ICU_POC: AN EMR-BASED POINT OF CARE SYSTEM DESIGN FOR THE INTENSIVE CARE UNIT

By

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DEDICATION

I dedicate my dissertation work to my family, those alive and those who did not live to see my graduation especially my Dad, and my brother, Pius Onwuemelie Onuh, for their encouragement (both in words and actions), motivation, prayers and exemplary life which saw me through to my successful graduation.

I also dedicate this dissertation to my church family (The Legion of Mary Society) who has supported me throughout the process with persevered prayers. I will always appreciate them.

Finally, I dedicate this work and give special thanks to my wonderful and amiable kids, Chiemeka and Chidiuto for being there for me throughout the entire doctorate program. Both of you have been my best cheerleaders.

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List of Abbreviations

Acronyms	Full Meaning
ASP	Active Server Page
CCU	Critical Care Unit
CICU	Cardiac Intensive Care Unit
CSS	Cascading Stylesheet
EHR	Electronic Health Record
EMR	Electronic Medical Record
HTML	Hyper Text Markup Language
HTTP	Hypertext Transfer Protocol
ICU	Intensive Care Unit
IIS	Internet Information Service
IP	Internet Protocol
JSP	Java Server Pages
LAN	Local Area Network
LOS	Length of Stay
MICU	Medical Intensive Care Unit
MSL	Message Layer Security
MySQL	My Structured Query Language
NEHI	Network for Excellence in Health Innovations
NICU	Neuro Intensive Care Unit
OSI	Open Systems Interconnection
PHP	PHP: Hypertext Preprocessor
PICU	Pediatric Intensive Unit
POC	Point of Care
SICU	Surgical Intensive Care unit
SQL	Structured Query Language
SSL	Secure Sockets Layer
TCP	Transmission Communication Protocol
Tele-ICU	The telemedicine Technology
TSL	Transport Layer Security
URL	Uniform Resource Locator
WAMP	Windows Apache MySQL PHP

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ICU_POC: An EMR-Based Point of Care System Design for the Intensive Care Unit

Abstract by

CHIKA CORNELIA EMEKA-NWEZE

In this era of technological transformation in medicine, there is need to revolutionize the approach and procedures involved in the treatment of diseases to have a restructured understanding of the role of data and technology in the medical industry. Data is a key factor in diagnosis, management, and treatment of patients in any medical institution. Proper management and usage of patient's data will go a long way in helping the society save money, time and life of the patient. Having data is one thing and providing a system or means of translating the data is another issue.

This dissertation is proposing a design of a Point of Care system for the Intensive Care Unit (a.k.a ICU_POC), which is a system that integrates the capabilities of the bedside monitors, bedside eFlowsheet and the Electronic Medical Records in such a manner that the clinicians interact with one another in real time from different locations, to view, analyze, and even make necessary diagnoses on patients' ailment based on their medical records. It demonstrates how patient data from the monitors can be imported, processed, and transformed into meaningful and useful information, stored, reproduced and transferred automatically to all necessary locations securely and efficiently without any human manipulation.

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ICU_POC will grant physicians the remote capability in managing patients properly by providing accurate patient data, easy analysis and fast diagnosis of patient conditions. It creates an interface for physicians to query historical data and make proper assumptions based on previous medical conditions. The problem lies in managing data transfer securely between one hospital EMR database and the other for easy accessibility of data by the physicians. This work is challenged by designing a system that could provide a fast, accurate, secure and effective (FASE) diagnosis of medical conditions of the patients in the ICU. The proposed system has the potential of reducing patients' length of stay in the ICU by equipping the physicians with an easy way of managing patients' data seamlessly and diagnosing conditions quickly. This, in turn, will reduce the cost of care generally in the society.

Keywords: analysis; care; critical; data; EMR; ICU; information; integration; medicine; monitoring; numerics; phenotypic; physiological; POC; system; technology; visualization; waveform; web.

Chapter 1.0

Introduction

1.1 Background

Data is raw or unprocessed information that represent situations, ideas or objects at any point in time [1]. It is needed in every aspect of life and especially now more than before in the medical industry. Data is a key factor in diagnosis, management and treatment of patients in the hospital. In this era of technological transformation in medicine, there is need to revolutionize the approach and procedures involved in the treatment of diseases to have a restructured understanding of the role of data and technology in the medical industry. Having data is one thing and providing a system or means of translating the data into more useful form is another issue.

With the evolution of critical care medicine, the use of monitoring technology has created a great deal of technological advancement to the medial industry. The outcome of these development is the establishment of intensive care units where patients with special medical condition are grouped and care for using specialized equipment. Even though there is improvement in the technologies used in monitoring patients in the intensive

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care, the ability to automate the processing or analysis of data still lags. There are lots of manual capturing of medial information and no analysis on the physiological waveform data whatsoever. Even when these physiological data are obtainable, there is no process for the integration of such data in a form that is accessible or useful for physician to reference. This has created a bottleneck in monitoring patients at the intensive care unit [5].

Good medical care requires accurate records of greater detail than in the past. Clinicians are often unaware of treatment that patients have received from other providers and in other settings unless informed by the patient themselves. Proper management and usage of patient's data will go a long way in helping the society to save money, time and life of the patient.

The idea of ICU_POC, an Intensive Care Point of Care system was therefore conceived with the goal of addressing these needs and many more especially concerning those critically sick patients who in most cases cannot express themselves due to the nature of their ailment. It is believed that this ICU_POC will be a dream come true and that many benefits will be derived in addition to achieving the following;

- Accurate data collection
- Proper data storage
- Easy generation of patient data
- Secure data transfer across medical EMR and institutions
- Fast and easy access to patient's historical information

- Reliable diagnosis and prompt treatment of patients in the ICU.

1.2 Motivation

Big Data!!! There is data everywhere especially in the medical industry but how much of this data is accessible, meaningful and useful to people who need it. The intensive care unit has got patient monitors filled with much data in addition to nurse notes, demographics, progress notes, problems, medication, and vital signs, past medical history, immunizations, laboratory data and radiology reports. Data is so much that the providers have to go through several documentations. They are faced with the ability to coordinate all these and make up meaningful conclusion over a critical patient condition [2].

The need for a fast, accurate, secure and effective (FASE) diagnosis of medical conditions of the patients at the ICU is the reason for my delving into this area of study. I happened to be at the intensive care unit to see my mum in very critical condition. Seeing how the body loses life in micro-seconds interval of time is very traumatic. Thus, the need to provide a good decision-making mechanism to help the physicians in making recommendations, diagnosis or proffering medication promptly. This project work focuses on the best way to monitor intensive care patients while generating accurate and reliable statistics to enable the physicians to have less time to think in reaching conclusions about critical conditions. The immediate need for these data to be organized, integrated and transformed into actionable information that can be distributed to required units for effective and improved patient care cannot be over emphasized [2].

1.3 Statement of Problem

The health industry is potentially facing a huge issue concerning hospitals in the United States that hold so much on intensive care units and their intensivists who are attending to over six million of the geriatric and critically ill patients yearly [6]. There is an ever-growing count and criticality of patients at the intensive care unit with the United States population getting older. Also of concern, is the issue of shortage or scarcity of critical care professionals for the management of this increasing count of intensive care patients. Data collected in 2010 revealed that there were five thousand, five hundred (5,500) qualified and certified intensivists serving six thousand (6000) intensive care units [7]. This revelation implies that there is less than 1:1 ratio of ICUs to intensivists in the United States.

Accurate and timely information management is critical in medical industry more especially at the intensive care unit where medical conditions change with the click of a mouse. Time is money and a stitch in time saves nine. Patients spend much time in the intensive care unit than is necessary sometimes due to unavailability of qualified professionals, delays and procedures that if taken care of, could save a number of lives and money.

In today's ICU, there is so much documentation and data needed. These enormous data will continue to create delays and obstacles if not handled properly. Physicians are faced with the stress of going through different pieces of information and understanding those before making serious decision regarding their critically ill patients. Some patients will end up getting worse with their condition.

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Patients expect immediate attention on coming to the ICU as well as proper diagnosis thereby reducing the length of stay once proper diagnosis is made and appropriate medication initiated. The amount of time spent at the ICU by patients creates a huge financial cost to humanity when considering the cost of services rendered by the hospital as well as the friends and families who spend time caring for these patients. “The average ICU length of stay (LOS) is 3.3 days, and for every day spent in an ICU bed, the average patient spends an additional 1.5 days in a non-ICU bed [3]. It costs about 10,700 and 6,600 US dollars for a patient with mechanical ventilation and without mechanical ventilation respectively on a patient’s first day at the ICU. Day 2 costs are about 4700 and 3500 US dollars with and without mechanical ventilations respectively. Then on day 3, it gets to 4000 and 3000 with and without mechanical ventilation respectively [4].

The proposed ICU_POC is developed to get the necessary data properly managed, integrated and represented in a manner that it will be useful in reducing time, money and increase resources for more patients in the ICU.

1.4 Contributions

ICU_POC is intended to help in the realization of the future and ideal critical care unit by providing the capabilities necessary for the interpretation of physiological data from multiple sources, and specifically, the continuous integration and time synchronization of multiple channels of physiological data. [5] clearly stated a hypothesis that, “Patient care in the ICU can be significantly improved through the application of complex system analysis methods to acquired and synchronize physiological signal data”. This is the goal of this project, to effect positive impact in the outcome of medical treatment in the ICU.

A telemedicine technology (Tele-ICU) is one of the promising path being adopted by the Network for Excellence in Health Innovation (NEHI) to address the intensive care unit staffing concerns in the United States. The development of ICU_POC will catalyze and improve the adoption of Tele-ICU such that the remote physicians can in addition to the real-time audio/video monitoring, be able to directly import these data remotely for the analysis of the phenotypic and physiological data by themselves. They will be able to extract and store such information and make references or draw some conclusions based on such historical data in future. ICU_POC will create an interface for integration of Tele-ICU capabilities and provide the enabling environment for data analysis / visualization as well as the integration with EMR system for future reference [6, 7]. ICU_POC will reduce cost of care by reducing the length of stay and the operating cost which is one of the issues faced by Tele-ICU technology today. It will also provide a uniform system in a uniform platform which will be easier to manage and control.

ICU_POC will grant physicians the remote capability in managing patients properly by providing easy analysis and fast diagnosis of patient conditions based on availability of necessary information and efficient access to patients’ information. It involves accurate and secure management of patient data, the ability to query historical data and make proper assumptions based on previous medical conditions. This system is designed with the following ideas:

- Constant observation and immediacy of action.
- Detection and treatment of life-threatening diseases.
- Monitoring techniques
- Storage and retrieval of EMR data

The proposed system has the potential of reducing patients’ length of stay in the ICU by equipping the physicians with an easy way of managing patients’ data seamlessly and diagnosing conditions quickly. This in turn will reduces cost of care generally in the society. The medical industry, especially the Intensive Care Unit stand to benefit substantially from the adoption of this proposed system. Intensive care is all about constant observation and immediacy of action regarding the patient. It requires proper detection and treatment of life-threatening diseases of varying nature, good treatment and monitoring techniques. It also needs proper dissemination of data and information to relevant units of the system to achieve speedy results. Additionally, being the first to adopt this solution, University Hospital stands to gain considerable recognition as an industry trend-setter in the areas of quality and care.

1.5 Dissertation Structure

This work is structured into five main chapters. Firstly, Chapter One, **Introduction** of the entire system was given where the background and motivation goals of the project was described. This chapter gives the problem statement of the project, the contributions of the project to the society and the structure / outline of the work. Chapter Two is **Literature Review**, considers the academic background studies relating to data informatics, health or medical informatics under which we looked at HL7 Messaging techniques and Electronic Medical Records. Intensive Care Units generally, Tele-ICUs and point of care systems were discussed as well. Chapter Three has **System Architecture and Development of ICU_POC**. This chapter addresses hardware and software design of the project. It deals with analysis and development of the actual point of care system, explaining the code development behind each entity and possible details involved. The web platform design of ICU_POC were also covered here. Chapter Four is the **ICU_POC Implementation** which is a demonstration of the entire system. This walks through the step-by-step processes required to import data from the monitors, visualization and final transfer to EMR database. It also has the interface for the EMR query engine. Finally, Chapter Five deals with **Summary and Conclusions** and gives a general summary of the work done in this project. Limitations and suggestions for future work ideas were discussed as well.

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Chapter 2.0

Literature Review

2.1 Data Informatics

Informatics originated from the German word "*Informatik*" [8] by a German scientist and one of the founders of computer science called Karl Steinbuch. Karl coined the word "*Informatik*" in 1957 [9] which later became computer science in German. The French term "*Informatique*" also coined by Philippe Dreyfus as well as "*informatica*", all pointed to the same meaning: application of computers to store and process information [10]. It is the art and science of using computers and information systems to process data / information automatically [11]. As an academic field, informatics involves the practice of information processing, and the engineering of information systems [11]. With the application of computer science and generally, information technology in all areas of life today and more especially in the medical industry, one goes back to reflect on what Karl Steinbuch has predicted [12] in 1966, "*In a few decades time, computers will be interwoven into almost every industrial product*" [9]. Information is information about information, data, knowledge … and ideas [11]. Data on its own becomes a vital piece in trying to process information. There is an internet of big data today but it's not all about the data nor the size of the data. Good analyses are always obtained from a sample data which is usually small subset compared to the population in question [14]. Data has become very cheap but means of processing this data is hard to find. It is important to get the two aligned to ensure a progressive processing of useful information [13].

2.2 Health Informatics

With the increasing shift from fee-for-service payment systems to value-based care, informatics and data analytics have become indispensable operations for healthcare organizations. Practitioners are faced with a wealth of healthcare data every day. These data need to be processed and analyzed for decision making purposes [15]. Electronic health records has become very common and in the medical industry thereby bringing informatics to the forefront of medicine. It is being used to acquire, process, analyze and manage large chunk of this medical data in a bid to manage and enhance information usage for an improved quality of care [16]. The healthcare industry and information technology has got interwoven as well as with Information Sciences by medical informatics [17]. One can hardly go without the other especially in this present dispensation.

"Better collection and analysis of health data may save lives, cut costs, and expand access to care" [35]. Health informatics involves the study of health information management methods that supports health information technology. It involves medical record systems such as electronic health records (EHR), electronic medical records (EMR), health information exchange standards like Health Level 7 (HL7), medical terminologies and portable medical devices for the collection of health data[19].

Figure 2.2 Medicine Interwoven by Information Technology.

2.2.1 **Health Level Seven International (HL7)**

As Health informatics gains more ground in the society, Information Technology also becomes more involved in design, development and management of information systems for the healthcare industry. This IT involvement will bring about automation of most manual data related operations and interoperable healthcare information systems thereby providing lower medical costs, increased efficiency and error reduction, improved medical care and patient satisfaction [19]. In a bid to ensure interoperability and smooth data transfer across disparate healthcare systems, there was a need to get a unified means of understanding medical information coming from different units. Hence the origin of Health Level-7 (HL7).

HL7 is a standardized way of formatting and defining, exchanging and developing electronic medical records used by various international healthcare providers. It is a set of rules guiding how healthcare systems interact with one another in order to share information.

These set of standards were developed by the healthcare IT standard-setting authority HL7 International and concentrates on the application level which is the seventh level of the International Organization for Standardization (ISO) seven-layer communications model for Open Systems Interconnection (OSI) [25]. This is where the name got originated from. HL7 covers both clinical and administrative data elements in transmission [20, 21]. It reduces the tendency of seeing medical care as being geographically distant and highly variable [20]. It helps in reducing time spent in filing forms and telling much stories by the physicians. Once data has been transmitted from the patient's previous provider, it helps the current provider to view the history and go ahead to make necessary diagnosis. HL7 should ideally help everyone secure access to the right medical data when needed [25].

2.2.2 HL7 Interface Engine

Healthcare industries create special software systems to connect legacy systems using standard messaging protocols [26]. With the use of HL7 interface engine, different legacy systems get interconnected seamlessly with minimal cost. It also helps in data sharing across non-hospital systems like the labs systems. They create a common ground among these disparate systems based on defined rules by the organizations.

It is difficult if not impossible to share or transmit medical information between two healthcare systems without first knowing the basic make-up of the system and creating an interface that will match the individual system. This is one of the challenges ICU_POC has faced in trying to integrate with a live EMR system.

2.3 Electronic Health Records

An Electronic Health Record (EHR) is an electronic version of a patient's medical history, that is maintained by the provider over time, and may include all of the key administrative clinical data relevant to that persons care under a particular provider, including demographics, progress notes, problems, medications, vital signs, past medical history, immunizations, laboratory data and radiology reports The EHR automates access to information and has the potential to streamline the clinician's workflow. The EHR can also support other care-related activities directly or indirectly through various interfaces, including evidence-based decision support, quality management, and outcomes reporting. It is an electronic record of health-related information on an individual that conforms to nationally recognized interoperability standards and that can be created, managed, and consulted by authorized clinicians and staff across more than one health care organization [29].

Electronic health records (EHRs) are real-time, patient-centered records that make information available instantly and securely to authorized users. While an EHR does contain the medical and treatment histories of patients, an EHR system is built to go beyond standard clinical data collected in a provider's office and can be inclusive of a broader view of a patient's care [31].

EHRs are the next step in the continued progress of healthcare that can strengthen the relationship between patients and clinicians. The data, and the timeliness and availability of it, will enable providers to make better decisions and provide better care.

For example, the EHR can improve patient care by:

- Reducing the incidence of medical error by improving the accuracy and clarity of medical records.
- Making the health information available, reducing duplication of tests, reducing delays in treatment, and patients well informed to take better decisions.
- Reducing medical error by improving the accuracy and clarity of medical records.

Our world has been radically transformed by digital technology – smart phones, tablets, and web-enabled devices have transformed our daily lives and the way we communicate. Medicine is an information-rich enterprise. A greater and more seamless flow of information within a digital health care infrastructure, created by electronic health records (EHRs), encompasses and leverages digital progress and can transform the way care is delivered and compensated. With EHRs, information is available whenever and wherever it is needed. The meaningful use requirement is waking up the idea about electronic health records which has existed long ago but seemed to have been at the back end of the health industry. [35]. Providers are seriously encouraged to adopt the system to ensure that their patients benefit from varying advantages obtainable by using EHR [32].

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2.4 Electronic Medical Records

An electronic medical record (EMR) is a digital version of a paper chart that contains all of a patient's medical history from one practice. An EMR is mostly used by providers for diagnosis and treatment [33]. Electronic medical record (EMR) systems, defined as "an electronic record of health-related information on an individual that can be created, gathered, managed, and consulted by authorized clinicians and staff within one health care organization," [29] have the potential to provide substantial benefits to physicians, clinic practices, and health care organizations.

Benefits of Electronic Medical Records - An EMR is more beneficial than paper records because it allows providers to:

- Track data over time
- Identify patients who are due for preventive visits and screenings
- Monitor how patients measure up to certain parameters, such as vaccinations and blood
- pressure readings
- Improve overall quality of care in a practice.

The information stored in EMRs is not easily shared with providers outside of a practice. A patient's record might even have to be printed out and delivered by mail to specialists and other members of the care team [28,33].

These systems can facilitate workflow and improve the quality of patient care and patient safety. Despite these benefits, widespread adoption of EMRs in the United States is low; a recent survey indicated that only 4 percent of ambulatory physicians reported having an extensive, fully functional electronic records system and 13 percent reported having a basic system [30].

2.4.1 **OpenEMR**

OpenEMR is an open source medical software which serves as a practice management system (PMS) as well as EMR system. Its features of PMS enable it to handle administrative and financial aspect of the medical services.

The server side language used in this development work is PHP which was initially know as Personal Home Page tool. Today it is widely known as PHP: Hypertext Preprocessor due to its capability to interact with HTML, also being that it is a precompiled tool [34]. It also complements with client side language, HTML which stands for Hyper Text markup Language for the pages and text displays. MySQL database was used for the development and which is a relational database management system.

The electronic medical record of the OpenEMR was utilized in this project as the EMR for the housing historical data from the bedside eFlowsheet. Due to some security reasons, it was difficult to use a live hospital EMR for this work. Several efforts were made and all proved abortive. The evolution of OpenEMR became very useful and an opportunity to actualize the processes involved.

OpenEMR has continued to undergo improvements by the project team and now has support for up to 19 languages. It has all the basic modules of any healthcare

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electronic records management system. It is a very robust, intuitive and user-friendly system for small healthcare establishments [61].

