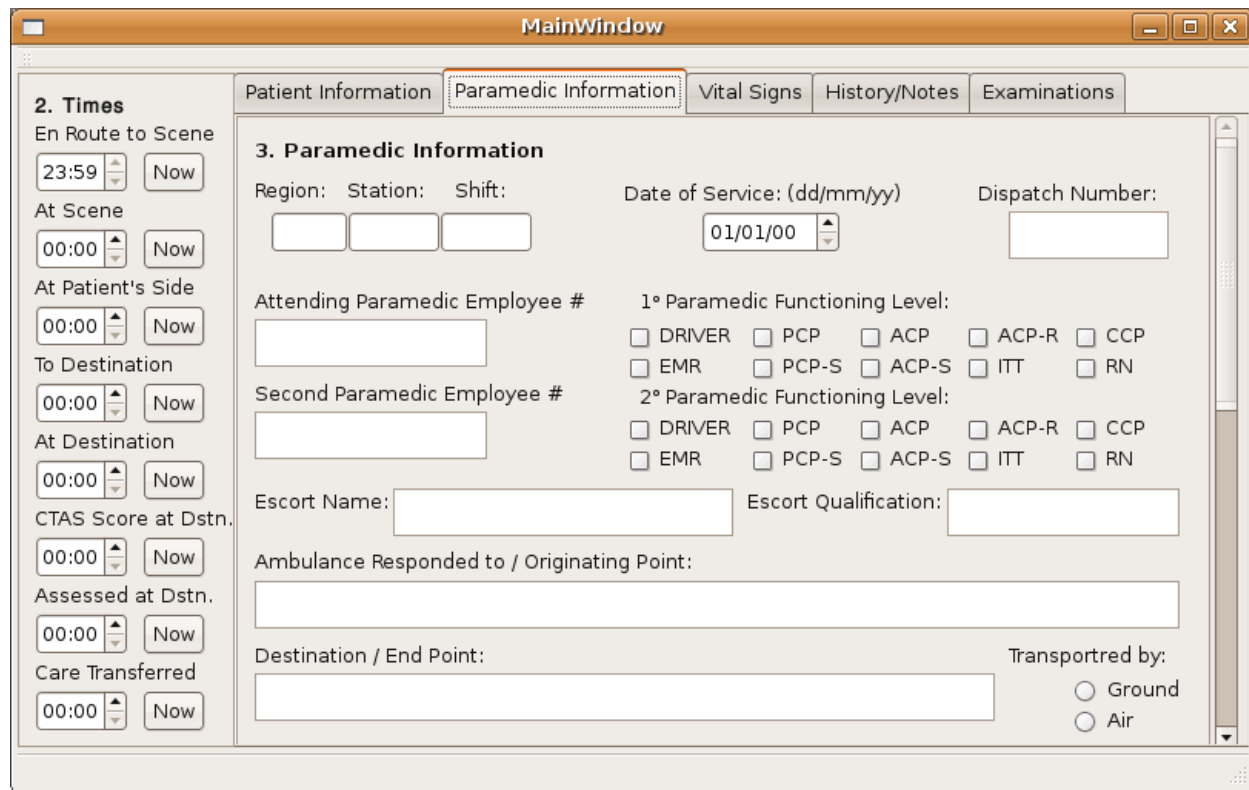
Figure 15 - Draft tablet GUI for the paramedics to use

The GUI is split into two main sections, the times section on the left, and the dispatch information section on the right.

The purpose of the trip planning section is to provide the hospital with detailed en-route information so they can be prepared for treatment as soon as possible when the patient arrives. The trip planning information also serve to rate the patient's priority by using the Canadian Triage & Acuity Scale (CTAS). The patient information section consists of several tabs for different categories of information. For organizational sake, we believe having individual tabs representing different categories is less confusing than having one long page with all the fields.

In order to make the user input convenient, there should be minimal requirement to enter text wherever possible. Since we are using a touch screen keyboard for entering text, it will never out perform a traditional keyboard due to its size. Instead, we use check boxes and drop down menu as much as possible since those are very simple to operate.

Qt from Nokia is chosen to be the user interface (UI) development framework. It's free GUI developing software, and supports cross-platform applications. ARM processor OMAP3530, which is the main processor of the hardware board we have chosen, also supports Qt application with appropriate compilation tools. Qt is also a modularized application development environment, so we can choose to load desired modules only to reduce the memory requirement of the tablet. The ability to support multi-

threading application made it further satisfying to our application, as the processing time would be minimized and ability handling data transmission simultaneously during other operations is provided. It's also well compatible with C++ language development [17].