2.5 Intensive Care Unit

An Intensive Care Unit (ICU) or critical care unit (CCU) as the name implies is a part of the hospital where patients who have very serious or traumatic conditions are accommodated, observed and treatment with very prompt attention. Once a patient is said to be in an Intensive Care Unit, everyone gets nervous and feels that is a terrible condition. It is the best place to cater for patients with severe and life-threatening illnesses and injuries, which require constant, close monitoring and support from specialist, equipment and medications in order to ensure normal bodily functions. The environment at the ICU is completely different from the ordinary hospital units based on the staff-to-patient ratio, availability of special resources as well as the prompt attention given to any symptom exhibited by the patients. The medical personnel posted to the ICU are specially trained to work in the ICU environment. [44, 45]. The Intensive Care Society recommends minimum of 15 consultants sessions to an ICU of 4 or more beds out of which 10 should be fixed daytime sessions. A minimum of 7 fixed daytime sessions from the consultants, dedicated exclusively to the practice of intensive care medicine is required to achieve training recognition [38]. The introduction and utilization of this critical care units in hospitals for the proper management of critically ill patient has yielded positive fruits and improved the outcome by reduction in expected mortality up to 60% [43, 44].

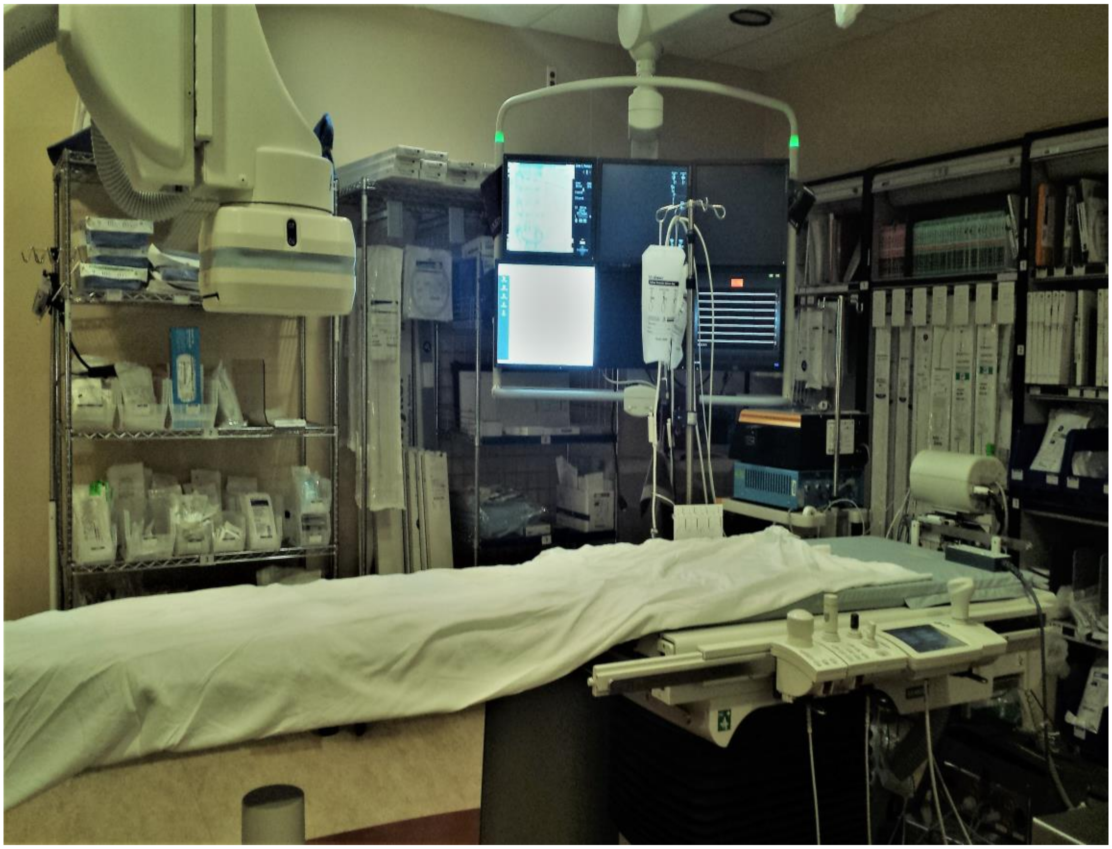

Figure 2.5 Operating Unit of a Cardiac Intensive Care Unit (CICU)

2.5.1 Different ICU Types

There are different types of intensive care units in the hospital system with the responsibility of providing critical care to patients with serious medical issues. The settings are basically the same but each of the types are challenged with attending to a specific specialty or the other. The ICU_POC project is designed with all the different ICU setting in mind. The idea in this work could be applied in any of the following types of intensive care units.

- **Medical Intensive Care Unit (MICU) -** MICU is the type of intensive care unit where adults and elderly people with critical health conditions are managed and cared for by the health professionals. The data that were used in this ICU_POC project work as test cases were generated from the medical intensive unit (MICU).
- **Cardiac Intensive Care Unit (CICU) or Coronary Care Unit (CCU) –** specifically caters for patients with congenital heart related issues or life-threatening acute conditions such as cardiac arrest. Figure 2.5 shows an operating room of a cardiac intensive care unit.
- **Neonatal intensive care unit (NICU) –** takes care of infants with critical conditions right from birth and who have not left the hospital since they were delivered.
- **Pediatric intensive care unit (PICU)** – manages pediatric patients with different life-threatening conditions.
- **Psychiatric intensive care unit (PICU) –** are for patients who have one psychiatric situation or the other and who seem to have the possibility of being harmful.
- **Neurological Intensive Care Unit (NICU)** – sees patients with some neurological issues and who need constant monitoring and may require hourly neurological observation
- **Trauma Intensive Care Unit (Trauma ICU)** – only available in a trauma certified hospital with a dedicated Trauma Emergency Department. Usually equipped with teams of specialists.

- **Post-Anesthesia Care Unit (PACU) –** for post-surgical patients that need observation to get stabilized. These patients must meet up with specified physiological criteria before they are escorted back with a qualified nurse to the ward.

2.5.2 An Ideal or Future ICU

Information Technology is being utilized extensively by the medical industry to bring about great positive improvements just like in all spheres of life. Some medical procedures and diagnosis should be predictable going by the kind of technological transformations that are becoming obtainable in medicine. "As the medical community increasingly embraces the power of technology to help improve health outcomes for patients, predictive medicine is finally becoming a reality." [32].

In a short while to come, information technology will be heavily employed in the extraction and management of data in such a way that useful information is generated especially in the intensive care unit (ICU) [5]. Critical care involves highly complex decision-making to treat vital organ system failure and prevent life-threatening deterioration. It is by nature, data-intense with hundreds of changing variables confronting the clinician at the same time. In today's ICU, there are enormous amounts of data, much more than, integrate and act upon reliably. In short, our ability to acquire data has outstripped our ability to understand it. This is because, despite the growth of critical care, the basic approach of information management in the ICU has remained essentially unchanged over the past 4 decades. Providers must navigate through a jungle of monitors, screens, software applications, and often supplemental paper charts inherent in today's cacophony of information systems. Data from patient monitors and devices, which drove the growth of critical care in general and especially neuro-critical care, although available visually at the bedside, is difficult to acquire in electronic (digital) format. And there is limited medical device interoperability or integration with the electronic medical record (EMR). Therefore, the current state of today's ICU, as can be seen in Figure 2.5.2, is such that information is not available even though there is data everywhere [40]. This project is geared towards getting these data integrated and consolidated to offer more useful information.

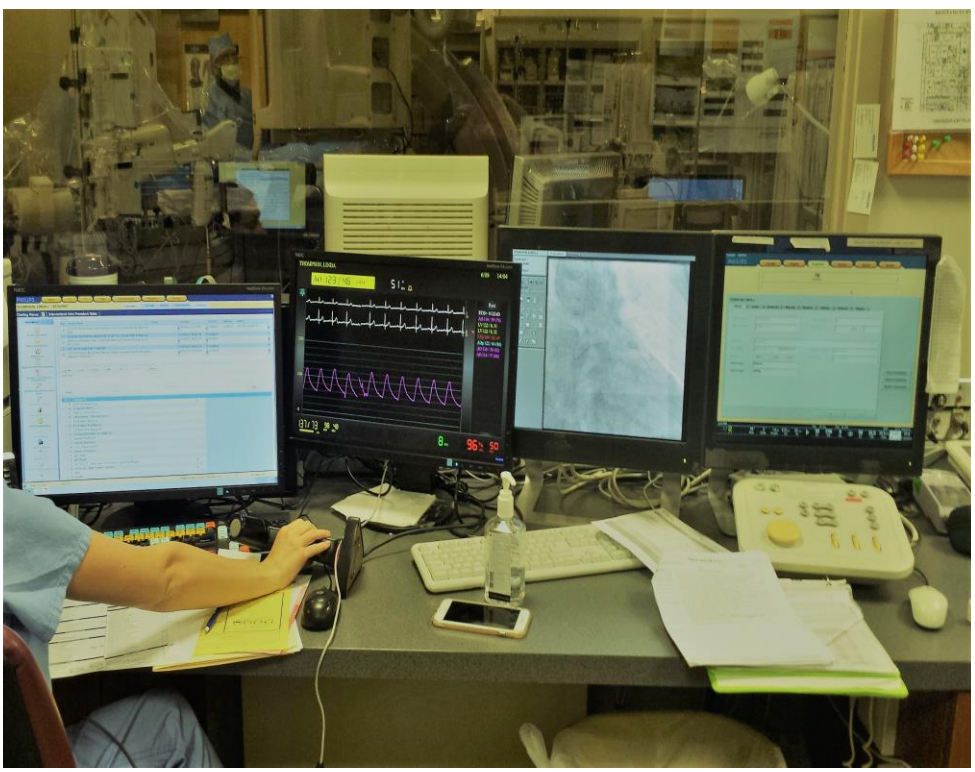

Figure 2.5.2 Physician Desk in Today's Cardiac Critical Care Unit.

2.6 the Integrated Medical Environment - Improved

We believe that the future of intensive care monitoring lies in the following aspects. First, the next generation of intelligent monitoring systems should have the functionality of integration and time-synchronization of multiple channels of physiological data continuously and simultaneously.

In addition, the system should be capable of processing physiological data in real-time, and using new dynamic analytic tools such as multivariate analysis and nonlinear time series analysis to facilitate rapid diagnoses and support clinical decision-making.

Last but not the least, the system should exhibit the clinical information in a user-friendly Graphical User Interface to facilitate clinical decision-making. The combination of all three elements, data integration, processing, and visualization, is far beyond the scope of what is commercially available today [40, 2].

the Integrated Medical Environment (tIME) [2] proposed and which is undergoing development at Case Western Reserve University in collaboration with the University Hospitals Case Medical Center has achieved the first part of the tIME model, the real-time data acquisition system. The remaining parts of the model, a middleware informatics architecture and user-friendly graphics interface are underway [2]. Figure 2.6 shows an improved tIME system with the ICU_POC functionality in place. It is a step up with the ability to not only acquire data but also analyze and integrate the data with the EMR system.

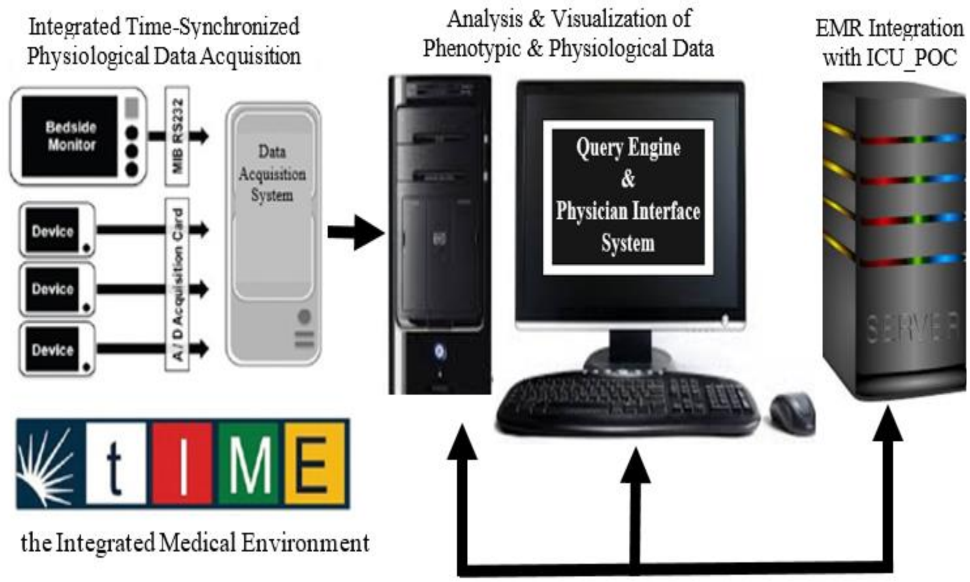

Figure 2.6 the Integrated Medical Environment - Improved.

2.7 The Telemedicine Technology (Tele-ICU)

The telemedicine technology platform employs some specific hardware and software components designed to enable remote physicians the ability to remotely monitor Intensive care patients through real-time audio/video observation.

The aim of Tele-ICU is to address the issue of scarcity of qualified critical care professionals in the United States intensive care units. In 2013, Network for Excellence in Health Innovations (NEHI) has recorded that there were 54 Tele-ICU monitoring centers in the United States. Studies from [7] implies that there is less than 1:1 ratio of ICUs to intensivists in the United States. This unavailable of qualified professionals has created the problem of increasingly high cost of care in the critical care units where cost of care appears to be relatively high compared to an ordinary hospital care [62]. Figure 2.7a show a

2011Charges and discharges with or without ICU Stay from the hospital in 29 states. It has the potential to help in reducing length of stay in the ICU by managing the available critical care resources across many institutions remotely [6, 7].

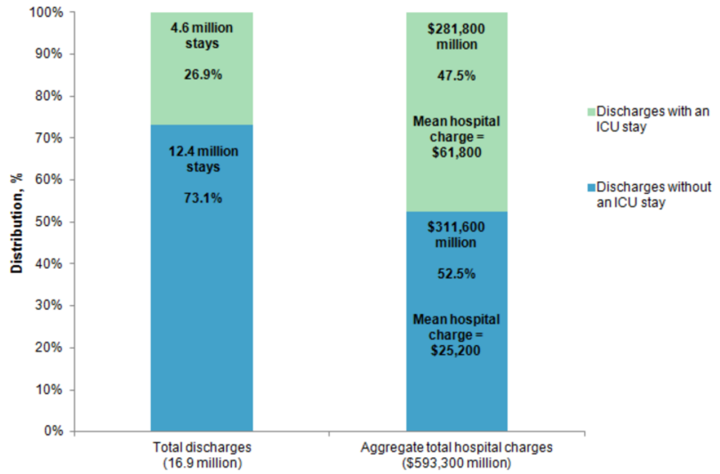

Figure 2.7a Adult hospital stays and aggregate total hospital charges by intensive care unit (ICU) use in 29 States [62]

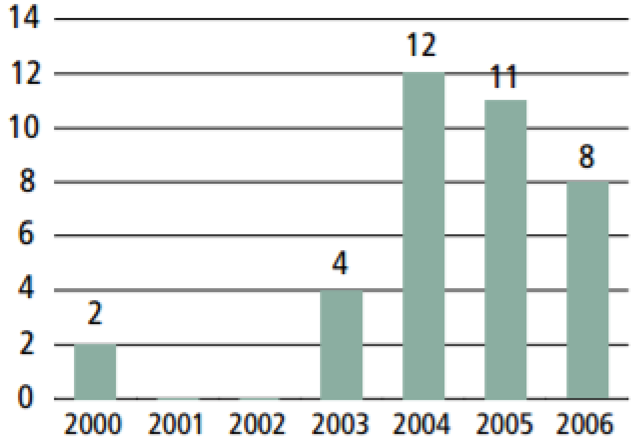

Figure 2.7b Number of Tele-ICU Command Center [63].

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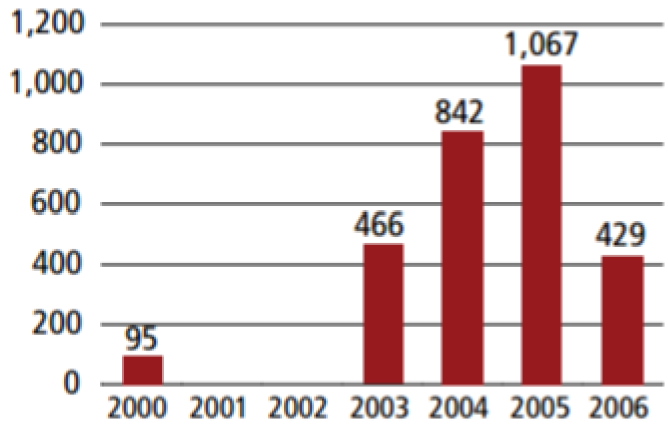

Figure 2.7c New Beds Covered Per Year [63].

Even though the Tele-ICU technology has demonstrated some positive potential of reducing cost of care as well as length of stay in the ICU, there are some barriers to the growth as seen in Figure 2.7b and 2.7c. There has been a drop in the number of new center installations as well as in the number of new ICU beds. The cost of installation ranges between, two to five million United States dollars according to [64]. Cost of maintenance of a center is also an issue and has been a serious factor in the drop of the Tele-ICU centers.

ICU-POC offers a system that will take the real-time generated data from the bedside monitor and make it available to physicians for them to do the analysis directly and make inferences / diagnosis. It also provides the integration capability with EMRs in addition to offering a uniform and standard operating environment across all users. It will aid both command center and remote intensivists to quickly make references and diagnoses of a condition. Above all there is minimal to zero cost for the maintenance as well as setting up of new ICU site for the use of this ICU_POC system.

2.8 Point of Care (POC) Application

Point of care application is a system designed to provide physicians / nurses with immediate and necessary care on the patient condition right by the patient bedside. It is the intersection between informatics and healthcare. This interaction is seen to take place during the clinical encounter [47, 48]. Point of care (POC) simply put identifies the location at which patient care was given [46]. It follows that the point of care application deals with providing timely information and data as at when needed through a specially designed system aimed at speeding up care and providing secure and quality information to enable the medical personnel make vital decisions in a timely fashion.

Technological advancement and revolution in the health care industry has provided opportunities for the growth of patient care in a positive way more than ever [24]. The employment of informatics in medicine has gone a long way to enhance the quality and speed of care in human health. “Clinical point of care helps to deliver healthcare products and services to patients at the time of care directly at the patient's bedside” [41]. It aids in providing treatment to patients right when they need it and helps in maintaining the provider’s attention since all he needed is right there on the system. There is no room for delay and distraction.

Point of care model in healthcare delivery system has numerous advantages ranging from improvements in providing data in an entirely and accurate manner to timeliness of information and reports. Inaccurate data and inconsistencies are easily observed through the system validation rules right on the spot [48]. Having electronic data in POC systems ensures that such data can be reproduced to meet documentation needs at the point of care right away. Access to individual patient records at the clinical level is very fast. The medical personnel have immediate availability of information in the system while managing the patient. It also allows prompt and efficient sharing of patient information between physicians in different locations about patient condition. The availability of electronic medical records as historical data for reference enables the clinicians to abide by the standard health management procedures that allow for a comprehensive standardization of every patient's visit [48].

Point of systems are huge catalyst behind the rapid transformations that is being experienced in the medical industry. Healthcare is continuously improving and applying such ideas that shift the traditional fee for service approach of the industry towards quality of care that is measured by certain metrics as developed by the accountable care organizations. Physicians are now being reimbursed by the insurance providers based on serious considerations (by the quality alliance team) on these quality metrics [49]. These changes are not only experienced in the general practice but also in medical laboratories [50].

Conclusively, the adoption of EMR and Point of Care systems by the medical industry will have serious positive impact in patient treatment outcome [52]. The development of the proposed ICU_POC is in line with this initiative and stands to promote the success of the anticipated positive advancement in the intensive care units and generally in the medical industry. Chapter three will help us understand some of the underlying designs that were employed in the development of ICU_POC. It will throw more light to the architectural

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design, tools, both hardware and software as well as the network technologies that were considered during the system development.

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Chapter 3.0

System Architecture and Development of ICU_POC

3.1 Introduction

The proposed point of care system was designed for use in the intensive care unit. It is also known as ICU_POC and it will be referred to as ICU_POC though out this dissertation. ICU_POC is intended to take data generated from the devices and data from the patient monitoring system, process the data using a specifically developed software to extract vital information from the data. The processed data is stored locally on a database and then analyzed and approved to be transferred to an EMR database. It involves the use systems both hardware, middleware and software such as computers, cables, network infrastructure, internet capabilities, configurations and some technical know-how to get everything together. The security of the tools and the entire system were also considered. Most importantly, data security is one of the most important consideration especially since medical information is involved.

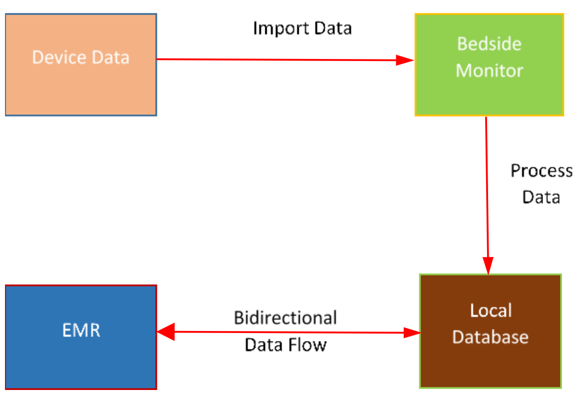

Figure 3.1 ICU_POC System Sketch

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3.2 ICU_POC Architectural Design

Architectural design is the structural setup of hardware, software, network components, sub systems and devices of some kind such that their interconnectivity follows a set of the principles guiding the development and design of the entire system. It concerns the different aspects of the entire system in terms of the front-end and back-end requirements. This chapter will look at the subsystems that make up ICU_POC and their relationship, their installation, configuration, process and implementation. It will throw light on the web design architectures, network technologies and applications as well as the development styles that gave way to this application.

3.2.1 Client-Server Architecture

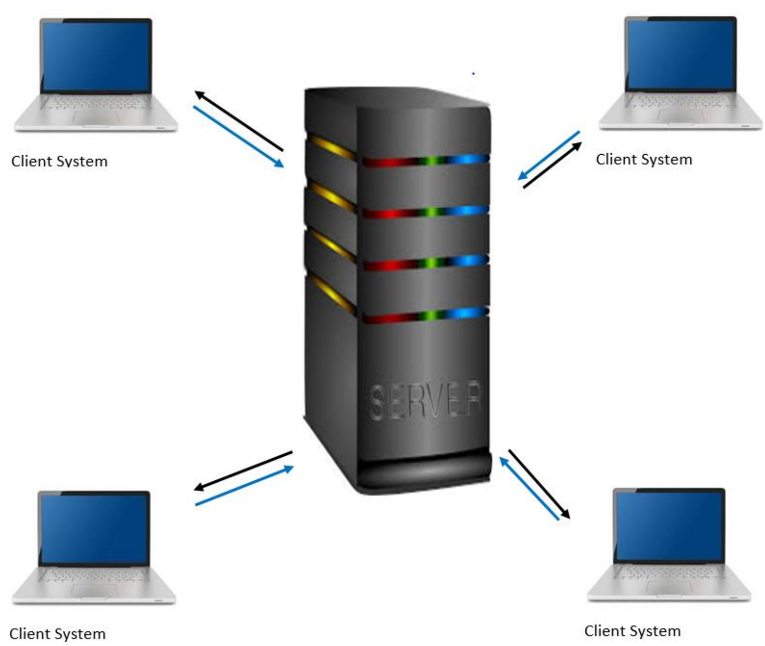

Figure: 3.2.1a Client Server Architecture

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ICU_POC is designed based on the client-server architectural model. In this type of model, the client systems are hosted in different locations away from the server system and each uniformly setup to request and receive resources from the server. It is a cost-effective model compared to a distributed system where by each system is setup as an entity of its own. It has the advantage of ease of maintenance since once the server is addressed, all other connected client machines will be updated uniformly and simultaneously. Figure 3.2.1 above gives a systematic design of the client-server model.

- **Web Platform Architecture (WPA) -** is a form of a client-server model with hardware and software infrastructures in place. It is easy to setup but once the networking and intranet issues / components of the platform comes into question, the whole system becomes a bit difficult to understand. The client -server model could also be viewed as a layered architecture with different infrastructure existing at the server level while the client layer also has its own setup. The web platform architecture is based on the following concepts.

- **TCP/IP (Transmission Control Protocol/Internet Protocol) -** is the basic communication language of the Internet as well as private networks. It is a two-layer program such that where the TCP is the higher level that is responsible for splitting up of message requests (to the network) into smaller chunks called packets. In return of the response to the request message, it also reassembles the response message packets into a full / complete message. Then the IP is responsible for the routing or addressing of the packets to the right address using the IP address and port numbers of the client machine or the server. The TCP/IP model resembles the Open Systems Interconnection (OSI) as seen in Figure 3.2.1b except that the presentation and session layers are not applicable to TCP/IP. The network layer of the OSI model is the internet layer of the other and finally, the data link and physical later becomes the network access in the TC/IP model.

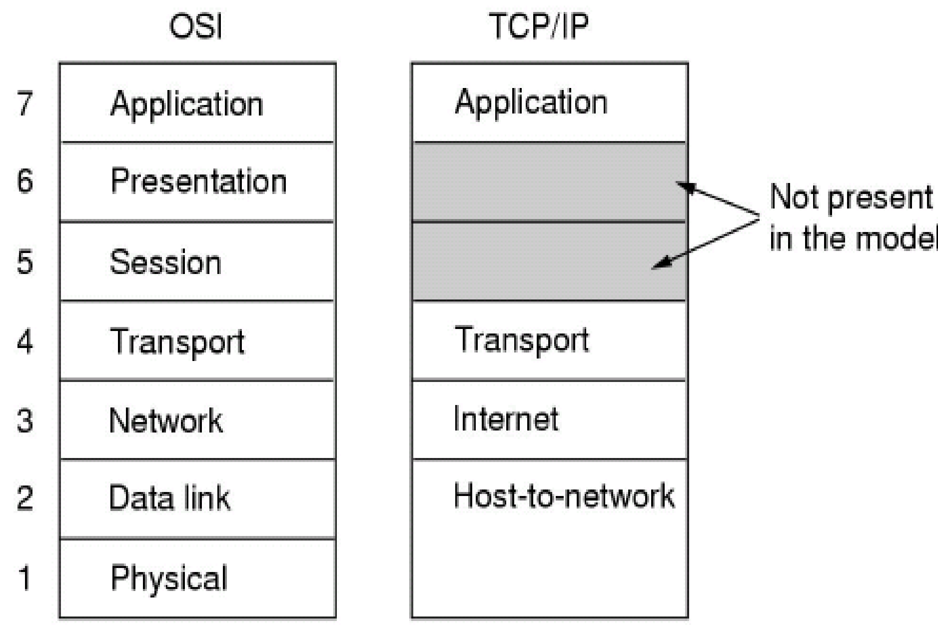

Figure 3.2.1b TCP/IP vs OSI Model [10].

Figure 3.2.1c shows how a request message is transmitted from one TCP/IP layer to the other in descending order and how the response message is received by the different layers in ascending order. The transport and internet layers manipulates the data to ensure its integrity and proper delivery across the network layer. The application layer is where the request and response messages are originated. The protocol at the application layer is the HTTP and will be discussed next.

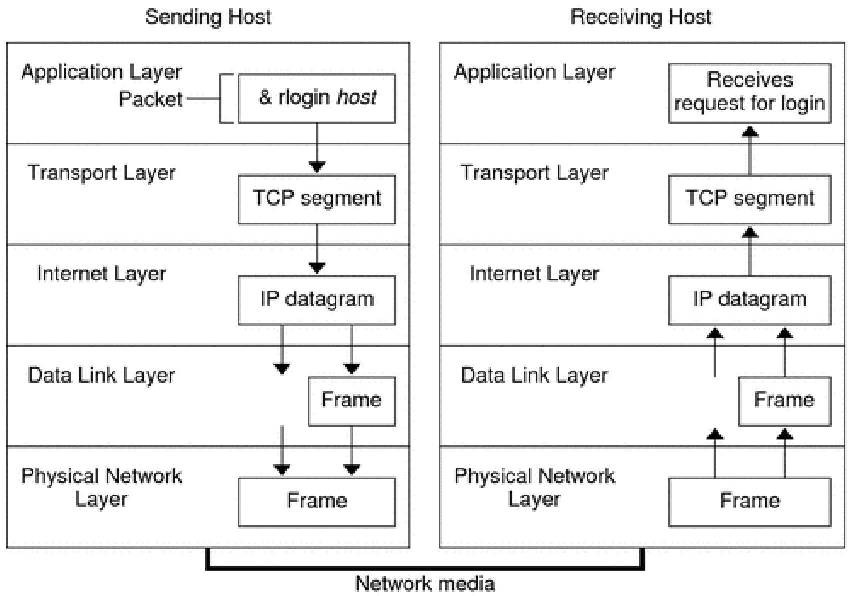

Figure 3.2.1c Message transmission over TCP/IP Model [9].

- **HTTP (Hypertext Transfer Protocol)** – is the basic element of every website Uniform Resource Locator (URL) which tells the internet where to get the requested information. HTTP is an application layer protocol that accounts for data transmission and communication over the World Wide Web (www) and so much depends on the reliable lower layer – the transport layer. It drives the transmission of hypertext which are structured texts that hyperlinks between nodes in containing text. On the event that the request made to the www has some issue, a response message is always sent back to the sender in the form of a status code. A list of some common http status code can be seen in Table 3.2.1.

Status Code	Reason Phrase	Description
100	Continue	Client should continue sending its request. This is a special status code; see below for details.
101	Switching Protocols	The client has used the *Upgrade* header to request the use of an alternative protocol and the server has agreed.
200	OK	Generic successful request message response. This is the code sent most often when a request is filled normally.
201	Created	The request was successful and resulted in a resource being created. This would be a typical response to a *PUT* method.
202	Accepted	The request was accepted by the server but has not yet been processed. This is an intentionally "non-committal" response that does not tell the client whether or not the request will be carried out; the client determines the eventual disposition of the request in some unspecified way. It is used only in special circumstances.
301	Moved Permanently	The resource requested has been moved to a new URL permanently. Any future requests for this resource should use the new URL.
400	Bad Request	Server says, "huh?" J Generic response when the request cannot be understood or carried out due to a problem on the client's end.
401	Unauthorized	The client is not authorized to access the resource. Often returned if an attempt is made to access a resource protected by a password or some other means without the appropriate credentials.
402	Payment Required	This is reserved for future use. Its mere presence in the HTTP standard has caused a lot of people to scratch their chins and go "hmm…" J
403	Forbidden	The request has been disallowed by the server. This is a generic "no way" response that is not related to authorization. For example, if the maintainer of Web site blocks access to it from a particular client, any requests from that client will result in a 403 reply.
404	Not Found	The most common HTTP error message, returned when the server cannot locate the requested resource. Usually occurs due to either the server having moved/removed the resource, or the client giving an invalid URL (misspellings being the most common cause.)
500	Internal Server Error	Generic error message indicating that the request could not be fulfilled due to a server problem.
501	Not Implemented	The server does not know how to carry out the request, so it cannot satisfy it.
502	Bad Gateway	The server, while acting as a gateway or proxy, received an invalid response from another server it tried to access on the client's behalf.
503	Service Unavailable	The server is temporarily unable to fulfill the request for internal reasons. This is often returned when a server is overloaded or down for maintenance.
504	Gateway Timeout	The server, while acting as a gateway or proxy, timed out while waiting for a response from another server it tried to access on the client's behalf.

Table 3.2.1 Common HTTP Status Code [77].

- **HTML (Hypertext Markup Language)** – the set of codes and symbols called markup or element that tells the web browser how to present the information / data for the user. Each HTML element has an open and close tags indicating the beginning and end of the element.

- **Server Applications** - the server is responsible for the control, management and maintenance from the time the user logs into the system till the user logs out.

The server is also responsible for granting user access to the system. The server processed data requests in a centralized location thereby removing data dependencies that there could arise in a distributed environment.

- **Client Applications –** the client is concerned with creating an environment for the user to be able to request and receive information in the desired format. It forwards the user's request to the right server for processing and response. The client provides data and information to all users in a uniform and consistent manner.

- **Client-Server Benefits –** the client-side model offers a centralized storage of data and reduces operating cost as well as setup / installation cost. Update to the entire system involves only one single point change and all systems are affected. There is separation of responsibilities such that the client knows nothing about what the server does to get the requested information. They both communicate through specific standard interfaces. The Apache Community spawned PHP which is as good as JSP and ASP, but Open Source. Developers can generate their code using any choice scripting software and launch directly to the website pages using some markup languages. It works very well with HTML and the web servers process the codes directly.

3.2.2 **Web Service (WS) Security**

WS security specification, ratified by the Advancing Open Standards for Information Society (OASIS) has stated the need to encrypt messages on end to end especially messages that are traversing across many intermediaries. It is seen that messages lose the cryptographic protection once they traverse an intermediate server. Figure 3.2.2 show the design the Transport Layer Security (TSL) and Message Layer Security models. In transport layer model, the messages get vulnerable to attack once they pass through the server. The message layer security model allows for flexibility where messages can be updated at any intermediate point. This creates an opportunity to transfer messages across any protocol not minding the protocol security. ICU_POC, built on PHP is good since PHP has full implementation of WS-Security with Apache web services [72, 73, 74].

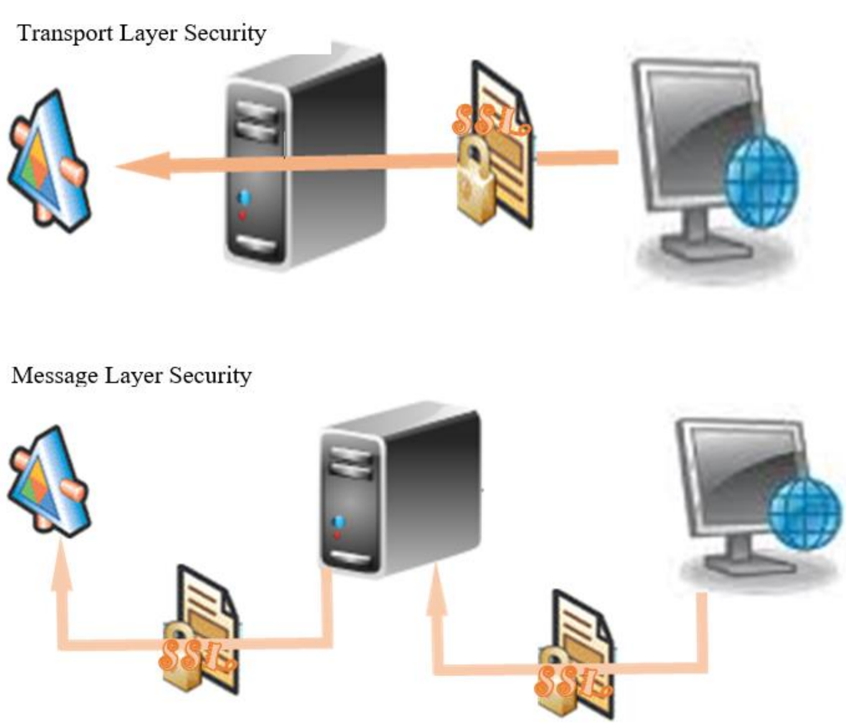

Figure 3.2.2 Web Service Security Architecture

3.3 Design Specification

In ICU_POC system design, numerous requirements were considered ranging from hardware requirements, as software requirements cost of tools to ease of implementation. The hardware requirements are the tools, machinery and other durable equipment that will be used. On the other hand, the software requirements were the programs, both the developed on the course of this work as well as the off the shell, open source programs and the operating information used by the computer to get this work done.

Figure 3.3 shows the layering of this project work and the different components making up the server as well as the client layers. One of the main benefit of layering is that of separation of responsibilities between the two layers such that there is room for easy management of issues across the entire system.

- Web server
- Application server
- Database
- Legacy systems
- Web services

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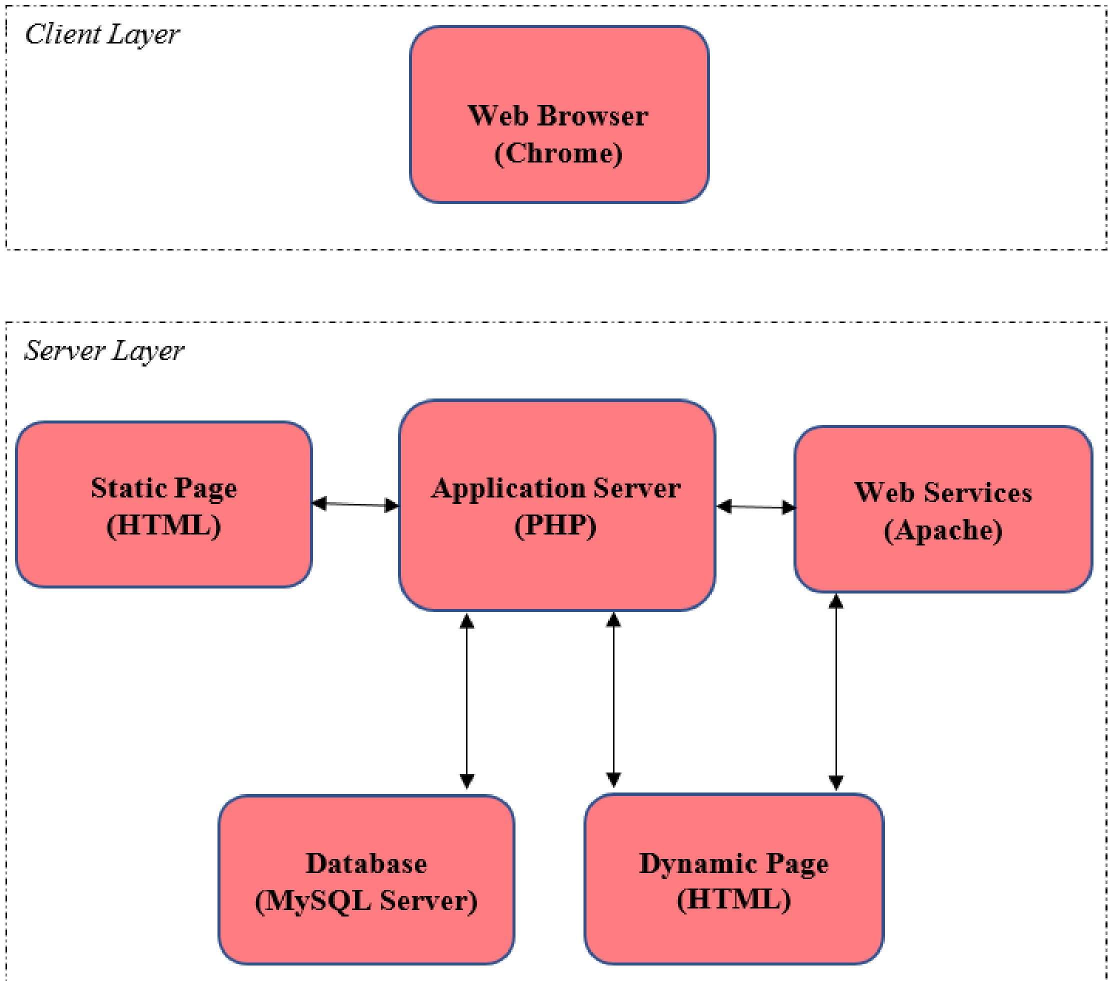

Figure 3.3 Client-Server Layers

3.3.1 Hardware Requirement

The most important tools needed in this project is a computer. A computer to be used for web design with large hard disk and random-access memory (RAM), high processing speed and large storage capacity to aid in processing and analyzing the image and binary files.

- A standard Windows 7 (and above) personal computer with large memory and data space is needed to be connected to the Phillips IntelliVue MP70 Patient Bedside Monitor for data acquisition.
- A Microsoft Windows 10 Home Edition Laptop was used with the following specification was used to the program development and analysis.
    - Minimum of 1 TB Hard Disk space required for data storage.
    - 64 Bit Windows Operating System
    - 16.0 GB RAM (15.8 GB usable)
    - Intel (R) Core (TM) i7-6500U CPU @ 2.5GHz
    - Intel (R) Dual Band Wireless-AC 3165
    - RJ45 LAN Network adapter
- 3mm Network cable to connect the computer to the RJ45 adapter.
- Database Server with Terabytes of storage space to house the image and data files.
- Phillips IntelliVue MP70 Patient Bedside Monitoring System

3.3.2 Software Requirement (PHP)

The website for this project was developed locally using the following web development tools. Cost and ease of implementation were the main consideration in the choice of most of the software.