The overall operation of the tablet GUI is summarized in Figure 16 below.
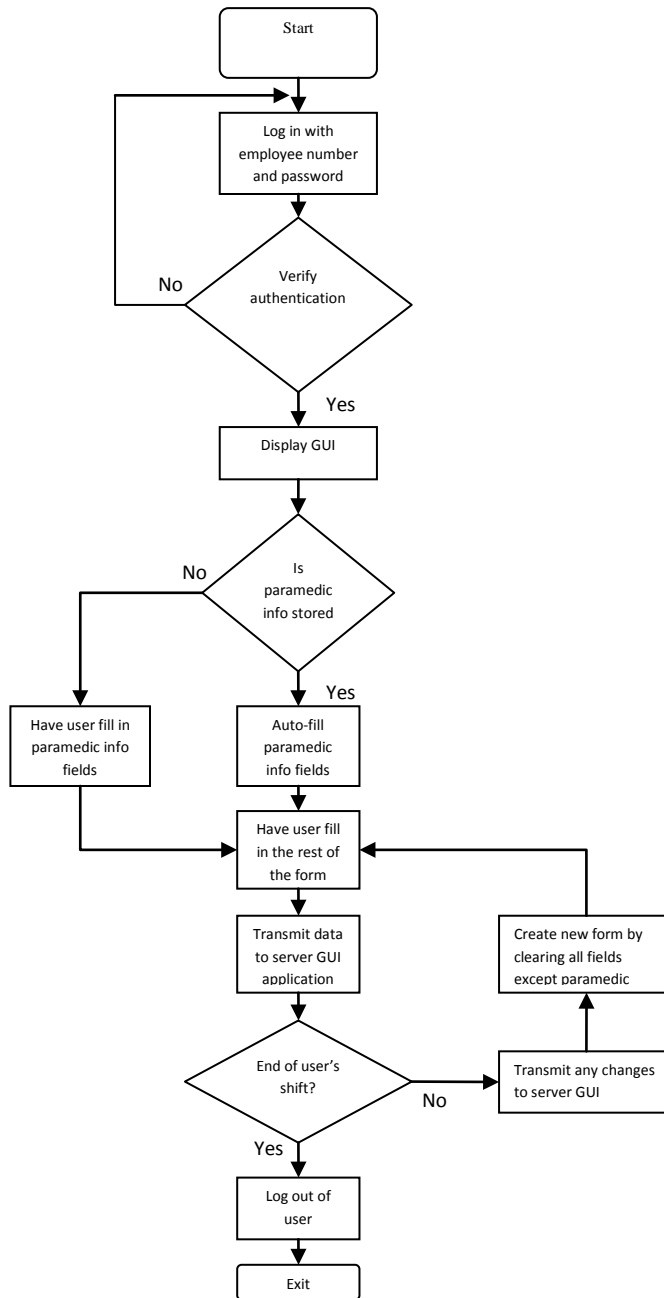

Figure 16 - Overall tablet GUI user operation flow chart

5.2 Hardware Choice

When selecting the proper hardware device for our application, we had several criteria that need to be met. These criteria are: cost, wireless connectivity, light and mobile, touch screen, screen size above 7", has a camera, and support I/O.

We had a few choices to choose from, iPad, tablet PC, or development board kits. The iPad has all the features we were looking for except one, I/O port. Since we needed to connect our device to potential medical equipments, we needed the iPad to have USB or serial port connectivity. The next choice is a tablet PC, it has all the features we wanted, but it costs too much. The tablet PC also includes a lot of functions that we don't need, and it's too heavy and bulky for the paramedics to carry around in the field. So we were left to choose the development board kit.

We chose the Devkit8000 board (Figure 17) provided by Embest which is a clone of the Beagleboard from DigiKey [18]. The board is relatively inexpensive and has all the functions we want with some modifications. The board runs on a relatively powerful ARM OMAP3530 processor running at 600MHz with 256Mb of RAM [18]. There will only be a customized GUI running on the tablet device, thus this CPU provides enough computation power to handle all the features the RDS will require. It also supports USB 2.0 and serial port for connecting to medical equipment. More importantly, it supports WiFi, 7" or 10" touch screen (we purchased 7"), and USB digital camera.

Although there are a lot of customization that needs to be done in order to get all the components working, it is still worth the work required because of the cost required from a tablet PC. Below is an image of the development board Devkit8000.
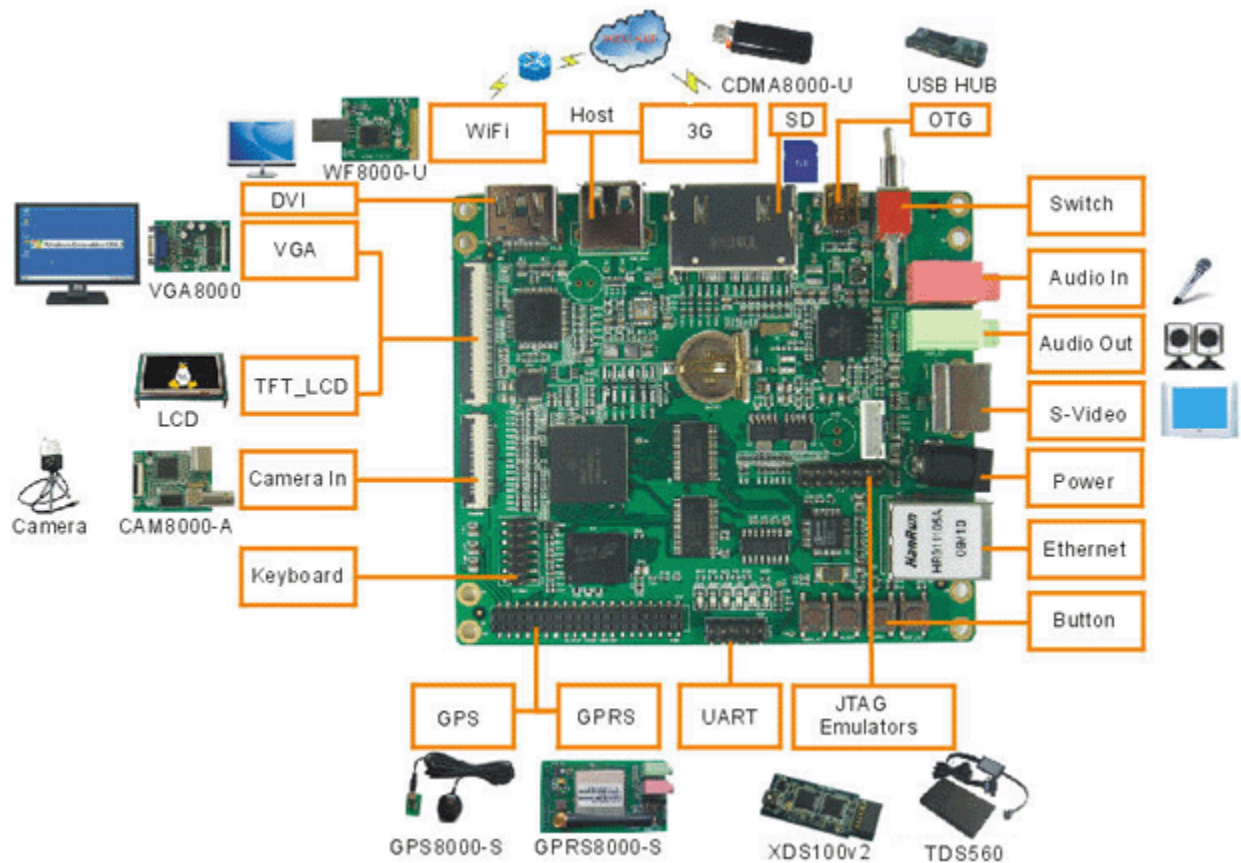
Figure 17 - Devkit8000 Development Board [18]