➢ PHP Hypertext Preprocessor (PHP) 7.0.4 Scripting Software

PHP is scripting software and an open source server side development tool entirely developed by a community of volunteers. One does not need to obtain a license to use this product and there is not special hardware requirement cost for setup. Additionally, all the associated tools for running PHP (for example, HTML, MySQL) are all open sourced as well. It is freely available and appears to be one of the world's popular programming language for web design. It is a very powerful tool and the developer's choice for data driven web application design. It is the answer when one is designing dynamic websites and is in use in over twenty million web sites and more than a third of the world's website. [68].

PHP is beneficial due to its ease of use and scalability with high compatibility for varying data formats and database platforms. At the time of system analysis, I had considered many development tools, example JAVA, C, ASP.NET, Perl, to mention but a few. Even though, some of those were server side scripting tools, PHP stood clear amongst its alternatives considering its high compatibility for varying data formats and platforms. It runs on MS Windows, UNIX and MAC operating systems. It is also portable in the sense that you can move a completed web development project from one operating platform to another and run it seamlessly. This is a vital consideration especially for an application that has the potential of running across multi-platform environment.

PHP is easy to learn. It has installation / setup tools readily and freely available with guides. I did not learn PHP but just saw myself developing codes with PHP. A novice can use this as well as experts in the field due to numerous, straight and quality documentations. “Simplicity is the ultimate sophistication”, Said Leonardo da Vinci. It is a very simple, dynamic, reliable and sophisticated software with consistent and human readable syntaxes [68].

- **Apache Web Server** – Is the tool responsible for the for the web hosting. It provides the opportunity of hosting the web server locally on the personal computer other that incurring the cost of buying a domain and paying for the hosting fees. Another alternative would be to Install and configure Internet Information Service (IIS).

- **MySQL 5.7.11** – This is a relational Database Management System (DBMS) that hosts the data both locally and on the OpenEMR system. It works very well with PHP in web design and both always go together in the selection of web development tools.

- **Dreamweaver or Sublime Test 3 Editor** - Dream weaver is a web development tool that has an array of site management tools and help users design, code and manage websites as well as mobile content. It is positioned as a versatile web design tool and provides the opportunity to visualize the look and feel of the site as once develops the site.

- **Hypertext Markup Language (HTML 5) -** is the set of symbols or codes inserted in a file intended for display on a World Wide Web browser page. It is a web design tool also which is responsible for creating and beautifying web pages. They were used in this work to display the server side data processed by PHP to the browser. Special technique was also employed in this work using HTML5 to design the pages in such a way that they are platform compliant. **Cascading Stylesheet (CSS)** – This is a Web page got from different sources that define how pages are displayed and what goes where and how they look on a website [72]. CSS are used to define where the navigation bar goes, where the headers go, dashboards and the likes on a web page. Without CSS, most pages will be unreadable as all information will be clumsy and disorganized. CSS is the web page organizer.

- **JavaScript and jQuery** – These tools were employed in this project to add some animation, responsiveness and visualization effects on the web pages.

- **WAMP** – which stands for Windows, Apache MySQL, and PHP is a single package installation containing Apache web server, MySQL database server, PHP scripting tool in its single install. It is an express way to get PHP setup as an alternative to installing and configuring each of those tools individually.

3.4 ICU_POC Web Design

This software development project has been designed using PHP as the base development tool. It was the choice based on the various reasons and benefits as enumerated in section 3.3.2 earlier. The design also considered a lot of security issues especially being that medical data / information is involved. The application programs have been created in such a way that the security control checks who is able to log onto the application. Session cookies were employed to track administrators who log into the system. No one has access to any data or information unless they are authorized and have logged into the system. There is system log maintained on the local database as well.

HTML5 and CSS3 were used for designing the web pages. HTML5 created the pages and while CSS3 defined the rules of how the pages would appear. The pages are built with fluid layout technique. This ensures that the site will be observable with different operating system / platform including mobile device. The pages get adjusted automatically according to the device one is using to view them. ICU_POC is designed with much responsiveness and animation. JavaScript and jQuery were responsible for this responsiveness. These are the power behind the visualization of the phenotypic and physiological charts generated in this work. JavaScript was utilized in plotting the chats. Figure 3.4 shows the web layout of the ICU_POC. It shows the main system hosting the PHP application server, the local MySQL database as well as the Apache web server in one box. This connects to the web browser through a secure Hypertext Transfer Protocol (HTTPS) for data request / communication.

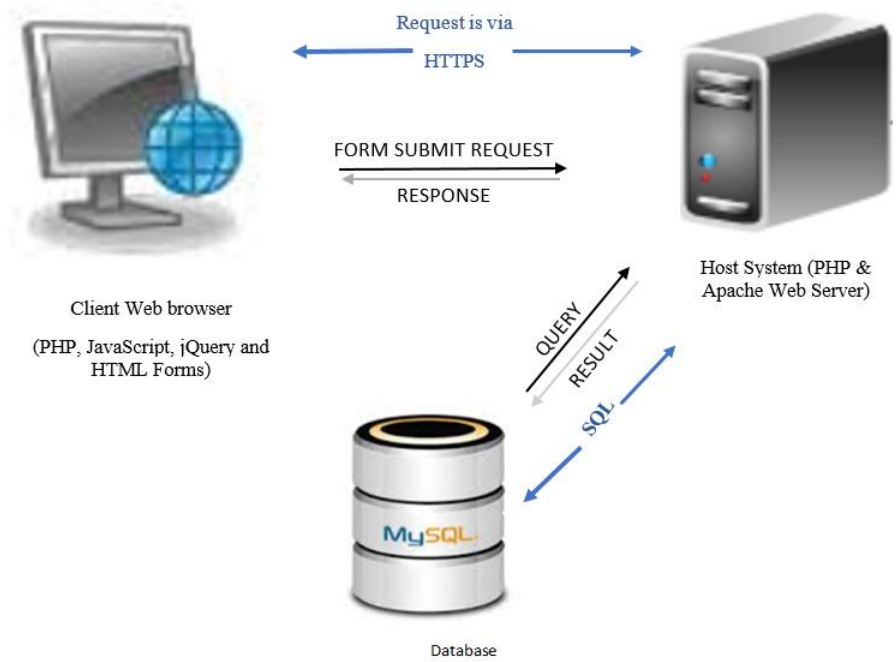

Figure: 3.4 PHP Web Application Architecture

3.4.1 ICU_POC Security Features

As earlier mentioned in section 3.2.2, security of this system was considered seriously an issue and as such all systems should have a secure connection to the application. Physical security to the system was ensured. Windows Endpoint Antivirus protection was also constantly scanned and applied to ensure there was no issues during the process of development. ICU_POC was tested with a website that is securely hosted by Bluehost and having a dedicated IP address. With the IP address, users can connect to the application and using the appropriate URL details. This is as against using shared IP address and saving the system from potential vulnerability. The site was also provided with a Secure Sockets Layer (SSL) which help to ensure there is standard security technology as data is being transferred from one system to the other. It allows the application to enjoy an encrypted link between systems as data is being shared from the web server and a browser. Fig 3.4.1 *[taken from my PHP class notes]*, describes how data is moving from one end to the other and being encrypted and decrypted as needed.

Another level of security measure in place was to use PHP echo statement to create the HTML forms in this project. This grants PHP the ability to check the session cookies on all the pages. The pages have also been designed to pass variables to other pages using HTML Post methods in most cases as against GET method which is prone to some security flaws.

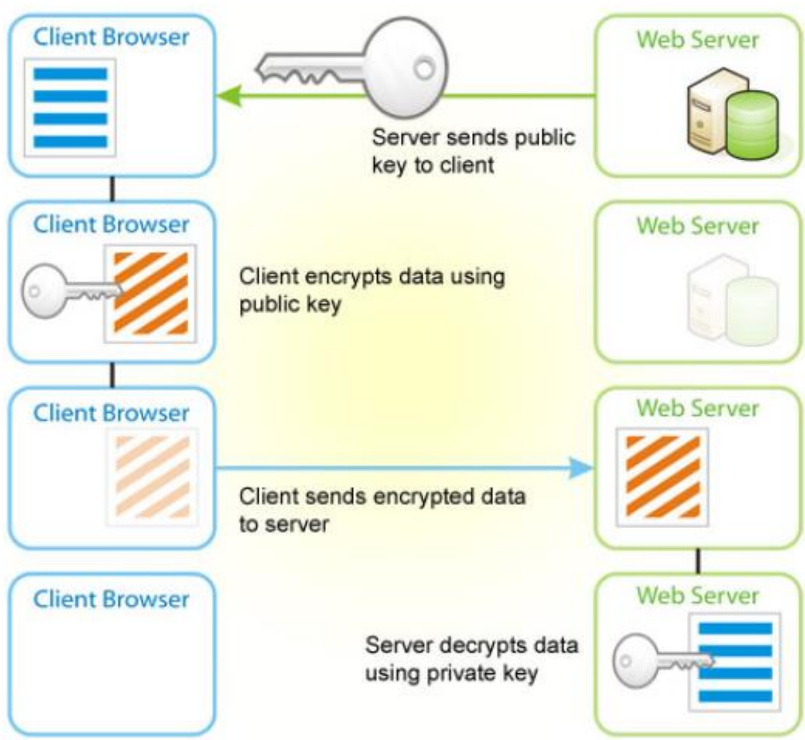

Figure 3.4.1 Encryption Key Exchange

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3.4.2 ICU_POC Database Structure

As earlier stated, the database used in ICU_POC application is MySQL version 5.7.11. MySQL supports various storage engines but the storage engine used in this project is MyISAM. It tells MySQL how the tables and data should be stored and handled. It is fast compared to the alternative storage engine called InnoDB and which is the default selected by MySQL. Even though the later supports lots of advanced features like many commercial database servers, MyISAM was selected due to its fast processing time and especially since the databases on this work did not require advanced features such as transactions or foreign key data constraints.

Fig 3.4.2a and Figure 3.4.2b below show the storage engine and the collation options used on the database. The collation type of utf8_unicode_ci was selected to take care of possible special characters that might be used in the site especially dealing with the binary files. Then the *ci* in it makes data objects case insensitive.

Id	Patient_ID	Date_Time	SAT_O2	PLETH_RATE	OXIM_REL	BEAT_RATE	RESP_RATE	ECG_CNT	ART_MEAN	ART_SYS	ART_DIA	PULS_RATE	NONINV_SYS	NONINV_DIA	NONINV_MEAN	NONINV_RATE	User	Date_Approved
12262	12345678	6-13-2017 17:00:00	95	60	10	60	15	0	91	120	70	60	8388607	8388607	8388607	0	EMR	2017-06-14 06:47:49
8173	12345678	8-31-2016 17:00:00	97	72	2	74	23	0	87	95	83	66	159	67	91	71	EMR	2017-04-30 13:52:01
8174	12345678	8-31-2016 22:00:00	97	73	2	74	24	0	56	61	53	43	159	68	91	70	EMR	2017-04-30 13:52:02
8175	12345678	8-31-2016 23:00:00	97	73	2	74	25	0	36	39	34	28	155	69	92	71	EMR	2017-04-30 13:52:03
8315	12345678	8-31-2016 1:00:00	97	54	2	54	20	0	101	134	83	54	168	80	104	49	EMR	2017-06-10 03:51:35
8318	12345678	8-31-2016 4:00:00	97	52	3	52	18	0	96	128	78	52	154	72	95	49	EMR	2017-06-10 03:51:37

Figure 3.4.2a ICU_POC Records in the Approval Table

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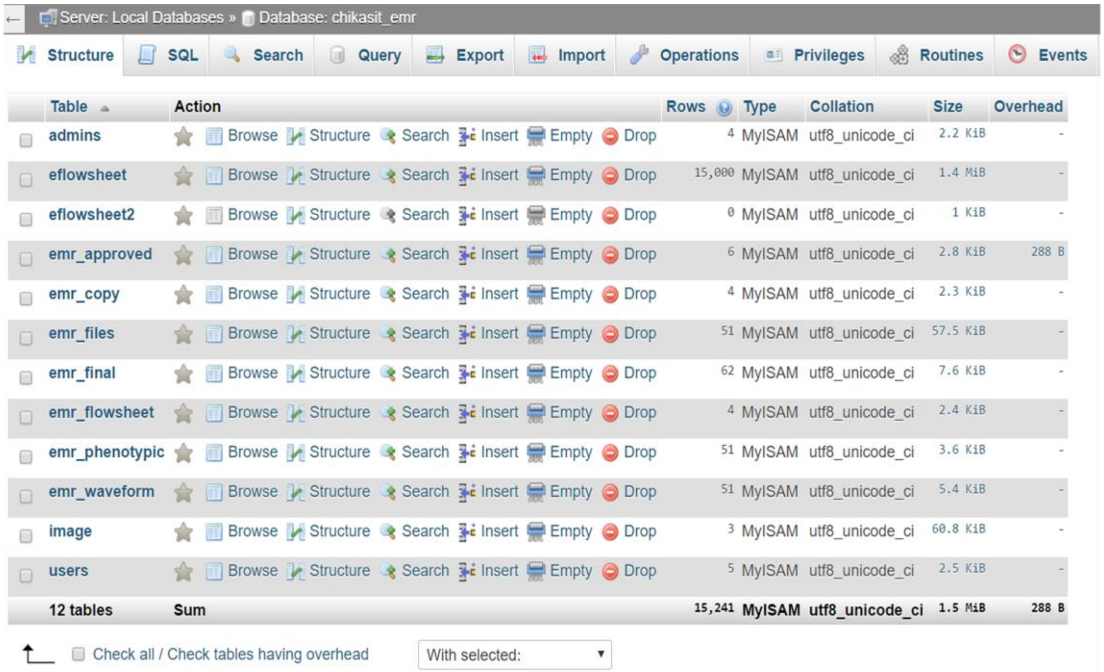

Table	Action	Rows	Type	Collation	Size	Overhead
admins	Browse Structure Search Insert Empty Drop	4	MyISAM	utf8_unicode_ci	2.2 KiB	-
eflowsheet	Browse Structure Search Insert Empty Drop	15,000	MyISAM	utf8_unicode_ci	1.4 MiB	-
eflowsheet2	Browse Structure Search Insert Empty Drop	0	MyISAM	utf8_unicode_ci	1 KiB	-
emr_approved	Browse Structure Search Insert Empty Drop	6	MyISAM	utf8_unicode_ci	2.8 KiB	288 B
emr_copy	Browse Structure Search Insert Empty Drop	4	MyISAM	utf8_unicode_ci	2.3 KiB	-
emr_files	Browse Structure Search Insert Empty Drop	51	MyISAM	utf8_unicode_ci	57.5 KiB	-
emr_final	Browse Structure Search Insert Empty Drop	62	MyISAM	utf8_unicode_ci	7.6 KiB	-
emr_flowsheet	Browse Structure Search Insert Empty Drop	4	MyISAM	utf8_unicode_ci	2.4 KiB	-
emr_phenotypic	Browse Structure Search Insert Empty Drop	51	MyISAM	utf8_unicode_ci	3.6 KiB	-
emr_waveform	Browse Structure Search Insert Empty Drop	51	MyISAM	utf8_unicode_ci	5.4 KiB	-
image	Browse Structure Search Insert Empty Drop	3	MyISAM	utf8_unicode_ci	60.8 KiB	-
users	Browse Structure Search Insert Empty Drop	5	MyISAM	utf8_unicode_ci	2.5 KiB	-
12 tables	Sum	15,241	MyISAM	utf8_unicode_ci	1.5 MiB	288 B

Figure 3.4.2b ICU_POC Database Structure

Looking at the individual tables it is seen that data gets stored locally on the local database initially on the *eflowsheet table* from where it is processed and aggregated into hourly data and tenporarily stored on the *EMR_Flowsheet*, waiting for approval. On approval, it is then moved to the *EMR_Approved* table. Once an approval is given, data gets transferred from ICU_POC application local database to the *EMR_Final* table inside OpenEMR database. It is from the *EMR_Final* table that the query engine fetches the result. It keeps the records as log as they are needed or archived. Other tables that is obtainable in the OpenEMR database is the Admins and User tables. This helps to ensure that only authosized users can gain access to the data. Additionally, the two tables used in storing the parsed files are also located in the OpenEMR database. The *EMR_*Phenotypic is for storing phenotypic data files. Upon query, if data related to any of these files were fetched, the files will also be accessible such that charts can be reproduced fresh upon request. The same is also applicable to the EMR_Waveform table. It holds the physiologial waveform binary data. The table structures are shown in Figure 3.4.2c.

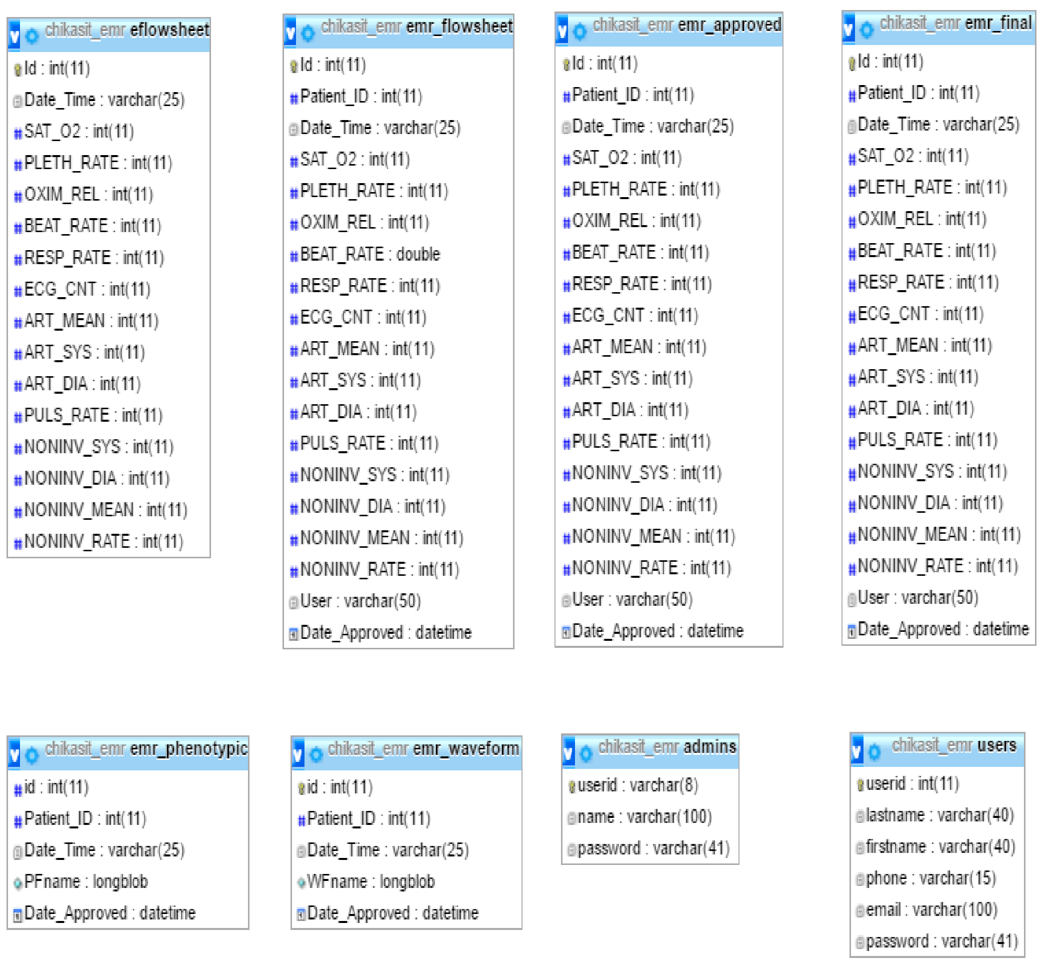

Figure 3.4.2c ICU_POC Database Table Structures

3.5 Data Generation from the Monitor

The generation of raw numerical and physiological data is not within the scope of this project. However, is good to mention that the data used to perform the analysis in this work were generated from the patient directly using Philips IntelliVue MP70 bedside patient monitor. In [71], data acquisition module was used to acquire real-time physiological data from the patient monitor using serial communications and saved the extracted data into the hard disk of a local computer. Then a parsing program is used to parse the data files and rename them in a specified format as detailed in Table 3.5.1 below. The processing module of the ICU_POC is then able to read data directly from the extracted files as data is being streamed from the monitor. Once the system automatically generates and saves data files in the hard drive, the files can be accessed by any data analysis tool.

The proposed system can access the generated data files at this point by browsing to the computer on which these data are hosted either directly or remotely through a file transfer protocol (FTP). Figure 3.5 has a picture of an MP70 Monitoring System as it is being configured and connected to a local system to data acquisition. One can see the waveforms as displayed on the screen. As soon as data has been generated, they can be analyzed and visualized right away with the ICU_POC system.

In this project work, 14 channels of data were generated from the monitor, imported, processed, analyzed and visualized. The following table 3.5 has a list of the phenotypic and physiological channels that were observed.

`

Figure 3.5 Simulation / Setup of the Philips IntelliVue MP70 Monitoring System

S/N	Channel	Meaning
1	NOM PULS OXIM SAT O2	Pulse Oximetry Oxygen Saturated
2	NOM_PLETH_PULS_RATE	Pulse Oximeter Plethysmograph
3	NOM_PULS_OXIM_PERF_REL	Pulse Oximetry Relative Perfusion
4	NOM PRESS BLD NONINV SYS	Non-Invasive Systolic Blood Pressure
5	NOM_PRESS_BLD_NONINV_DIA	Non-Invasive Diastolic Blood Pressure
6	NOM_PRESS_BLD_NONINV_MEAN	Non-Invasive Mean Blood Pressure
7	NOM PRESS BLD NONINV PULS RATE	Non-Invasive Pulse Rate
8	NOM ECG CARD BEAT RATE	Electrocardiogram Heart Beat Rate
9	NOM_RESP_RATE	Respiratory Rate
10	NOM_ECG_V_P_C_CNT	Electrocardiogram
11	NOM PRESS BLD ART MEAN	Non-Invasive Mean Arterial Blood Pressure
12	NOM PRESS BLD ART SYS	Non-Invasive Systolic Arterial Blood Pressure
13	NOM PRESS BLD ART DIA	Non-Invasive Diastolic Arterial Blood Pressure
14	NOM PULS RATE	Pulse Rate

Table 3.5 List of the physiological channels Analyzed in ICU_POC

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3.5.1 Parsed Data File Naming

The numeric parsed data is named in the form of "***UH34nsu16MP70T16_numerics_20160831_000000.csv"*** and the physiological waveform data named in the format "***UH34nsu16MP70T16_ECG_I_20160831_000000.txt***". The comma separated file named ***UH34nsu16MP70T16_numerics_20160831_000000.csv*** refers to a numerical or phenotypic file generated on August 31, 2016 starting at time 00:00:00 while file named UH34nsu16MP70T16***_ECG_I_20160831_000000.txt*** is a binary file of an example ECG physiological waveform data generated on August 31, 2016 starting at time 00:00:00. The file naming structure is shown in Table 3.5.1.

S/N	Symbols	Details
1	UH	Hospital Name
2	34	Clinical Department
3	Nsu	Area of the Hospital
4	16	Room Number
5	MP70	Monitor Model
6	T16	PatientID
7	Numerics	Signal Type
8	Wave	Signal Type
9	Alarm	Signal Type

Table. 3.5.1 Parsed Data File Naming Details.

s

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3.5.2 Parsed Data File Content

The parsed phenotypic numerical data has some vital information as interpreted in [71]. It has the Absolute Time Stamp which defines a time tag for the current numeric value in the IntelliVue monitor. The value is in the format "*YYYYMMDD HHmmss*". It also has the physio_id field that tells the physiological measurement in question as well as the unit_code field for the measuring unit. A bit field is used to tell the validity of the measurement and structured by the IntelliVue monitor. Lastly is the signal observed value which is a floating-point number. These phenotypic numerical and physiological waveform data files are then imported into ICU_POC for processing and analysis. See Figure 3.5.2a and 3.5.2b for samples.

Figure 3.5.2a *Sample Parsed Physiological Waveform Binary File.*

```
8/31/2016 0 :0 :0 :0     ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,100.00,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,53.00,| ,NOM_PULS_OXIM_PEF
8/31/2016 0 :0 :1 :24    ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,100.00,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,52.00,| ,NOM_PULS_OXIM_PEF
8/31/2016 0 :0 :2 :48    ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.90,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,51.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :3 :72    ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.80,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,51.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :4 :96    ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.90,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,51.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :5 :120   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.80,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,51.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :6 :144   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,52.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :7 :168   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.50,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,52.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :8 :192   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.40,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,52.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :9 :216   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.20,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,53.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :10:240   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.10,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,54.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :11:264   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.20,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,55.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :12:288   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.40,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,55.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :13:312   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,56.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :14:336   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.90,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,57.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :15:360   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,100.00,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,57.00,| ,NOM_PULS_OXIM_PEF
8/31/2016 0 :0 :16:384   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,100.00,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,56.00,| ,NOM_PULS_OXIM_PEF
8/31/2016 0 :0 :17:408   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,100.00,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,56.00,| ,NOM_PULS_OXIM_PEF
8/31/2016 0 :0 :18:432   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,100.00,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,55.00,| ,NOM_PULS_OXIM_PEF
8/31/2016 0 :0 :19:456   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,100.00,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,54.00,| ,NOM_PULS_OXIM_PEF
8/31/2016 0 :0 :20:480   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.90,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,53.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :21:504   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,53.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :22:528   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,54.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :23:552   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,54.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :24:576   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,55.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :25:600   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,57.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :26:624   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.70,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,57.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :27:648   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.60,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,57.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :28:672   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.60,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,57.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :29:696   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.60,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,56.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :30:720   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.50,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,55.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :31:744   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.50,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,54.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :32:768   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.50,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,53.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :33:792   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.40,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,52.00,| ,NOM_PULS_OXIM_PERF
8/31/2016 0 :0 :34:816   ,| ,NOM_PULS_OXIM_SAT_O2,ERROR,99.40,| ,NOM_PLETH_PULS_RATE,MSMT_STATE_AL_INHIBITED,52.00,| ,NOM_PULS_OXIM_PERF
```


Figure3.5.2b Sample of Parsed Phenotypic numerical comma separated file.

3.6 Modules and Functions

This project is sectioned into five basic modules for easy management. Each of the module has a specific function but still relates to other modules by either providing data for their processes or taking input from those. There is a symbiosis relationship across the different modules. There is also a connectivity to the OpenEMR system which was used as a test case to test our transfer to and from EMR. Figure 3.6 has a highlight of the modules in the ICU_POC system.

- The Bedside Monitor
- The eFlowsheet Unit
- The Phenotypic Data Processing Unit
- The Physiological Data Processing Unit
- The OpenEMR Interface with Query Engine

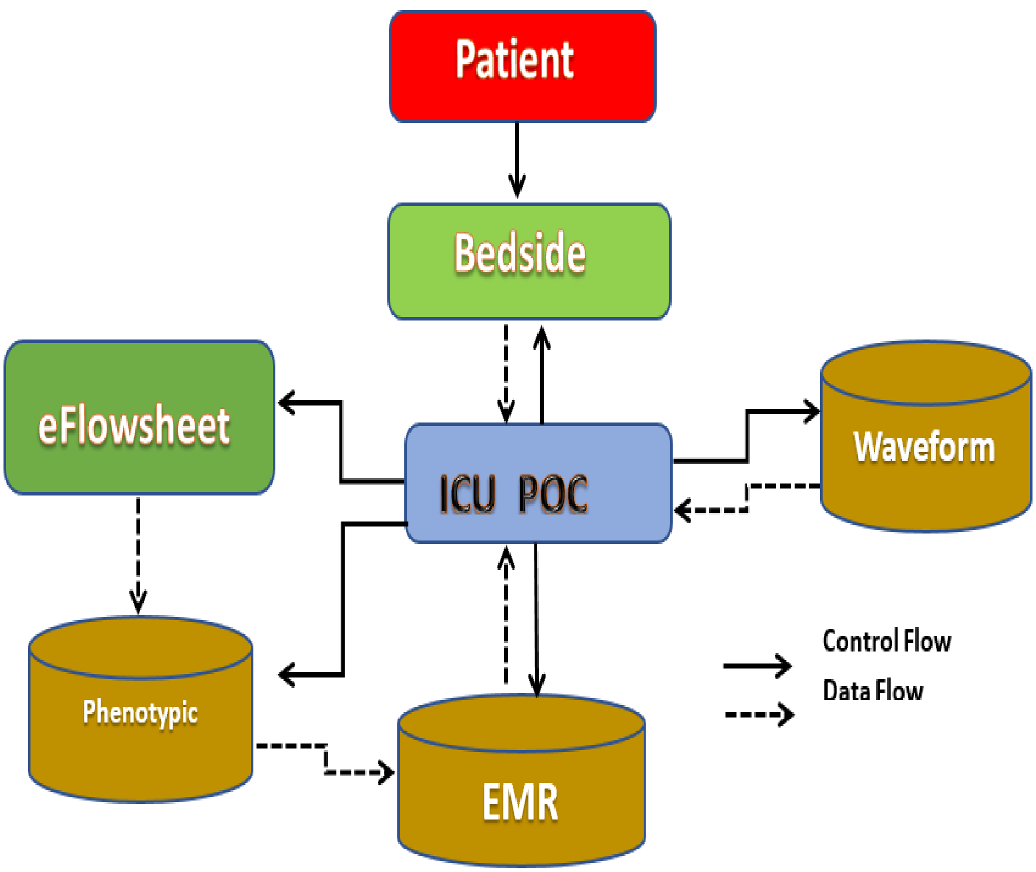

Figure 3.6 ICU_POC System Overview

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3.6.1 The Bedside Monitor

This is the initial computer that is responsible for capturing patient's information on arrival to the hospital ICU. It then goes along to display a high-level overview of the information pulled up from the patient's record if already existing in the hospital system. This computer has the IntelliVue Monitor attached to it. It also hosts the phenotypic numerical and physiological waveform data that were generated off the monitor. This system processes the raw devices data into the parsed format and saves them in a folder on the hard disk. This computer system is directly connected to the ICU_POC interface and provides the interface with raw data for processing and analysis.

These parsed phenotypic numerical data are then imported into the ICU_POC interface for extraction into a more formatted tab-delimited text file. These text files are then ready for processing and transforming into granulated epochs of data. From there, the granulated data files are further processed into hourly data records for analysis and visualization by the physicians.

In short, this module maintains the ICU_POC local database. It processes raw data from the Bedside, analyzes and transfers the approved records to the EMR. It has the feature that queries EMR database for patient data, fetches data and processes the visualization and comparison of the phenotypic and waveform data set.

3.6.2 Process Data

This module is responsible for transforming the parsed data from the Bedside Monitor and processing them by removing invalid data and representing the in such a way that it will be easier to analyze. It takes the epochs of data and reformats then in a tab delimited text file. These individual epochs of data are displayed for visualizing and approval. After that, the data is further processed and aggregated in an hourly basis. The hourly display records, which are averages of the individual epochs, can be further drilled down to see the individual data that made it up. At this point the data is ready to be visualized in tabular form as well as in the chart by the physician. He will then approve or argue if he is not in agreement. There is the option to approve one record or approve all record in the processed file. These hourly data can be further viewed to compare the phenotypic and the waveforms. Once the physician agrees, the records are approved. Approved data gets moved to the approval table. Then a second person goes in to verify the records and transfer to the EMR if all looks great. It is responsible for displaying the granulated patient data, aggregated hourly data and provides approval and transfer pages to the physician.

3.7 Numerical Phenotypic Data

This is the local database that hosts the phenotypic data generated from the Bedside Monitor. It links to the Hospital EMR database which in this case we are representing with the OpenEMR. The phenotypic and physiological waveform database has a relationship with which one can use to pull both data files for visualization and comparison.

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3.7.1 **eFlowsheet**

The parsed raw data from the monitor comes in a format that it will be difficult to take the data and do analysis. Therefore, the first step in processing patient data is to represent these data in a clean format removing invalid data sets and device generated erroneous data. This process also takes care of those devices that were not connected at the point of data acquisition and removes such invalid records. Once the bad data has been removed from the parsed data file, the output is loaded into a temp file from where the data are matched up with the necessary channels. Then the final output data is loaded into a text file ready for analysis and possible upload to the local database.

The text files are named according to the original parsed data still bearing the patient and hospital information with which the analysis will be called. For example, an output text file from *UH34nsu16MP70T16_numerics_20160831_000000.csv* will be named *eFlowSheet-UH34nsu16MP70T16_numerics_20160831_000000.csv*. Note that in some cases the parsed file will be very large and processing time will be very large. ICU_POC system is made intelligent enough to identify such large files by checking it against a certain threshold and once it exceeds, the output file is splited into number of files of the same naming conventions but appending a serial number to subsequent text files. For instance:

$rawCnt = count($nlines) // this counts the individual epochs in a parsed data file;

$max = 10000; // the threshold is set to a number;

$i = round($rawCnt/$max); // This divides the number of records by the threshold. $i then becomes the number of files that will be generated to the given file.

eFlowSheet-UH34nsu16MP70T16_numerics_20160831_000000.csv

eFlowSheet1-UH34nsu16MP70T16_numerics_20160831_000000.csv

eFlowSheet2-UH34nsu16MP70T16_numerics_20160831_000000.csv

Certain parameters are unique to each flowsheet and those are used to access each generated record from the text file unto the EMR database. These parameters are also used to generate the phenotypic visualization charts:

- Date of the epoch (8/31/2016)
- Start time (hour) of the epochs (0:0:0:0)
- End time (hour) of the epochs (0:0:0:0)
- Patient ID (XXXXXXX7) number
- The processed file name (*eFlowSheet-UH34nsu16MP70T16_numerics_20160831_000000.csv*)
- The channel values
- The number of epochs in the hourly record.

The processed granulated data are further processed into hourly records by generating the averages as shown in Figures 3.7.1a and 3.7.1b. The individual data epochs are looped through and all taken into consideration to produce the hourly data.

sum2 = 0; $sum3 = 0;

$sum2 = $sum2+$data[2]; $sum3 = $sum3+$data[3];

$Hourly2 = $sum2/$cnt; $Hourly3 = $sum3/$cnt;

8/31/2016	0:0:0:0	100.00	53.00	0.57	53.00	18.00	0.00	115.00	166.00	85.00	51.00	164.00	93.00	111.00
8/31/2016	0:0:1:24	100.00	52.00	0.57	52.00	19.00	0.00	115.00	165.00	85.00	54.00	164.00	93.00	111.00
8/31/2016	0:0:2:48	99.90	51.00	0.57	52.00	19.00	0.00	116.00	165.00	85.00	55.00	164.00	93.00	111.00
8/31/2016	0:0:3:72	99.80	51.00	0.57	53.00	19.00	0.00	117.00	166.00	87.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:4:96	99.90	51.00	0.55	54.00	18.00	0.00	119.00	167.00	88.00	63.00	164.00	93.00	111.00
8/31/2016	0:0:5:120	99.80	51.00	0.56	55.00	17.00	0.00	120.00	169.00	90.00	63.00	164.00	93.00	111.00
8/31/2016	0:0:6:144	99.70	52.00	0.56	56.00	17.00	0.00	120.00	169.00	90.00	63.00	164.00	93.00	111.00
8/31/2016	0:0:7:168	99.50	52.00	0.56	57.00	17.00	0.00	120.00	170.00	89.00	55.00	164.00	93.00	111.00
8/31/2016	0:0:8:192	99.40	52.00	0.58	57.00	17.00	0.00	119.00	171.00	89.00	51.00	164.00	93.00	111.00
8/31/2016	0:0:9:216	99.20	53.00	0.59	57.00	17.00	0.00	119.00	171.00	88.00	50.00	164.00	93.00	111.00
8/31/2016	0:0:10:240	99.10	54.00	0.61	56.00	17.00	0.00	118.00	170.00	87.00	51.00	164.00	93.00	111.00
8/31/2016	0:0:11:264	99.20	55.00	0.62	56.00	19.00	0.00	118.00	170.00	86.00	53.00	164.00	93.00	111.00
8/31/2016	0:0:12:288	99.40	55.00	0.62	56.00	19.00	0.00	118.00	170.00	86.00	54.00	164.00	93.00	111.00
8/31/2016	0:0:13:312	99.70	56.00	0.62	56.00	19.00	0.00	118.00	170.00	86.00	56.00	164.00	93.00	111.00
8/31/2016	0:0:14:336	99.90	57.00	0.62	57.00	19.00	0.00	119.00	171.00	86.00	57.00	164.00	93.00	111.00
8/31/2016	0:0:15:360	100.00	57.00	0.61	57.00	20.00	0.00	119.00	171.00	86.00	57.00	164.00	93.00	111.00
8/31/2016	0:0:16:384	100.00	56.00	0.61	56.00	20.00	0.00	120.00	172.00	86.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:17:408	100.00	56.00	0.61	56.00	21.00	0.00	120.00	172.00	86.00	58.00	164.00	93.00	111.00
8/31/2016	0:0:18:432	100.00	55.00	0.62	56.00	21.00	0.00	120.00	172.00	86.00	57.00	164.00	93.00	111.00
8/31/2016	0:0:19:456	100.00	54.00	0.62	55.00	21.00	0.00	121.00	173.00	86.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:20:480	99.90	53.00	0.63	55.00	21.00	0.00	121.00	173.00	86.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:21:504	99.70	53.00	0.63	55.00	20.00	0.00	120.00	173.00	87.00	53.00	164.00	93.00	111.00
8/31/2016	0:0:22:528	99.70	54.00	0.64	55.00	20.00	0.00	119.00	173.00	86.00	48.00	164.00	93.00	111.00
8/31/2016	0:0:23:552	99.70	54.00	0.66	51.00	20.00	0.00	119.00	171.00	86.00	49.00	164.00	93.00	111.00
8/31/2016	0:0:24:576	99.70	55.00	0.67	55.00	20.00	0.00	118.00	170.00	85.00	50.00	164.00	93.00	111.00
8/31/2016	0:0:25:600	99.70	57.00	0.69	55.00	20.00	0.00	118.00	169.00	85.00	54.00	164.00	93.00	111.00
8/31/2016	0:0:26:624	99.70	57.00	0.69	54.00	20.00	0.00	119.00	169.00	85.00	57.00	164.00	93.00	111.00
8/31/2016	0:0:27:648	99.60	57.00	0.70	54.00	19.00	0.00	119.00	170.00	86.00	58.00	164.00	93.00	111.00
8/31/2016	0:0:28:672	99.60	57.00	0.71	55.00	19.00	0.00	120.00	171.00	86.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:29:696	99.60	56.00	0.72	55.00	21.00	0.00	121.00	172.00	87.00	58.00	164.00	93.00	111.00
8/31/2016	0:0:30:720	99.50	55.00	0.72	55.00	21.00	0.00	122.00	173.00	87.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:31:744	99.50	54.00	0.72	55.00	21.00	0.00	123.00	174.00	88.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:32:768	99.50	53.00	0.72	55.00	20.00	0.00	123.00	175.00	88.00	58.00	164.00	93.00	111.00
8/31/2016	0:0:33:792	99.40	52.00	0.72	55.00	20.00	0.00	124.00	176.00	88.00	60.00	164.00	93.00	111.00
8/31/2016	0:0:34:816	99.40	52.00	0.72	55.00	20.00	0.00	124.00	177.00	89.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:35:840	99.30	52.00	0.72	56.00	20.00	0.00	125.00	177.00	89.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:36:864	99.30	53.00	0.73	56.00	20.00	0.00	125.00	178.00	90.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:37:888	99.20	55.00	0.74	58.00	21.00	0.00	126.00	179.00	90.00	59.00	164.00	93.00	111.00
8/31/2016	0:0:38:912	99.20	56.00	0.75	59.00	21.00	0.00	125.00	179.00	90.00	53.00	164.00	93.00	111.00
8/31/2016	0:0:39:936	99.20	57.00	0.76	59.00	21.00	0.00	125.00	179.00	90.00	53.00	164.00	93.00	111.00
8/31/2016	0:0:40:960	99.20	58.00	0.77	59.00	21.00	0.00	124.00	179.00	89.00	48.00	164.00	93.00	111.00
8/31/2016	0:0:41:984	99.20	59.00	0.78	59.00	21.00	0.00	124.00	178.00	88.00	51.00	164.00	93.00	111.00
8/31/2016	0:0:43:8	99.20	59.00	0.78	57.00	22.00	0.00	123.00	177.00	88.00	56.00	164.00	93.00	111.00

Figure 3.7.1a Processed Granulated Text File.