5.3 Physical Design

Since Devkit8000 is a development kit, it does not come with any casing for protection purposes. Thus, we have to manufacture our own casing to install the handheld tablet in. The case needs to be rigid with some shock absorbing bumpers on the side. The fit of the case is very important because we don't want any residue or liquid to accidentally touch the board through a crack. So, the opening of the case to display the screen should be a little bit smaller than the size of the physical touch screen. With that in mind, rear and front view of the production design of the casing is shown in Figure 18 and Figure 19.
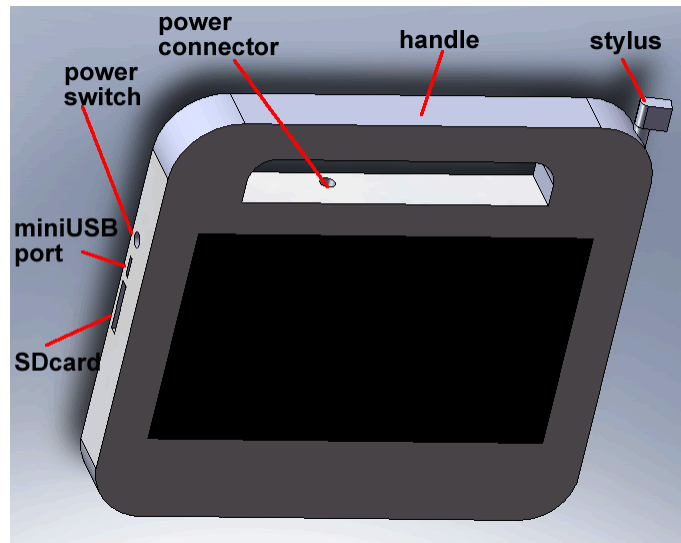
Figure 18 - Handheld tablet casing
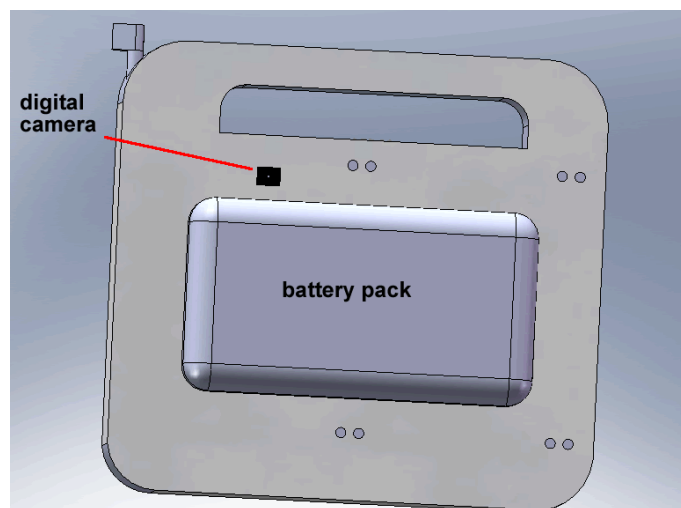
Figure 19 - Back of handheld tablet casing

Figure 20 and Figure 21 will show the dimensions of the casing in millimeters.

Figure 20 - Top view of handheld tablet with case dimensions in mm

Figure 21 - Side view of handheld tablet with case dimensions in mm

Figure 22 and Figure 23 will show the internal layout of our development board in the casing.

Figure 22 - Top view of the position of the touch screen with respect to the main board

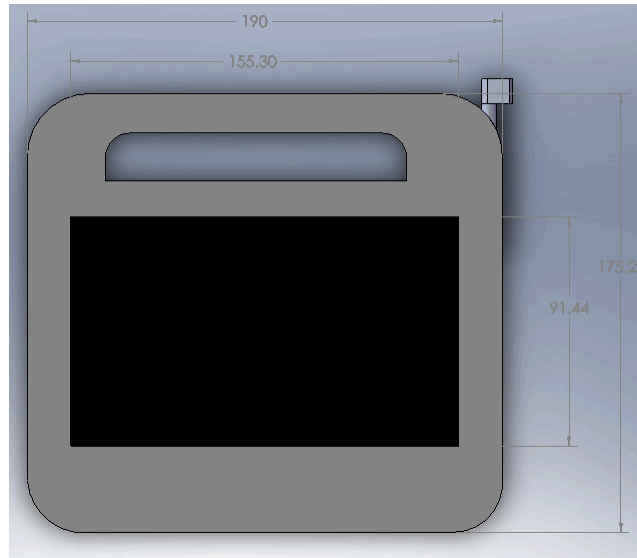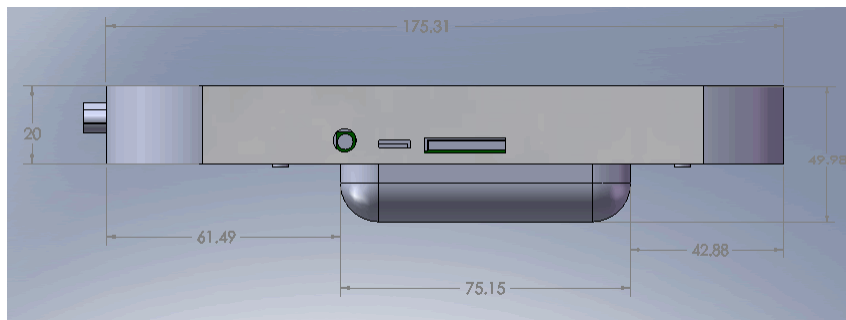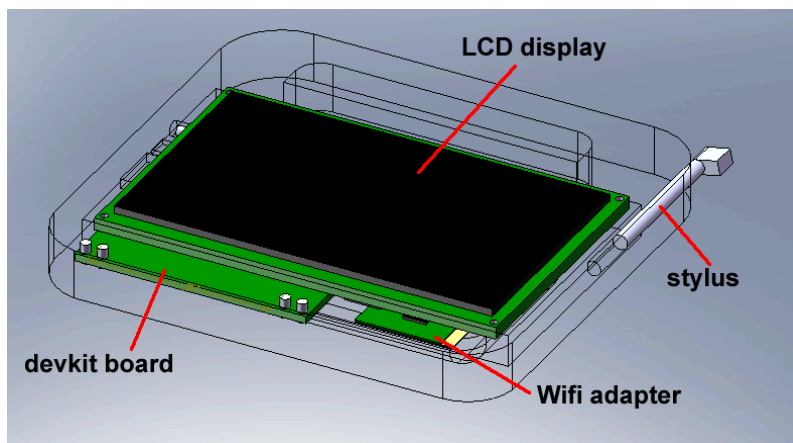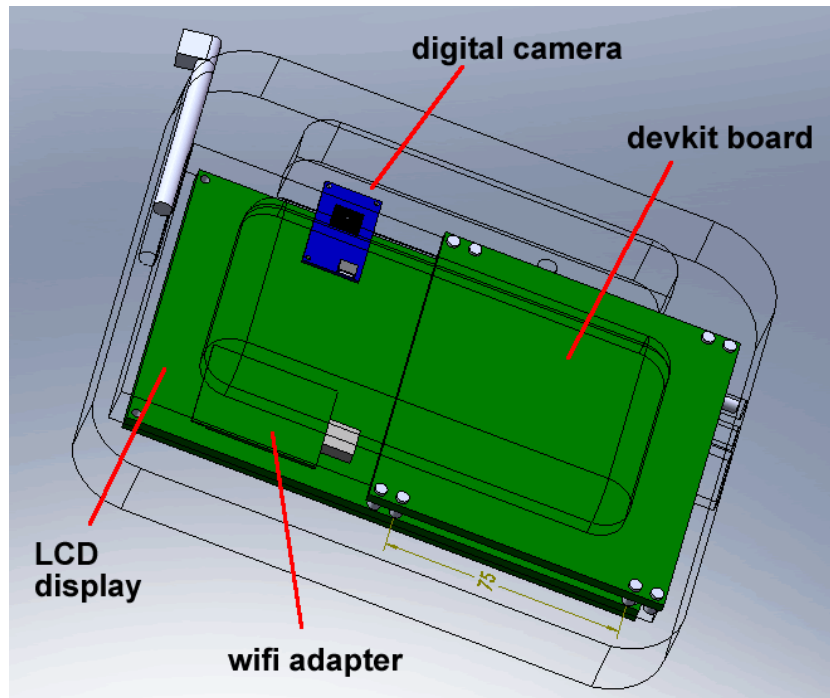**Figure 23 - Back view of the position of the touch screen with respect to the main board**

The dimensions are chosen to provide the most comfort to the user when holding the tablet. The casing material will be acrylonitrile butadiene styrene (ABS) plastic with rubber edges to act as shock absorber. ABS plastic is a common material used to enclose electronic components, and can operate between -25° C to 60°C which is well within the climate of Vancouver Lower Mainland and the interior cities.

5.4 Operating System Platform

Devkit8000 supports both Windows CE or Linux based systems. However, we chose the Angstorm Linux image that came with the kit because of the stability from a Linux system. Windows CE is known to have several issues on the Devkit8000 and would take a lot of effort to get it working properly. Linux has proven to be one of the most popular embedded operating systems in the market, and thus the amount of support available online was another consideration. The handheld device will require a lot of customization in the embedded software to enable particular system drivers. The customization ability of Linux will allow us to selectively install the needed drivers only and hence decrease the memory requirement of the device [19]. By reducing the memory required, we also decrease the leverage done to the handheld device processing unit.

5.5 Docking Station

During travel, the paramedics may not need to carry the handheld tablet all the time so there needs to be a docking station for the device. The station will provide stability and accessibility to make it easier for the paramedics to operate the tablet. In addition to provide ruggedness, the docking station will also provide external USB ports for connecting keyboards or any other peripherals desired. As well, the dock will also allow the paramedics to power the tablet using a power adapter. Having a keyboard will help

greatly in entering text on the electronic form in the GUI. The dock station will be bolted on the ambulance's front panel just under the windshield with a widget to allow turning of the dock and locking it in place. Figure 24 is a schematic of what the dock looks like in general.
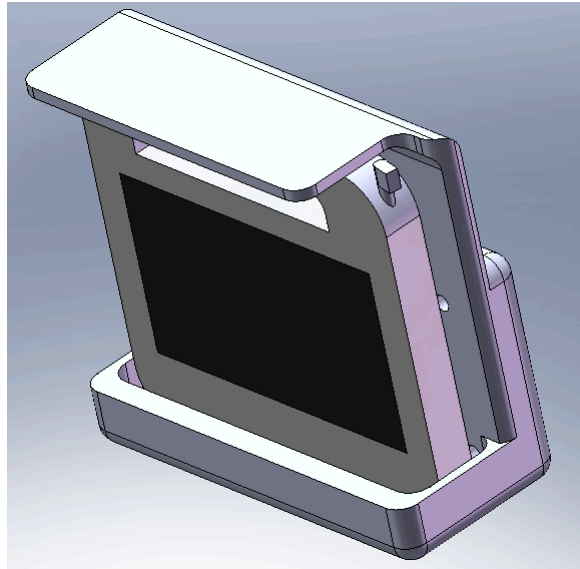