\N	12345678	8-31-2016 1:00:00	97	54	2	54	20	0	101	134	83	54	168	80	104	49	EMR	2017-05-17T22:06:14+00:00
\N	12345678	8-31-2016 2:00:00	97	54	3	54	19	0	100	131	83	54	160	76	99	50	EMR	2017-05-17T22:06:14+00:00
\N	12345678	8-31-2016 3:00:00	97	53	3	53	18	0	97	128	80	53	155	74	97	50	EMR	2017-05-17T22:06:15+00:00

Figure 3.7.2b Processed Hourly Text File

`

3.7.2 Phenotypic Data Visualization

In generating the phenotypic charts, an hour of interest is identified before approval and transfer to the EMR. Then a query is made to the local database where the records are saved, selecting all the epochs that constituted the hourly record. Some parameters that are key to the generation of each phenotypic chart from the hourly records processed from the flowsheets are then extracted from the query result.

The following are the parameters extracted from the query result.

- Date of the epoch (8/31/2016)
- Start time (hour) of the epochs (0:0:0:0)
- End time (hour) of the epochs (0:0:0:0)
- Patient ID (XXXXXXX) number
- The processed file name (*eFlowSheet-UH34nsu16MP70T16_numerics_20160831_000000.csv*)
- The channel values
- The number of epochs in the hourly record.

Based on the data extracted from the query, the size of the file is determined and if the hourly record happens to be the first of the file, we set the file size to 128000 as a default which implies 1000 epochs since each epoch of data has 128 bytes.

Once the necessary information is obtained, the channel values, that is the data values as well as time of epochs are then formatted in a JSON format. This is the format that the canvas JavaScript will use it to plot the chats.

3.8 Physiological Waveform Data

The waveform data is also being hosted by the local database. It also gets connected with the hospital EMR database and of course to the phenotypic database. The stores binary physiological waveform data files can be queried and called back for visualization and comparison if needed at any time.

3.8.1 Waveform Data Processing

In generating the physiological waveform charts, an hour of interest is identified just like the case of phenotypic. Then a query is made to the local database where the records are saved, selecting all the epochs that constituted the hourly record. Some parameters that are key to the generation of each phenotypic chart from the hourly records processed from the flowsheets are then extracted from the query result.

The following are the parameters extracted from the query result.

- Date of the epoch (8/31/2016)
- Start time (hour) of the epochs (0:0:0:0)
- End time (hour) of the epochs (0:0:0:0)
- Patient ID (XXXXXXX) number
- The processed file name (*eFlowSheet-UH34nsu16MP70T16_numerics_20160831_000000.csv*)
- The channel values

`

- The number of epochs in the hourly record.

Based on the data extracted from the query, the size of the file is determined and if the hourly record happens to be the first of the file, we set the file size to 128000 as a default which implies 1000 epochs since each epoch of data has 128 bytes.

Once the necessary information is obtained, the channel values, that is the data values as well as time of epochs are then formatted in a JSON format. This is the format that the canvas JavaScript will use it to plot the chats.

3.8.2 Waveform Visualization

The physiological waveform displays are generated from parsed binary files from the Bedside monitor. The data is arranged such that the first 8 bytes (64 bits) of each sample is time in milli-seconds and the second 8 bytes are data (128 bytes) per epoch. Data and time for each epoch are extracted from the binary file each epoch at a time and unpacked into an array of double data type of machine dependent size and representation. Figure 3.8.2 has a code snippet of the technique used in extracting and processing the physiological waveform data. It extracts the binary data and formats the output in a JSON format ready for plotting and chart display. The output charts can as well be exported and save for future reference.

list($t, $wav) = array_values(unpack("d*",$content));

The time part of the data is converted into numerical milli seconds data and further converted to gmdate format: *$timeR=gmdate("m/d/y H:i:s", $tim + (3600/24)*($timezone+date("I")));*

```php
<?php
  //Extracting data and time data packets and preparing output in Json format for the Chart
  $temp     = 'EMRTemp.txt';
  $fp       = fopen($temp , 'w+'); //Temp output file
  $handle   = fopen($filename, "rb");
  fseek($handle, $start);
  $contents = fread($handle, $fsize);
  fwrite($fp, $contents);  //Write temp data to file
  $fsz      = filesize($filename); $fsz2 = filesize($temp);
  $c1 = '{"y":'; $c2 = ',"label":"'; $c3 = '"}';
  $timeData = ""; $timeReal = ""; $waveData = ""; $dData = ""; $sep = "";$sep1 = "";
  $dataP = "";

  //the first 8 bytes (64 bits) ofeach sample is time in milli seconds and the second 8 bytes are data (128 bytes per epoch).
  $k =($fsize-1)/128;
  $sz = 128;
  for($n = 0; $n <= $k; $n++)
  {   //Extracting Time and Wave values.
      $ss = ($sz*$n);//+127;
      $handle2   = fopen($temp, "rb");
      fseek($handle2, $ss);
      $content = fread($handle2, 127);
      list($t, $wav) = array_values(unpack("d*",$content));
      $tim = $t/1000;
      $timezone  = -5; //(GMT -5:00) EST (U.S. & Canada)
      $timeR =  gmdate("m/d/y H:i:s", $tim + (3600/24)*($timezone+date("I")));

      //Setting the commas for separationg the values.
      If ($n <> 0) {
          $sep = ",";
          $sep1 = ",";
      }

      //Setting the Start and End time values.
      if ($origT != ""){
          $origT= $timeRi;
          $hrData = $timeRl;
      }

      //Setting the Start and End time values when the initial epoch is the starting point.
      If ($start == 0){
         If ($n == 0) {
              $timeRi = "$in 00:00:00";
              $dataP = $dataP.$sep1.$c1.$wav.$c2.$timeRi.$c3.",";
          }
      }Else{
          If ($n == 0) {
              $timeRi = $timeR;
          }
      }

      //Extracting the End time value.
      If ($n == round($k-1)) {
              $timeRl = $timeR;
      }
      $dataP = $dataP.$sep1.$c1.$wav.$c2.$timeR.$c3;
  }

  $dataPoints1 =  "[$dataP]";
  $dataPoints  =  "[$dataP]"; //This is the actual json data for the chart display.
  fclose($temp);

  //Setting the Start and End time values.
  if ($origT == ""){
      $origT  = $timeRi;
      $hrData = $timeRl;
  }
?>
```

Figure 3.8.2 Code Snippet behind the Binary Waveform Data Visualization

3.9 EMR Database Connectivity

The EMR database in this project is represented using an OpenEMR Application interface. It is and independent system that houses approved patient data. It accepts approved data from the eFlowsheet as well as transferred from the ICU_POC. OpenEMR is connected to the ICU_POC application for purposes of querying the database for different characteristics that might be of interest to the physician. The query interface of the ICU_POC can query a single patient as well as query across all patients that has certain characteristics in common.

3.9.1 The Query Engine

The query engine is used to query the EMR database for certain characteristics regarding the patient(s) of interest. A patient ID could be used to query the records for a patient or left blank indicating that the query is for all possible patients in the system. A sample query is shown in Figure 3.9.1.

`

```
SELECT * FROM EMR_Final
WHERE Patient_ID LIKE '%%'
AND SAT_O2 BETWEEN '90' and '120'
AND NONINV_SYS BETWEEN '80' and '150'
AND NONINV_DIA BETWEEN '50' and '80'
And YEAR(Date_Approved) Between '2016' AND '2016'
AND MONTH(Date_Approved) BETWEEN '01' AND '12'
AND DAY(Date_Approved) BETWEEN '01' AND '12';
```

Figure 3.9.1 A sample MySQL query.

Chapter three has shown the architectural design of ICU_POC. The web platform on which the system is build, the hardware and software, setup and configurations behind the scenes, the development styles as well as the network components that were employed in the design. Chapter four will give more understanding of the implementation of the developed system and demonstration of how the process flows from the importation of raw data from the acquisition system through the point where data gets transferred to OpenEMR. It will also show how these data can be queried and extracted back from OpenEMR such that historic visualization of the waveforms is possible.

Chapter 4.0

The ICU_POC Implementation

4.1 Introduction

A browser based system was decided upon due to the flexibility, cost effectiveness and ease of implementation. We considered that once a system has network / internet connectivity, and of course a browser, it will be easy to connect to the application without much stress. The implementation of ICU_POC is the minimal for a system that is internet ready. Most of the system in the hospital will be able to connect to the local machine hosting the parsed data file and unto which the Philips IntelliVue monitoring system is attached to as well.

The project has focused on the realization of the Integrated Medical Environment (tIME) goal as discussed in chapter 2.0, a real-time data acquisition system of this model has been developed [2]. Here we have addressed the aspect of creating a point of care application that will analyze the extracted data into a hypothetical form and provided a graphical user interface that will help in the accessibility / utilization of the relevant information. The ability to visualize the phenotypic and physiological data side by side as well as query the database for information across patients is an interesting scenario.

4.2 Dataflow from Bedside Monitor to eFlowsheet

The process originates from the point a patient gets transferred to the intensive care unit. The monitoring system is then setup in place and automatically, data acquisition program starts data generated once the programs are run. The extraction program and the file parsing program both get configured to extract data to a “Patient” named folder on the “C drive” of the system connected to the Philips MP70 monitoring system as displayed in Figure 4.2. The connection of both systems is done using an RJ45 network connector and a serial cable.

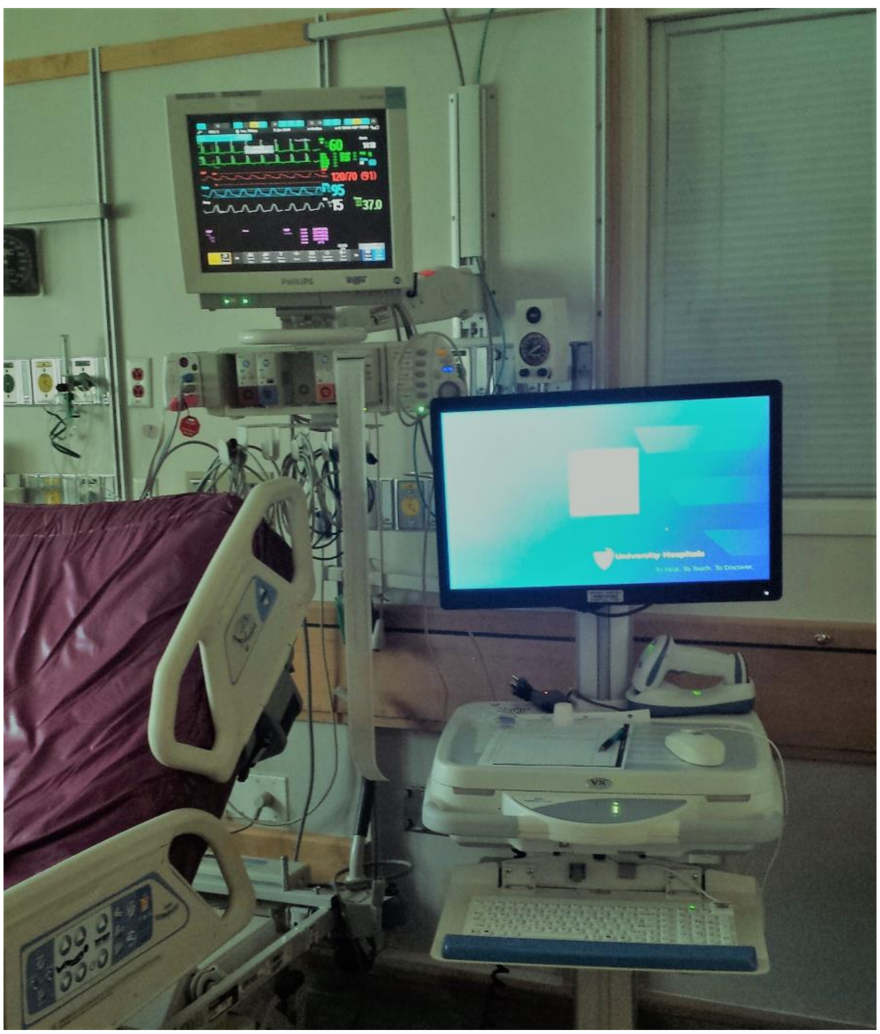

Figure 4.2 MP70 Bedside Monitor in a Sampled Cardiac Intensive Care Unit (CICU)

4.2.1 System Login

The security on this ICU_POC application is initiated right from the login page. The login page as displayed in Figure 4.2.1a below has two buttons. A button for existing users to login and a second button called Register New User which can only be activated when an admin has logged in. It is only an administrator of the application that has the privilege to create new users on the system. The session cookies are immediately enabled at a successful login to track user as he navigates the system. Upon a failed attempt to log into the system, a message is displayed telling that the login was invalid. It does not specify whether it is a wrong username or password for security reasons. See Figure 4.2.1b for the Invalid Login page.

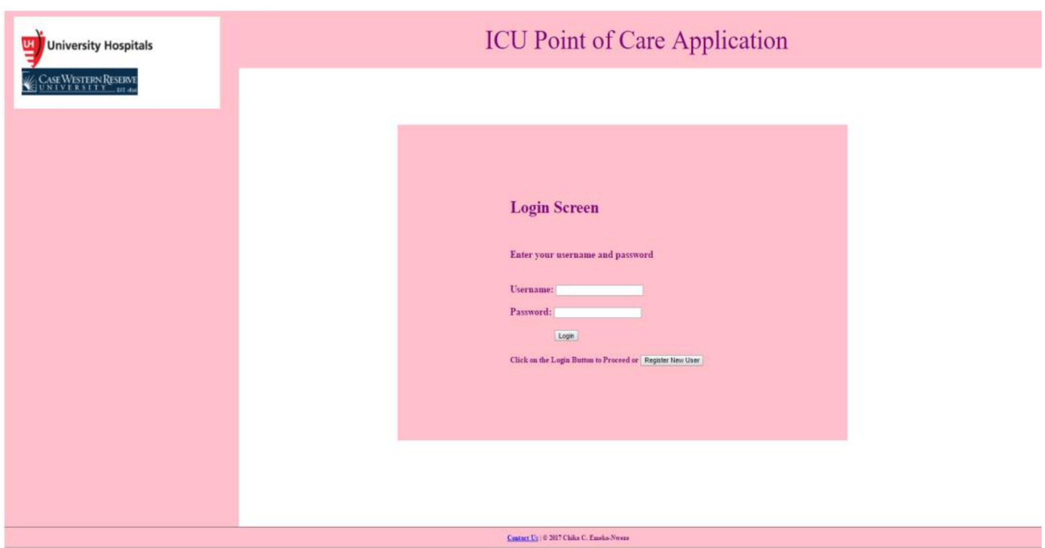

Figure 4.2.1a ICU_POC Login Screen

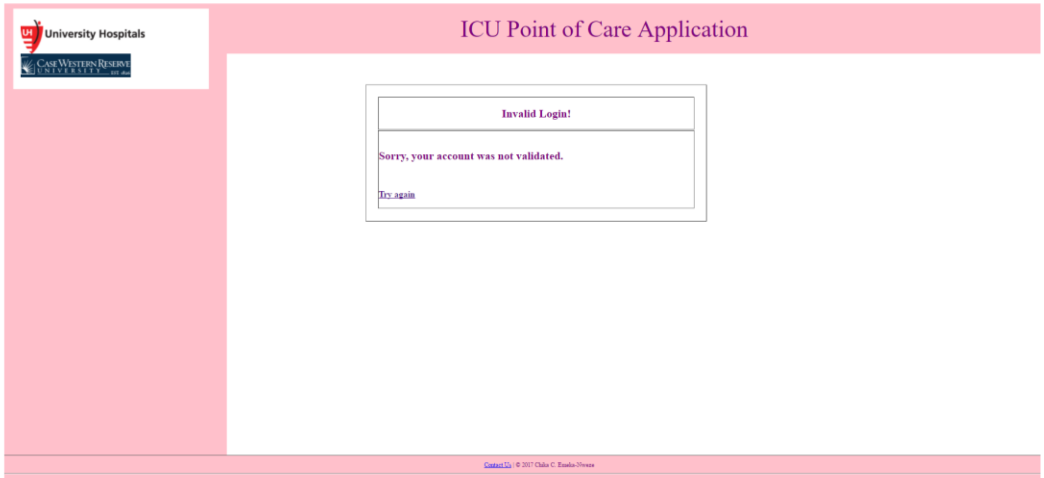

Figure 4.2.1b Invalid Login Page

Once an administrator has logged in he can use this New User page to create users on the application. The menus are also controlled based on what access a user has. Some users can import raw data files while others can process imported patient files. The other group can approve records, view the visualization screens, transfer records to EMR as well as generate query reports. All these functions are controlled as a security feature.

The New User Registration page has is used to capture basic user details to be created on the application. Vital details are validated right on the page and if not valid, it denies the user access and displays an error message. For instance, the email as well as passwords. Figure 4.2.1c displays the New User Registration page.

Figure 4.2.1c New User Registration Page

Likewise, registered user logins are checked to make sure they have the right credentials before they can access the application. With any discrepancy, an error message is displayed and the user is taken back to try again. Incomplete User Details page is here on Figure 4.2.1d

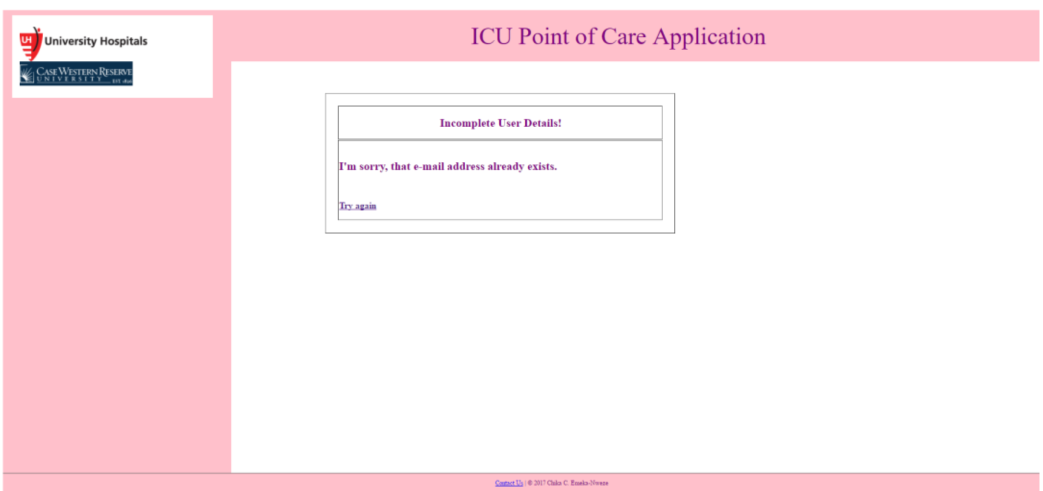

Figure 4.2.1d Incomplete User Registration Details Page

Once a successful login is achieved, the user gets directed to the home page as can be seen in Figure 4.2.1e. This is the main menu page from where the user can choose from a list of available menus. The menus differ depending on which page you are. There are 3 main menu items under which are other submenus.

- Process Data – to import the acquire data from the local bedside system that hosts the MP70 Philips monitoring system
- Query Engine – to query the OpenEMR for interested data.
- View Data Graphs – to view the phenotypic and physiological visualization waveforms.

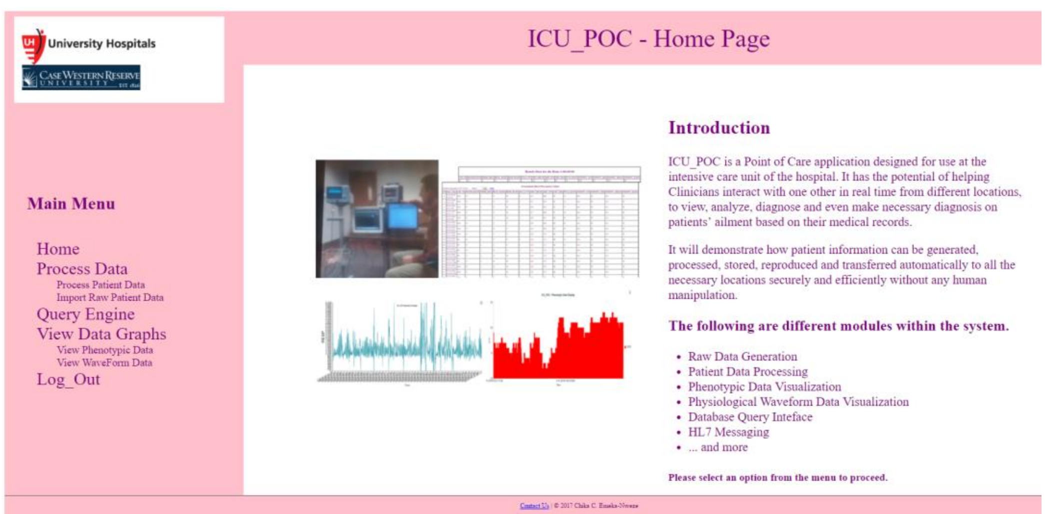

Figure 4.2.1e ICU_POC Main Menu page

4.2.2 Process Phenotypic Data

This menu item is responsible for the importation of the phenotypic and physiological waveform data files. It is also responsible for the processing of the files into aggregated records of the hourly data. There are other submenus under the Process Data menu which oversees the Approval of data as well as the transfer to EMR database. From this menu, one can go back and forth in the process of analyzing the data as desired. The two submenus here are:

- **Import Raw Data**

  This menu has the page from where the user will browse the windows file directory system and select the parsed phenotypic data (for instance, *UH34nsu16MP70T16_numerics_20160831_000000.csv).* The file is then processed with bad data removed *(e.g. "8388607")* appearing in some phenotypic files. Then the good data is extracted and reformatted. A summary page is displayed with a list of processed output files.