Figure 24 - Overview of the docking station schematic

Figures 25, 26, and 27 will show the dimensions (in mm) of the docking station from three different angles.
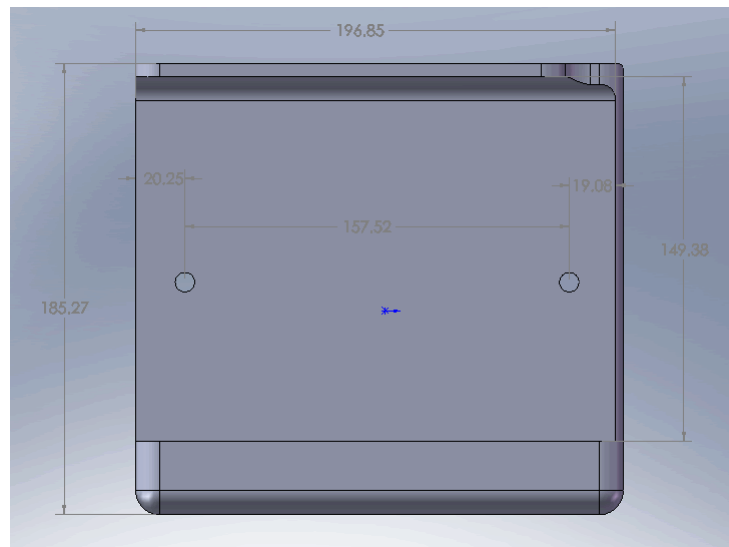
Figure 25 - Bird's eye view of the docking station with dimensions
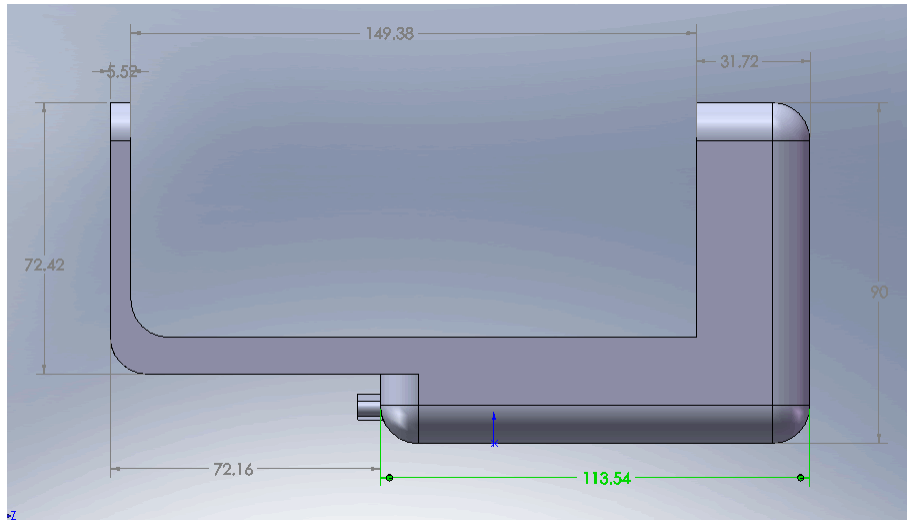
Figure 26 - Side view of the docking station with dimensions
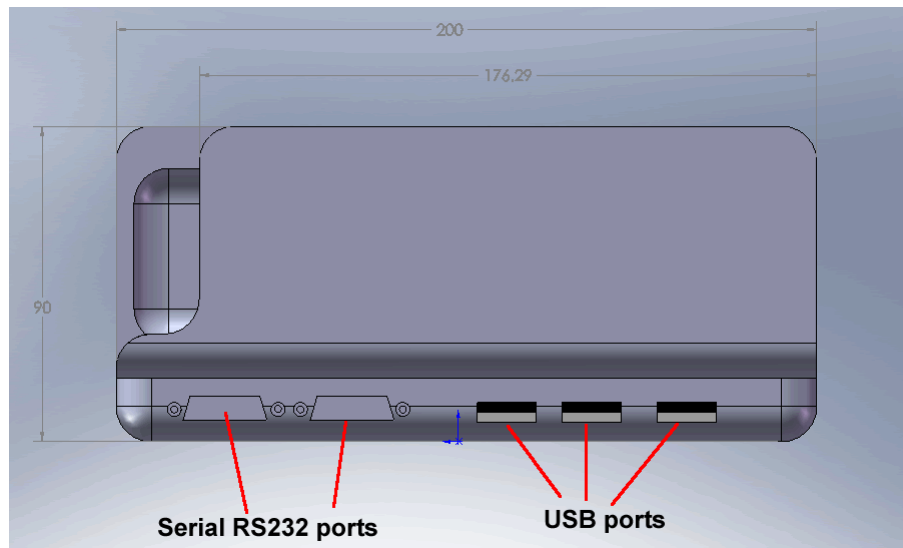
Figure 27 - Bottom up view of the docking station with I/O ports

5.6 Failsafe

The devkit8000 comes with 256M DDR SDRAM and 256M NAND flash. The fact that the tablet will only process form data and single image data indicates that we can easily provide a reserved memory allocation for back up purpose.

A high priority software protocol will be implemented as an auto-recovery mechanism. One main function of this protocol is to duplicate the input data to the reserve backup flash memory location. The tablet operating system will set a flag value to indicate the expected termination of the GUI software. If a crash occurs during operation, the flag will not be set, thus system will attempt to retrieve saved data from the reserved back location and automatically fill in the GUI. The protocol will be triggered every

time full set of information is entered to the tablet device. A full set of information is marked by the empty blanks on the GUI form, and image data for a single picture is treated as a full set.

Aside from local back up, tablet will also send the data every time a field is updated to the server to protect against system crashes. Those data will be marked with special tag to indicating that they are not ready for server display, unless paramedics validate the information. In such way, server side will also have a copy of the marginal information can be retrieve upon request by the tablet.

5.7 Safety and Security

Since all medical records of patients are considered confidential, the tablet will require the paramedics to log on prior to be able to enter patient's information. Also, after idling for 5 minutes the device will auto save the current progress and lock the screen. Also, as discussed in section 5.3, the handheld tablet will be enclosed to create a barrier between the components and the environment. The casing will prevent any possible micro or macro shock to the paramedics that can cause devastating results. As well, the casing will make sure the electronic component will not erode or explode on the hands of the operator during operation. A perfect seal between the joints of the casing will be ensured to enforce safe operation of the device.

5.8 Networking

As in the description of section 3, the ideal transmission will be done through 3G with WiFi enhancement. However, the prototype as a proof-of-concept design will only utilize WiFi network to provide the communication channel between the tablet and server. In the consideration of transmission speed, 3G and WiFi provide comparable bandwidth for both uplink and downlink. For example, the average download speed of AT&T's 3G network in the states is 1400 kbps and the average upload speed is 773 kbps [20]. The numbers are comparable to Telus' High Speed Lite internet at 1000 kbps download and 128 kbps upload [21]. This indicates that WiFi communication could well simulate the bandwidth limitation of the 3G network.

In the WiFi mode, there are many different type of internet protocols we can adapt to perform the transmission. Transmission Control Protocol (TCP) provides the guaranteed successful transmission of the data is the solution for all data transmission in the Remote Diagnostic System. Figure 28 indicates a transmission cycle of TCP connection where error presents,
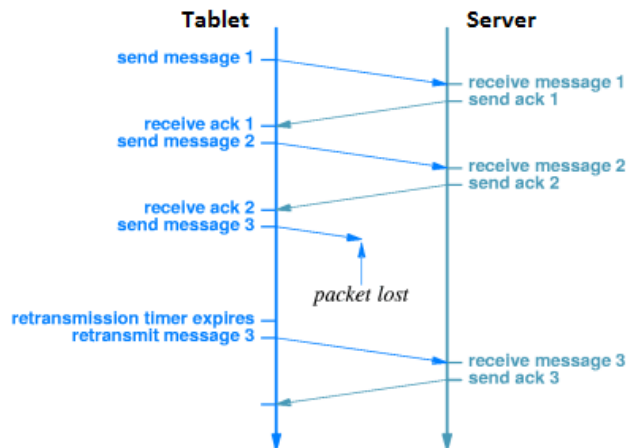
Figure 28 - TCP connection handling [22]

If there is any packet loss during the transmission, the retransmission will be automatically triggered by the TCP. This makes sure that every data transmitted by the tablet is successfully received by the server. In the final product using 3G network, we shall have the server echo the checksum of each packet transmitted back to the tablet as a mean to check for successful transmission. All data transmission will share the same communication channel using WiFi, however there will be data prioritization according their importance as described in earlier sections. Figure 29 is what a WiFi module looks like and its dimensions.
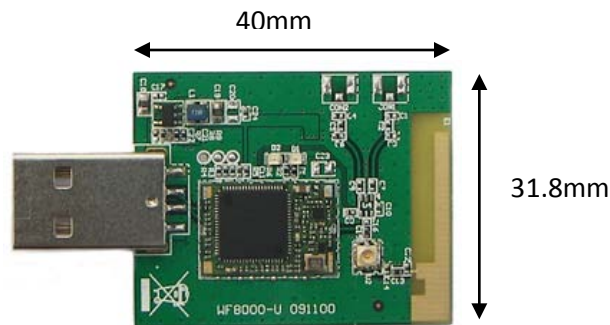
Figure 29 - Wifi module (WF8000-U) with dimensions [18]

5.9 Digital Camera

The digital camera is used to capture images of the patient's injuries, thus the quality of the image is very important. We chose a digital camera recommended by Embest because the specifications of the camera suggest that it is a good one. The camera's resolution is 3.2 Mega Pixels on a CMOS sensor, and keep in mind that most of the current commercial webcams are still 1.3 Mega Pixels or 2.0 Mega Pixels. After an initial testing on our home computer, we determined the camera to be very good and it was unnecessary to purchase another one. Figure 30 is a sample taken from the camera and Figure 31 is to give an idea how big the camera is.

Figure 30 - Sample image taken by digital camera module

Figure 31 - Size comparison of digital camera module to loonie

5.10 Power Supply

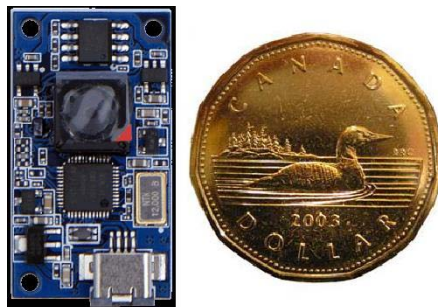Devkit8000 is powered by an AC adapter with input 100-240V at 0.2A with 50/60Hz and output 5V Direct Current at 2A. The development board draw 500mA during its operations, and all other component are powered through the board [23]. Typical resistive 7 inch touch screen consumes 2W of power [24]. WF8000-U module, the WiFi adapter, and CAM8000, the digital camera module attached to the board draw approximately additional 100mA while modules are operating continuously [25]. Those add up to approximately a total current draw of 1000mA.