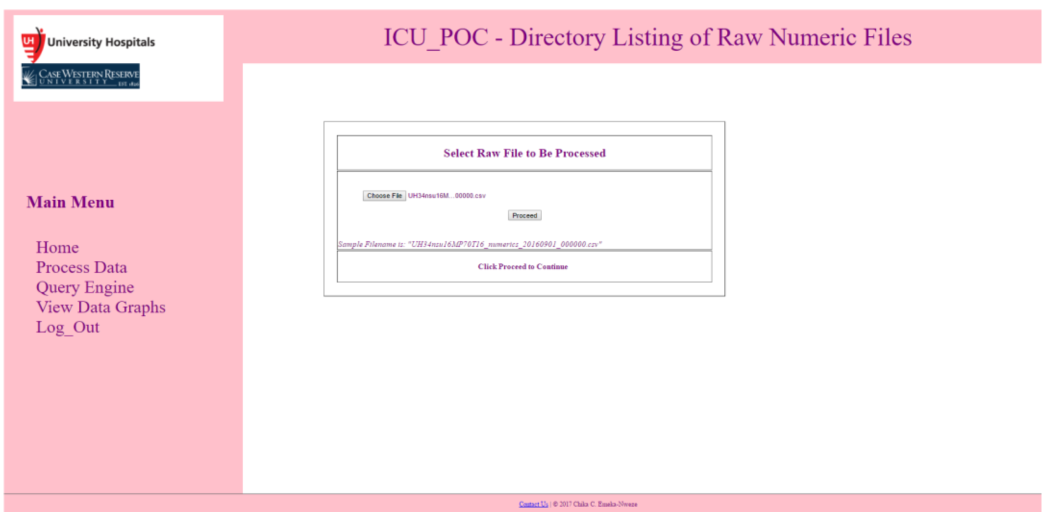

Figure 4.2.2a Directory Listing of Raw Numeric Files

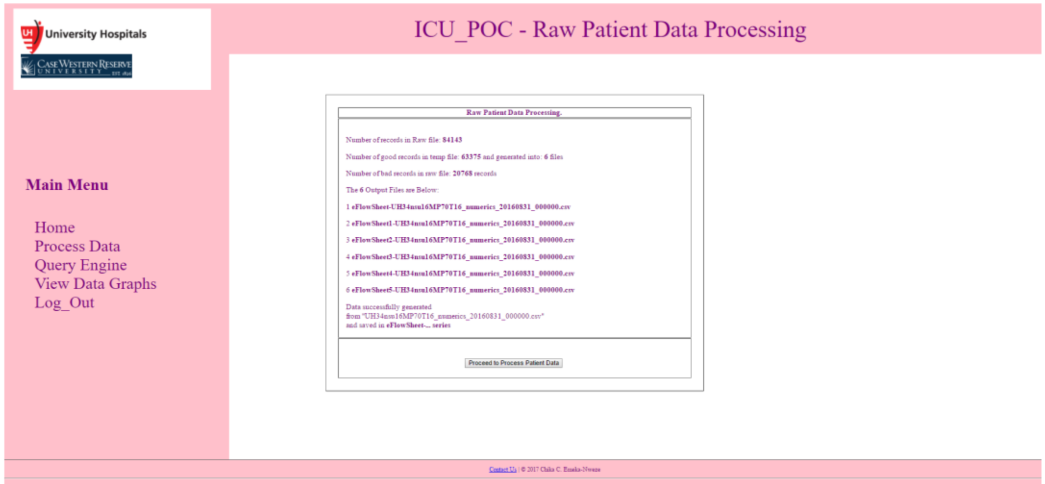

Figure 4.2.2b Raw Patient Data Processing Output Page

- **Process Patient Data**

  At this stage, the processed files are browsed and selected from the directory system. A processed file is then displayed with all the data epoch as generated from the monitor. From there, more menu items will be displayed for different options such as:

  - **Select Another File**: - this will circle back to the processed file selection page. And the process is repeated for another file accordingly.

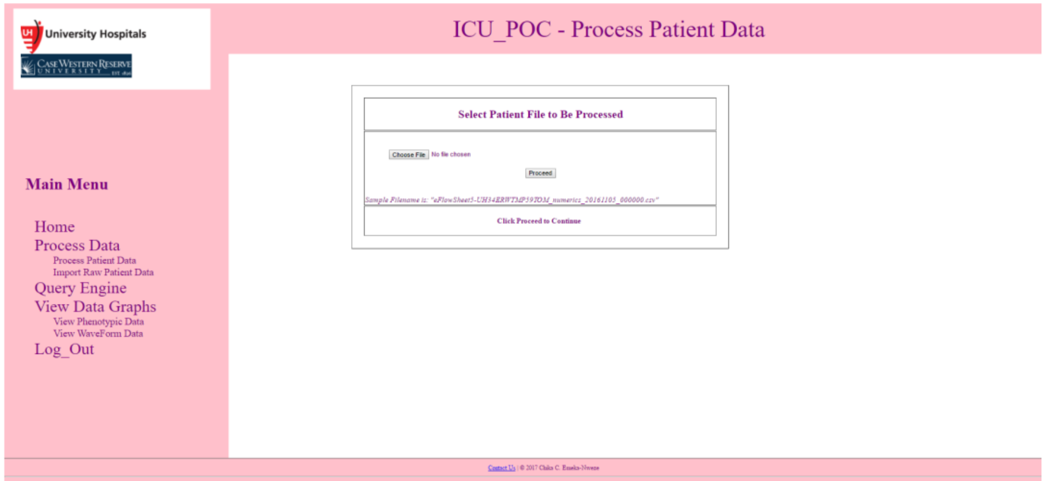

Figure 4.2.2c Directory Listing of Processed Files

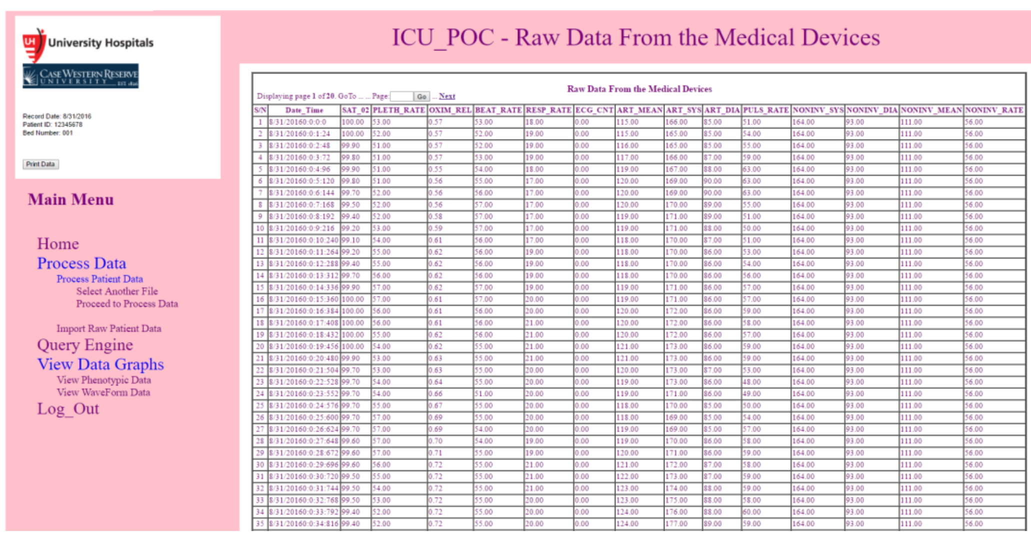

Figure 4.2.2d Display of Raw Data from Devices

- **Proceed to Process data**: - will aggregate the data epochs into hourly records. The hourly times are displayed with a hyperlink to the page where those individual epochs will be displayed again with the hourly record.

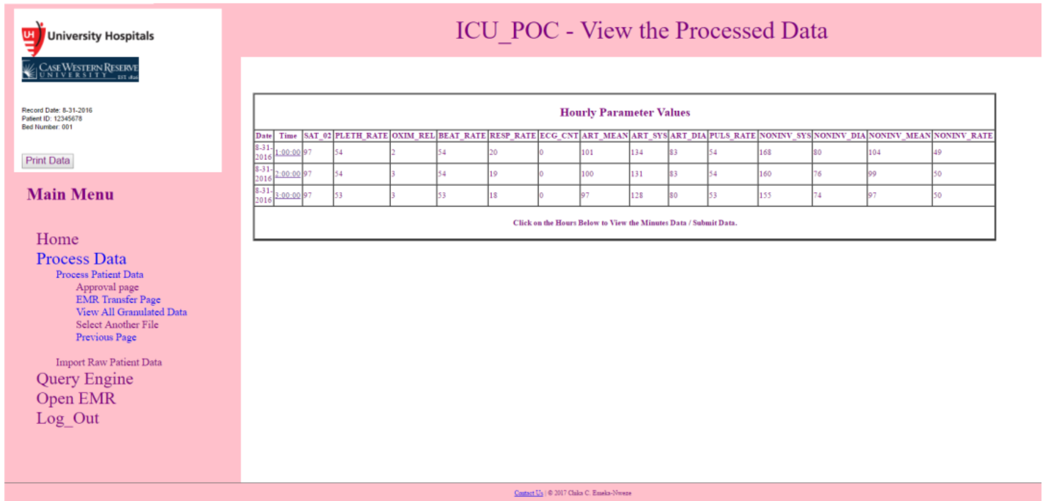

Figure 4.2.2e Display of the Processed Data

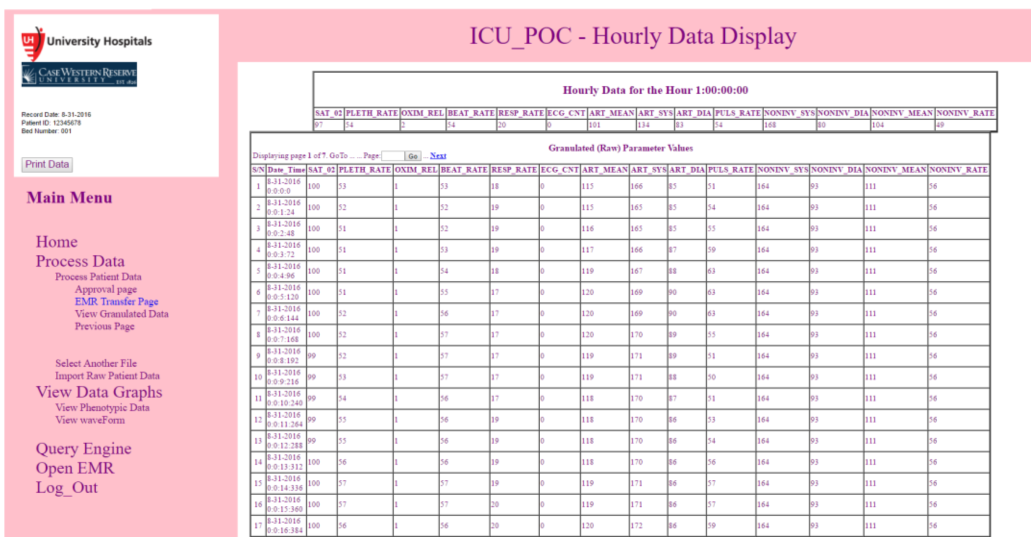

Figure 4.2.2f Hourly Data displayed with individual Data Epochs

4.3 Phenotypic Dataflow from eFlowsheet to EMR

Data gets processed into hourly records and gets transferred to the EMR in that hourly format. Before the transfer is made, a physician will have to approve the data by physically

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looking at the raw phenotypic data. He could also get to the phenotypic data visualization screen for any reason from this page. Once he is satisfied with the data, he can approve each record at a time or by selecting all records and clicking on the Approve button.

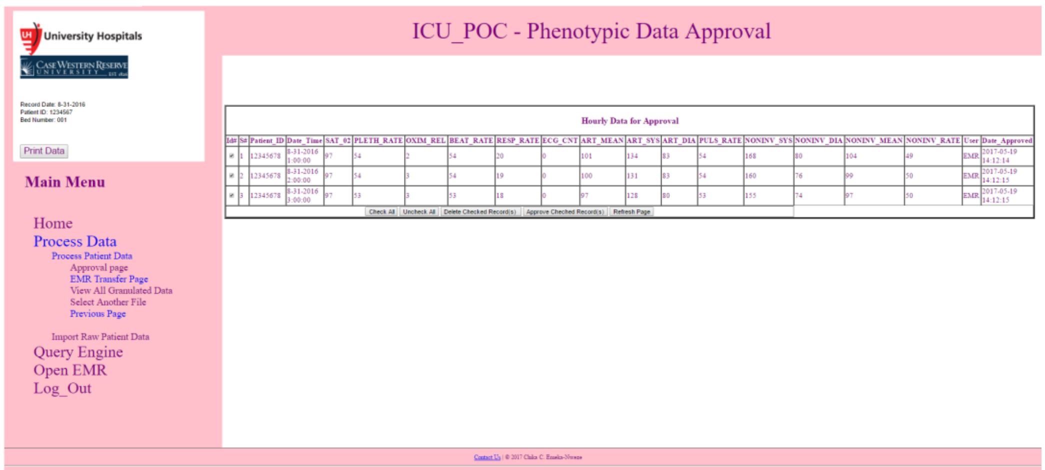

Figure 4.3a Data Approval Page with Records

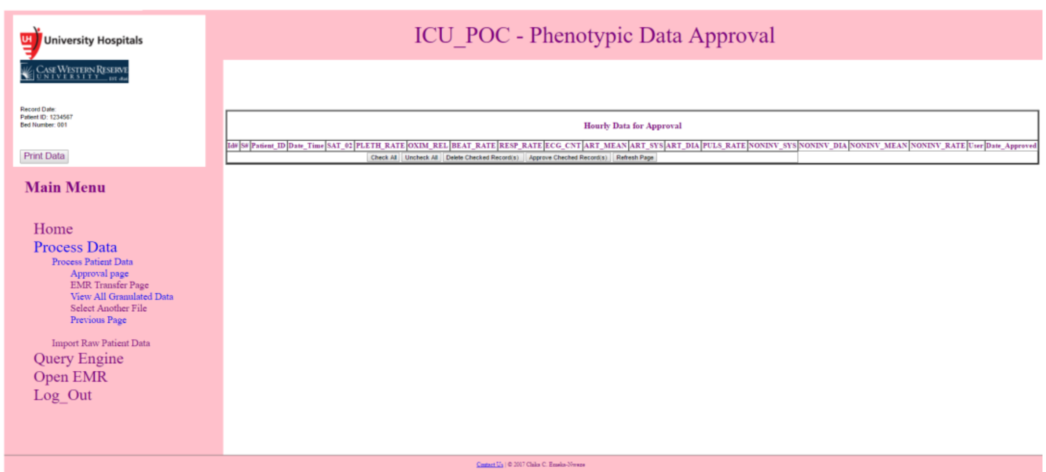

Figure 4.3b Data Approval Page (After Approval of Records)

Then the data get loaded in the local phenotypic database waiting to be transferred to EMR database. Even though we cannot at this point send HL7 message with this implementation, the HL7 messages associated with the approved records can be viewed from the EMR Transfer menu. On this page, one can select a record at a time or select all as well for batch processing either to view the HL7 messages or to transfer approved data to OpenEMR (EMR database).

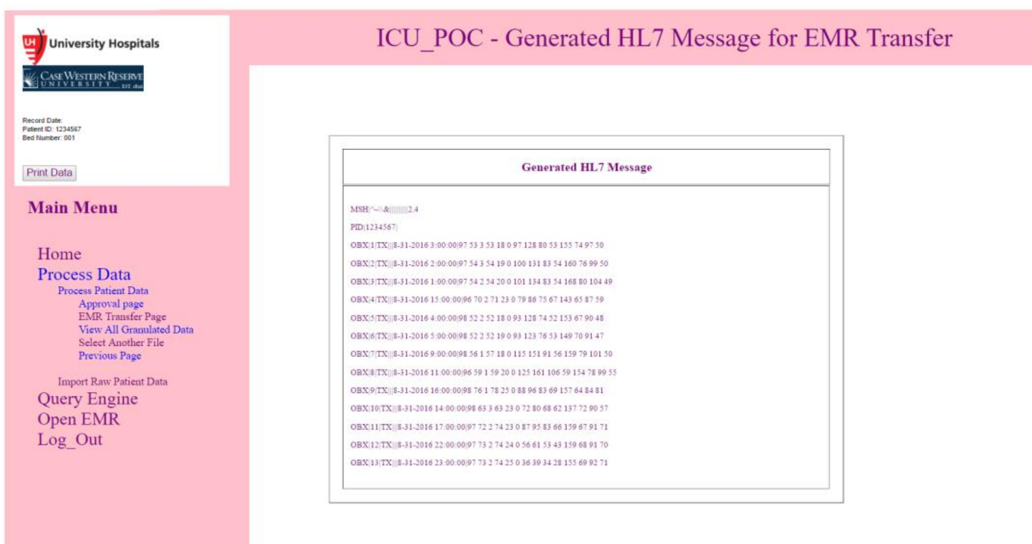

Figure 4.3c Generated HL7 Message for Select Records

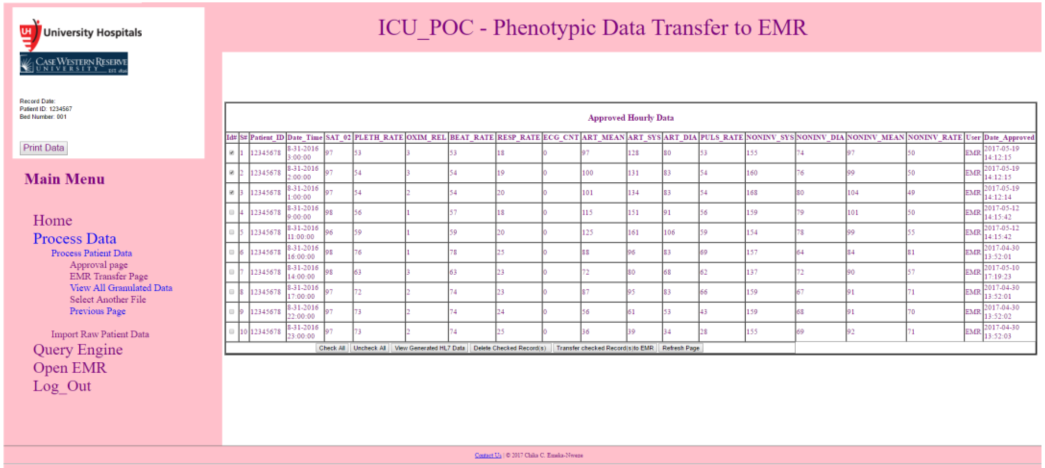

Figure 4.3d Data Transfer Page

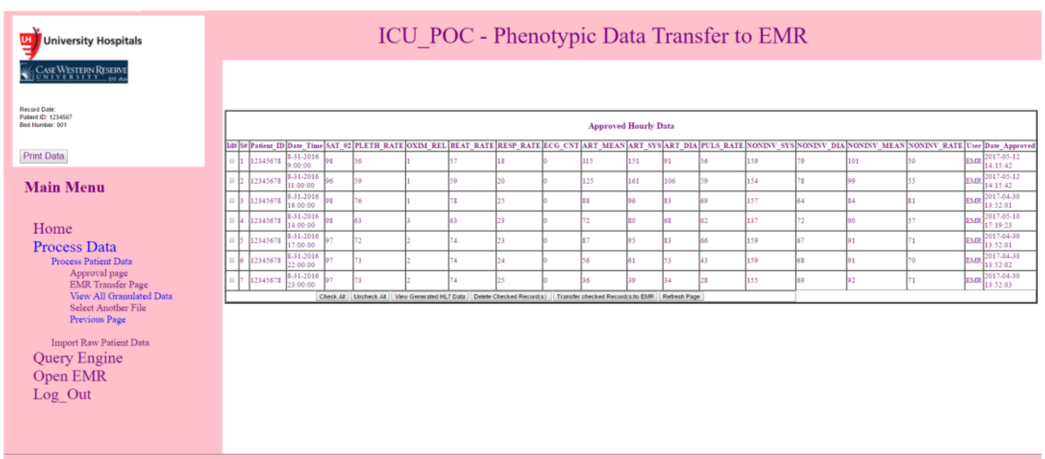

Figure 4.3e Data Transfer Page After Some Approvals.