The rechargeable Lithium-Ion battery with its flexible shape, light weight becomes the top choice in our selection. The 5V, 4800mAh Li-ion battery will be able to power the development board at full computation power for approximately 5 hrs. With power management system to allow device goes into sleep and suspend to ram mode, this operation time could be much longer as this theoretical value. At the same time a battery charger controller needs to be provided in order to avoid over charging the

battery and generate warning message when at low power. A LiPoly Charger based on the Max1555IC can be used to charge the battery [26]. However, the battery and charger will not be available in the prototype.

6. Vital Sign Signal Processing

Vital sign monitoring is a major component of the RDS design, it allows the hospital to view real-time status of the patient coming to the hospital. For prototyping, we are using serial port communication method as that's the I/O method of the pulse oximeter we have. In the final commercial product, the design will need to be changed to support USB as well in the future. The pulse oximeter transmits ASCII-1 data that includes the time, date, blood oxygen saturation level (SpO_2), and pulse rate. The data set is 66 bytes, and the setting for the serial port is: 9600 baud rate, 8 bit 1 stop and no flow control. Under the GUI, there will be a set of code that constantly checks for new data from the pulse oximeter every 1 second and selectively display only the SpO_2 and the pulse rate.

After reading the data from the pulse oximeter, they will be buffered in the program to send the information to the server every 5 seconds. Although the data can be acquired from the vital sign monitor every second, but we also have to consider the network load of the tablet because it is sending more than just one set of packet to the server. Also, the variation of SpO_2 and pulse rate isn't that significant so it is safe to send every 5 seconds to the server in the hospital.

7. System Test Plan

In order to ensure the all functions are covered in the design, we have set out a number of test plans. The preliminary tests will be done individually first, and after all the components are ready to be integrated, an integration test will follow.

7.1 Software Tests

Software testing is crucial in our product as most of its features are in embedded software. The software test cases will ensure the GUI is user friendly and bug free, and that all the functions are covered in the software design.

7.1.1 Software Test Case 1 – Handheld Tablet Graphical User Interface Intuitiveness
Purpose: Make sure that paramedics can easily use the tablet without trouble

Method:

1. Ask for volunteers from the BCAS
2. Have each of them operate the handheld tablet in an isolated room

Expected Result: The paramedics should be able to operate the device without hesitation. If one does hesitate, ask them for the reason and analyze whether it is an user error or system design error.

7.1.2 Software Test Case 2 – Server Graphical User Interface Intuitiveness

Purpose: Make sure that the triage nurses can easily use the Nurse Station software without trouble

Method:

1. Ask the nurse to run and log into the nurse station software
2. Have her fill in patient information like normal

Expected Result: The nurses should be able to operate the nurse station software without hesitation. If one does hesitate, ask them for the reason and analyze whether it is an user error or system design error.

7.1.3 Software Test Case 3 – Server Connectivity to the Database: Read

Purpose: Make sure that the server at the hospital can access the database to display patient information

Method:

1. Ask a nurse to open up the Nurse Station software and log in
2. Have the nurse check the whiteboard to make sure there are patient's populating the table

Expected Result: The table in the Nurse Station software should populate with patient information

7.1.4 Software Test Case 4 – Transmit Data from Tablet to Server

Purpose: Ensure that the connectivity between the two clients are in place

Method:

1. Have a paramedic enter some patient information onto the tablet
2. Confirm and send the data
3. Have a nurse log into the Nurse Station software and verify that a new patient data appeared

Expected Result: The information of the new patient should arrive at the server, get stored in the database, and the nurse should be able to see it on her screen

7.1.5 Software Test Case 5 – Server Connectivity to Database: Write

Purpose: The nurse not only needs to read patient information from database, but they also need to be able to enter new information and write to database

Method:

1. Have a nurse open the Nurse Station software and log in
2. Double click on one of the patient's name on the whiteboard
3. Modify or add new information to the patient
4. Click connect to submit the changes

Expected Result: The new information should be written on the SQL database, and if the same patient's profile is opened again, the new information should be pre-loaded. If the patient is new, he or she should show up on the whiteboard

7.1.6 Software Test Cast 6 – Database Field Constraints

Purpose: Some fields in the database can only take in certain values, and that feature needs to be protected to prevent data corruption.

Method:

1. Have a nurse open the Nurse Station software and log in
2. Go to the fields that have limited possible answers, ie. Gender, age, etc.
3. Check on the SQL database to see what data has been written to the corresponding fields
4. Have a paramedic do the same on his or her handheld tablet

Expected Result: The restrictive fields in the database should have only accepted certain input formats. For example, age should only accept numbers, and gender should only accept male, female, m, or f.

7.1.7 Software Test Case 7 – Only Authorized Personnel Can Edit the Medical History

Purpose: For security purposes, only certain people can access and edit certain fields in database

Method:

1. Have a nurse open the Nurse Station software and log in
2. Open up a patient's information from the whiteboard
3. Edit the medical history field
4. Have a paramedic do the similar thing on the handheld tablet

Expected Result: The nurse should be able to edit the medical history, however the paramedic should not be able to

7.1.8 Software Test Case 8 – Add New Patient to the Whiteboard

Purpose: For those patients not coming in by ambulance, they will need to be added by the nurse

Method:

1. Have a nurse open the Nurse Station software
2. Switch to edit mode and log in
3. From the whiteboard, select add new patient
4. Select the corresponding report and enter patient information

Expected Result: The new patient should show up on the whiteboard and stored on the database, also, double clicking it should bring up his or her information

7.1.9 Software Test Case 9 – Remove Patient Record from the Whiteboard

Purpose: When patients get discharged, they need to be removed from the whiteboard display

Method:

1.   Have a nurse open the Nurse Station software and log in
2.   Select a patient on the whiteboard
3.   Select delete

Expected Result: The patient record should disappear on the whiteboard and the database

7.1.10 Software Test Case 10 – Retrieve Image Data from a Patient
Purpose: For more serious injuries, sometimes patient will have images of their wound, and they need to be accessible for the nurses

Method:

1.   Have a nurse open the Nurse Station software and log in
2.   Double click on a patient on the whiteboard
3.   Click on patient image tab
4.   Select an image to display

Expected Result: A pop-up of the selected image should appear

7.2 Hardware Tests
The handheld tablet will be heavily used in emergency medical services, thus it is essential that it is durable to all plausible conditions.

7.2.1 Hardware Test Case 1 – Handheld Tablet Operate Solely On Battery
Purpose: Ensure that handheld tablet is able to operate for an adequate amount of time solely dependent on Li-ion battery pack

Method:

1.   Fully charge the a new Li-ion battery and install it to the tablet device
2.   Disable the power management feature
3.   Allow device to run at full processing power
4.   Check to see that warning message is displayed after approximately 4hr stating batter is running low.
5.   After batter is fully used, fully charge the battery again and install it to the tablet
6.   Enable the power management feature
7.   Allow device to run in normal operation mode
8.   Observe the device are able to switch between awake, sleep, and suspend to ram mode
9.   Record the operation duration until the battery is depleted,
10. Check for the warning message when battery has only 20% of the fully charge power.

Expected Result: The tablet should be able to run on battery for at least 5 hours with and without power management feature

7.2.2 Hardware Test Case 2 – Handheld Tablet Shock Test

Purpose: Handheld tablet must be able to withstand an adequate amount of shock

Method:

1. Turn handheld tablet on
2. Place the tablet on the docking station in the ambulance
3. Drive the ambulance around the city, and operate the tablet

Expected Result: The tablet should still be functioning while suffering from the vibration and rocking due to the movement of the vehicle

7.2.3 Hardware Test Case 3 – Handheld Tablet Spill Test

Purpose: Handheld tablet must be able to withstand an adequate amount of liquid to handle raining conditions

Method:

1. Turn handheld tablet on
2. Half a cup of liquid will be spilled all over the tablet to ensure it is still operational

Expected Result: If the seal on the casing is as designed, the tablet should still be operational

7.2.4 Hardware Test Case 4 – Handheld Tablet Drop Test

Purpose: Handheld tablet must be durable enough to withstand a drop when accidents happen during operation

Method:

1. Turn handheld tablet on
2. Handheld tablet will be dropped from 1.5 meters high onto concrete floor

Expected Result: If the shock absorber on the case is working as designed, the tablet should still be operational

8. Conclusion

In this design specification document, the developers at MediCare Solutions have taken precautionary measures to ensure that all the functional specifications outlined in the *Functional Specification for a Remote Diagnostic System* [1] has been met. Although the design discussed is for a production level product, the steps to add enhancements to the product should not be difficult. All the design aspects will be followed to the best ability of the engineering team. At the very end, the proposed test plans will validate our design to make sure that the product is functioning as desired.

For the demonstration at the end of the course, a prototype design level product will be presented. The document represents a product at the production level, but for the time permitted in the course, just a prototype will be presented. For comparison purposes, please refer to our *Functional Specification for a Remote Diagnostic System* [1] to see specification in the prototype level and the production level.

Appendix A

Figure 32 - Form used by paramedics in BC provided by BCAS

Appendix B

Name	Characteristics	Data Transmission Speed Requirement
1G	Analog	None
2G	Digital	Messaging Capabilities
2.5G	Digital	Top Speed Less than 100Kbps
2.75G	Digital	Top Speed Up to 230Kbps
3G	Digital	Top Speed At Least 200Kbps
3.5G	Digital	Top Speed in Several Mbps
4G	Digital	Top Speed 10Mbps and Up

Table 2 - Mobile network classification [8]

Appendix C

Radio Resource Layer (RRC)	• Broadcast of information. • Establishment, maintenance and release of an RRC connection between the UE and UTRAN. • Establishment, reconfiguration and release of Radio Bearers. • Assignment, reconfiguration and release of radio resources for the RRC connection. • RRC connection mobility functions. • Control of requested Quality of Service. • UE measurement reporting and control of the reporting. • Outer loop power control. • Control of ciphering. • Paging • Initial cell selection and cell re-selection. • RRC message integrity protection.
Radio Link Layer (RLC)	• Segmentation and reassembly. • Padding. • Error correction. • In-sequence delivery of upper layer Packet Data Units (PDU:s). • Duplicate detection. • Flow control. • Sequence number check. • Protocol error detection and recovery. • Ciphering.
Medium Access Layer (MAC)	• Mapping between logical channels and transport channels. • Selection of appropriate Transport Format for each Transport Channel. • Priority handling between data flows of one UE. • Multiplexing/demultiplexing of upper layer PDU:s into/from transport blocks delivered to/from the physical layer on common transport channels. • Traffic volume measurement. • Transport Channel type switching. • Ciphering for transparent mode RLC.
Physical Layer (PHY)	• Error detection on transport channels and indication to higher layers. • Encoding/decoding of transport channels. • Modulation and spreading/demodulation and despreading of physical channels. • Frequency and time (chip, bit, slot, frame) synchronisation. • Radio characteristics measurements and indication to higher layers. • Inner - loop power control. • Radio frequency processing.

Table 3 - Table of 3G network layer functionalities [12]

References

[1]   MediCare Solutions, "Functional Specification for the Remote Diagnostic System," Simon Fraser University, Burnaby, BC, Canada, November 2010.

[2]   Ontario Ministry Of Health And Long-Term Care, "Emergency Room Wait Times," April 2010. [Online]. Available: http://edrs.waittimes.net/En/SearchSelection.aspx [Accessed: Nov. 8, 2010].

[3]   International Telecommunication Union, "About Mobile Technology and IMT-2000," April 2005. [Online]. Available: http://www.itu.int/osg/spu/imt-2000/technology.html#Cellular%20Standards%20for%20the%20Third%20Generation [Accessed: Nov. 8, 2010].

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