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4.4 Phenotypic Data Visualization

Data visualization is a major interesting part of this project. The processed phenotypic data can be visualized using the View Phenotypic Graph menu on the Processed Data or Hourly Data Displayed pages. The phenotypic data values are graphed across the time. The data on being processed, gets stored on the local database. From the database, the graphs are then generated by plotting the phenotypic values with time.

The graphs are animated with such capabilities that one can zoom in to the individual epochs, pan left to right as desired and be able to print the charts at will. The charts can as well be exported out and saved as an image file for future reference should the physician find any one of interest. There is the capability of viewing a single channel at a time by selecting the channel of interest from the *Channel* dropdown list or view all available channels in one chart display by clicking on the *View All Channels* button. From the *View All Channels* page, one can navigate back to *View Single Channel* as needed. The phenotypic data display pages for the single and all channels display has other information on the page like the name of the file in question as well as the Start time and End time of the displayed data. They also tell the number of epochs displayed on the screen.

Zooming in on the chart is as easy as using the mouse to highlight the area of interest. Then the reset button restores the chart back to its former.

Figure 4.4a displays a phenotypic data display of the RESP channel. It also shows Start Time of 0:00:00 which tells that this is the initial start of the data file. The End Time is also shown to be 1:00:00 with 5000 epochs of data displayed.

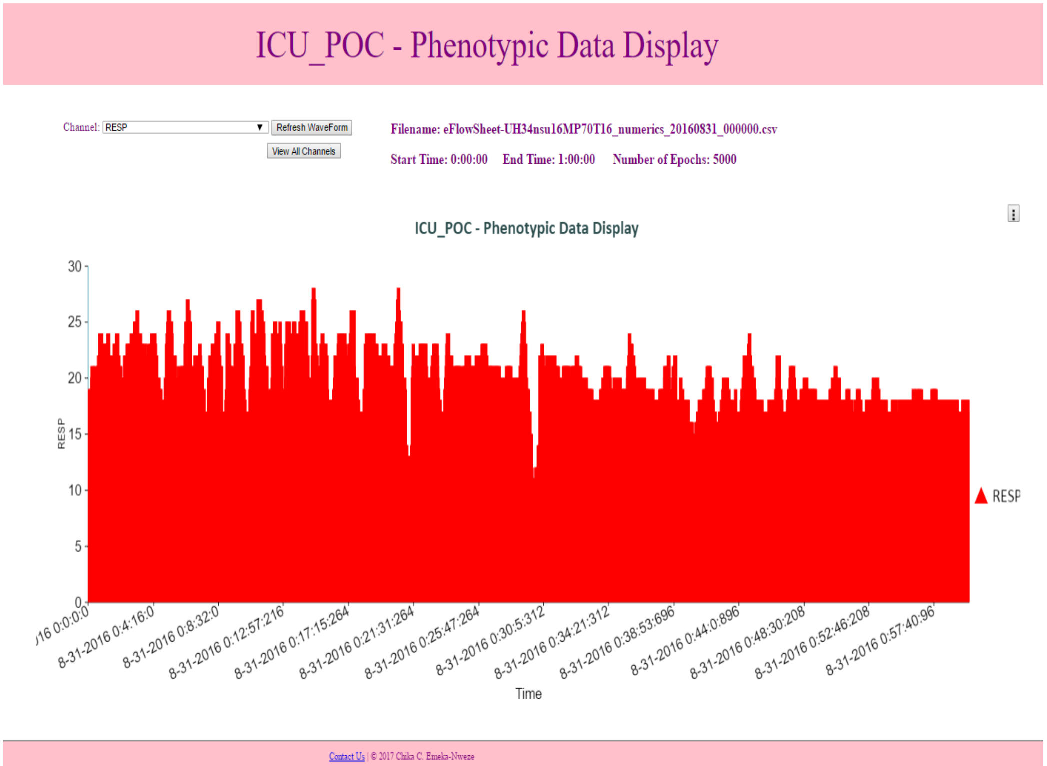

Figure 4.4a Phenotypic Data Visualization - RESP

Figure 4.4b shows a section of the chart as selected for deeper viewing. The selection on any area of the chart zooms into that section as much as one desires. Once done, the Reset button restores the page to its original display.

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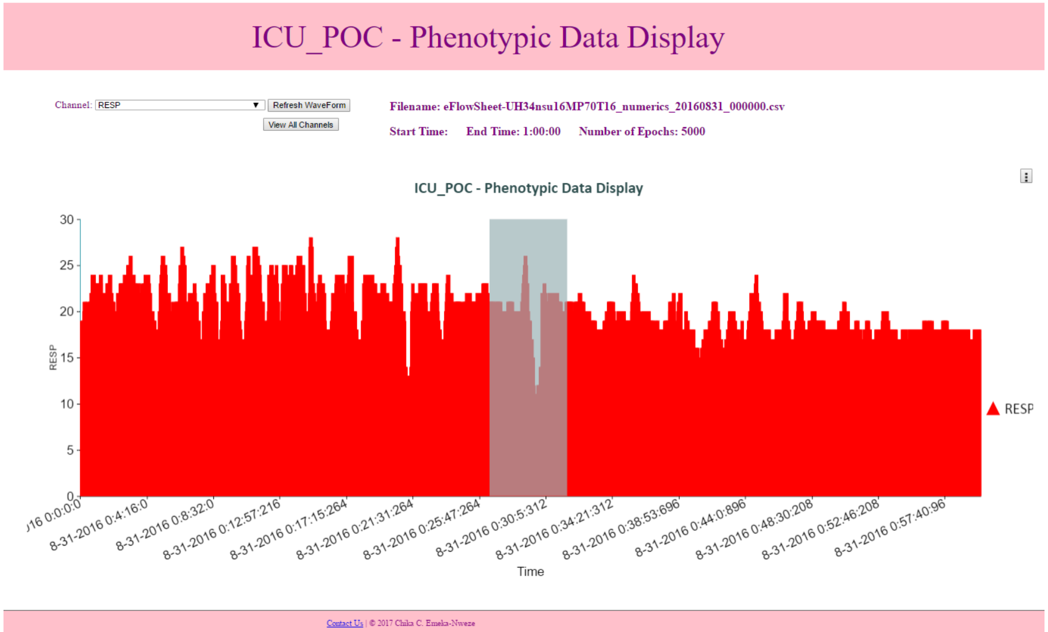

Figure 4.4b Phenotypic Data Visualization - RESP (Selected Area for Zooming)

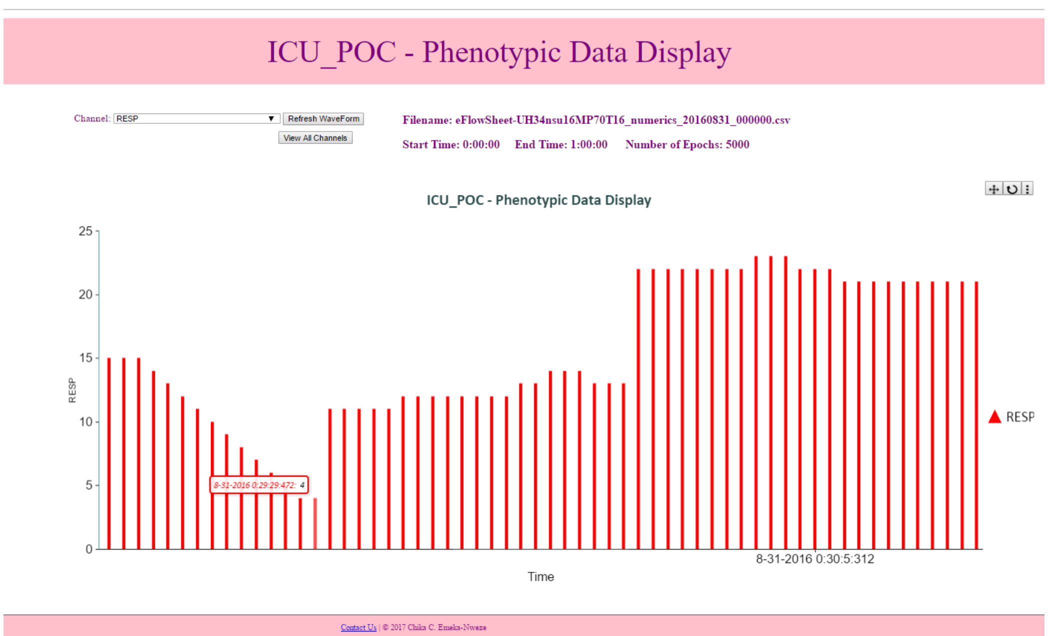

Figure 4.4c Phenotypic Data Visualization - RESP (Zoomed)

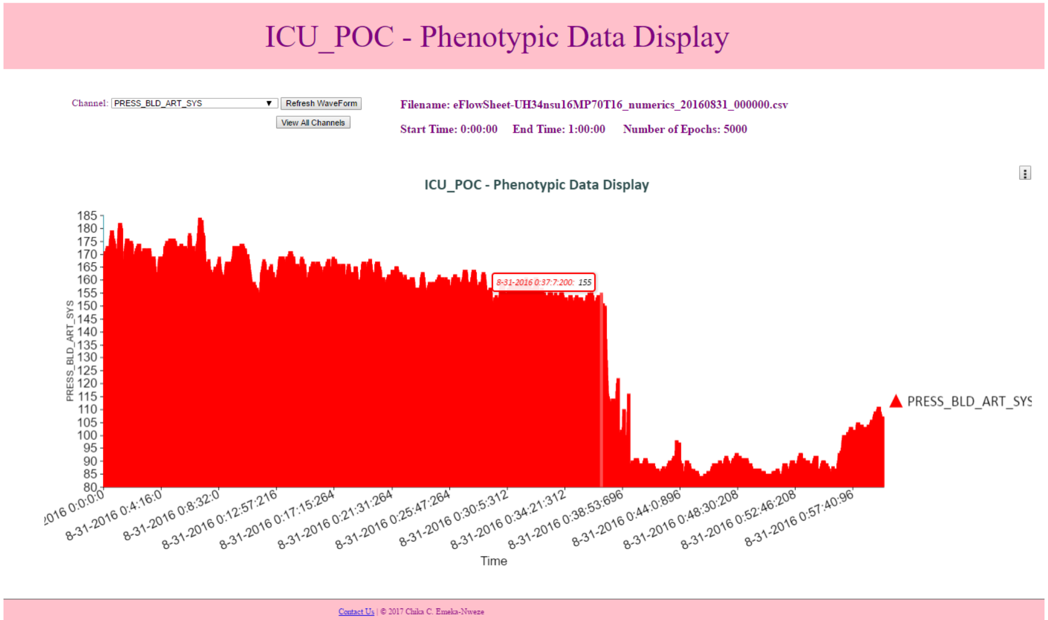

Figure 4.4d Phenotypic Data Visualization - PRESS_BLD_ART_SYS

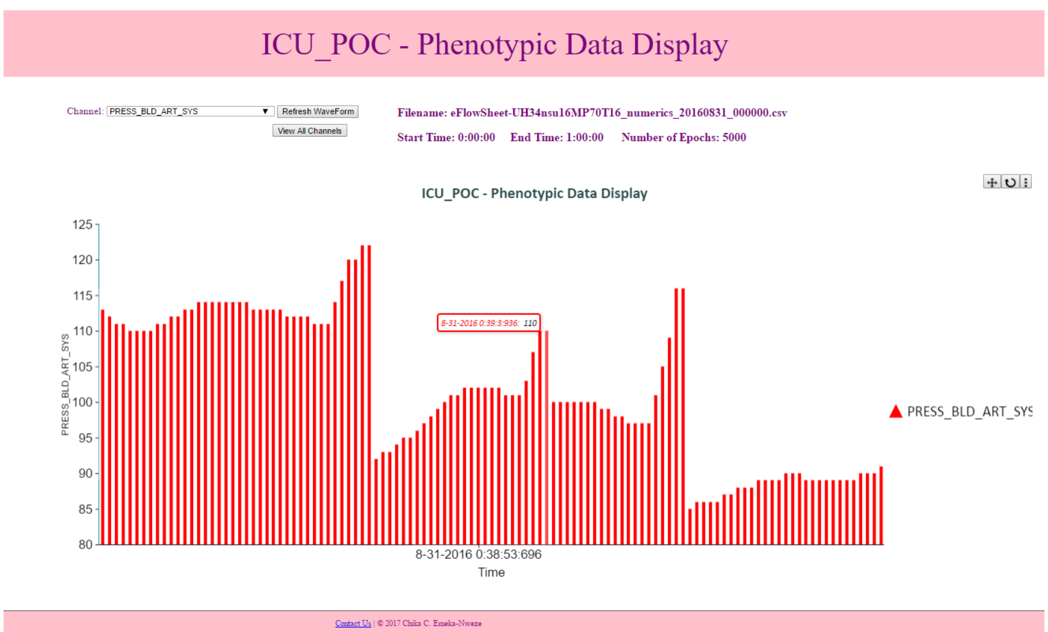

Figure 4.4e Phenotypic Data Visualization - PRESS_BLD_ART_SYS (Zoomed)

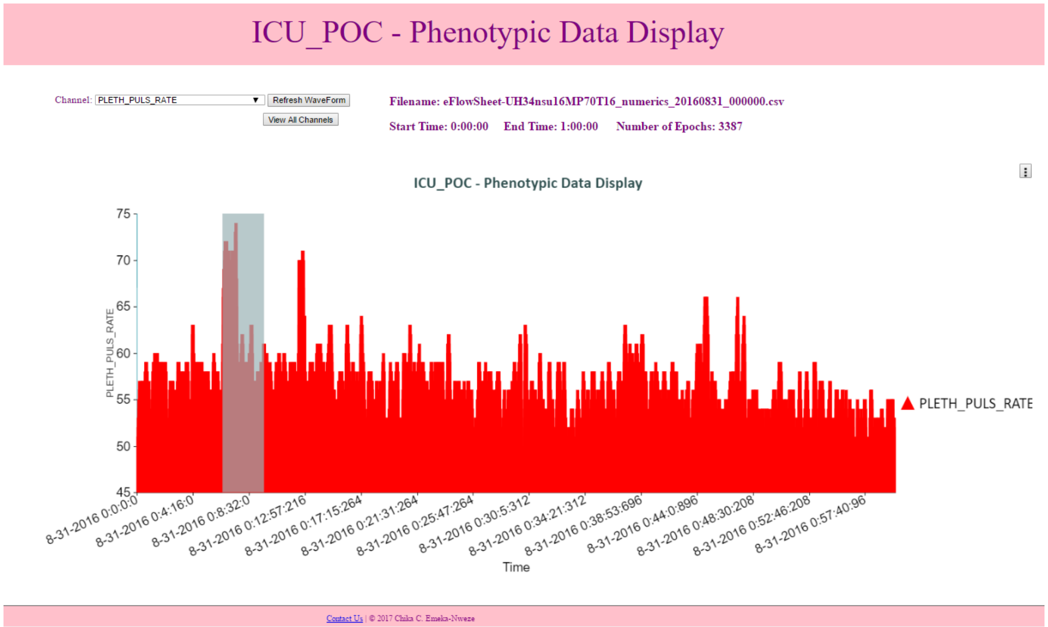

Figure 4.4f Phenotypic Data Visualization – PLETH_PULSE

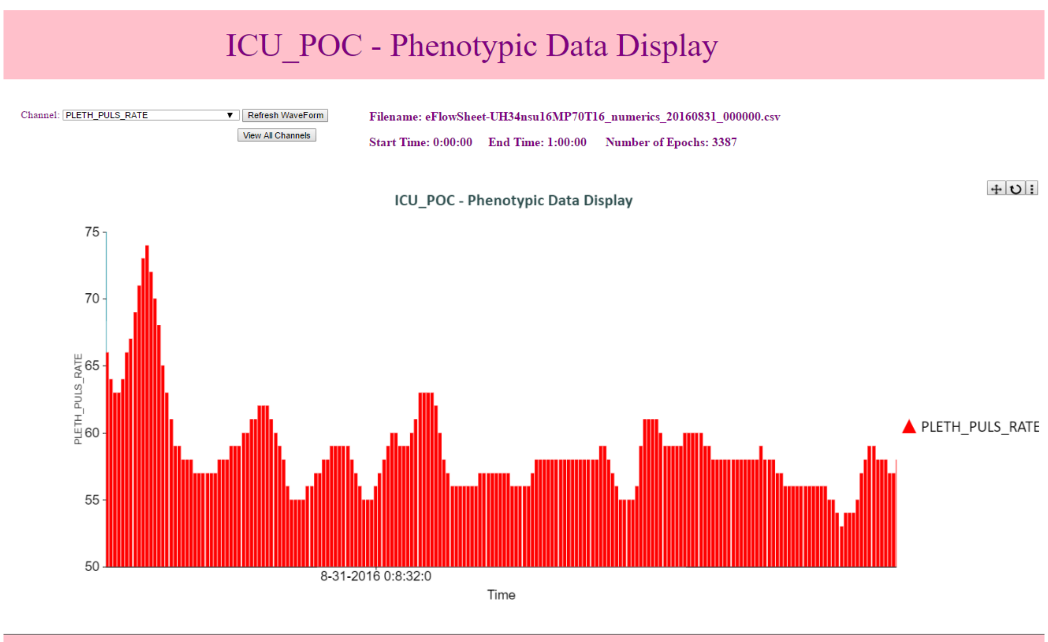

Figure 4.4g Phenotypic Data Visualization - PLETH_PULSE (Zoomed)

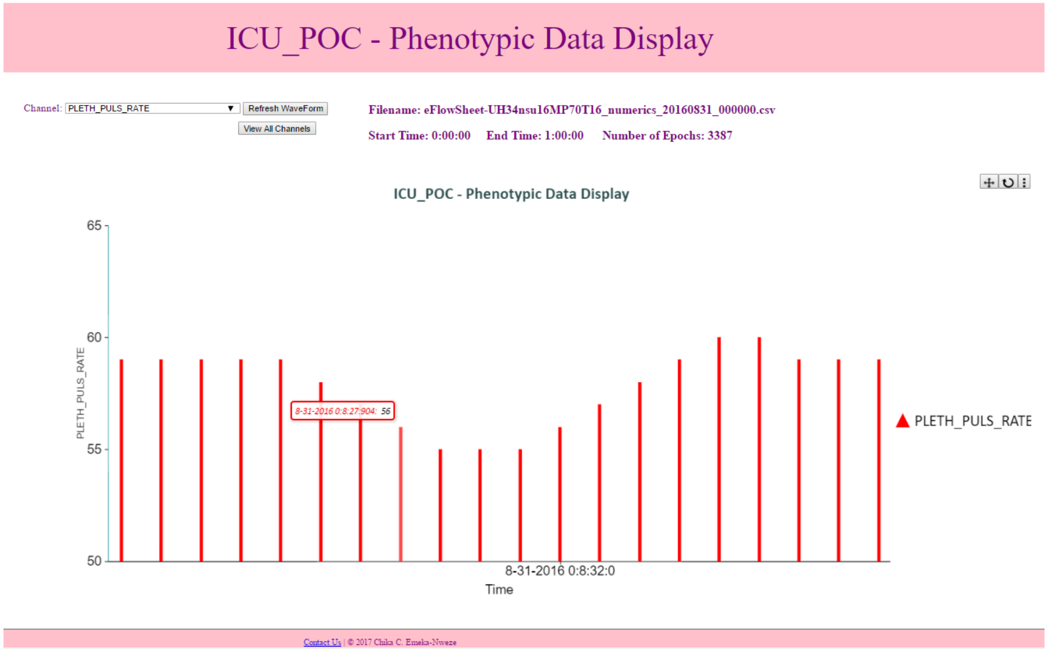

Figure 4.4h Phenotypic Data Visualization - PLETH_PULSE (Fully Zoomed)

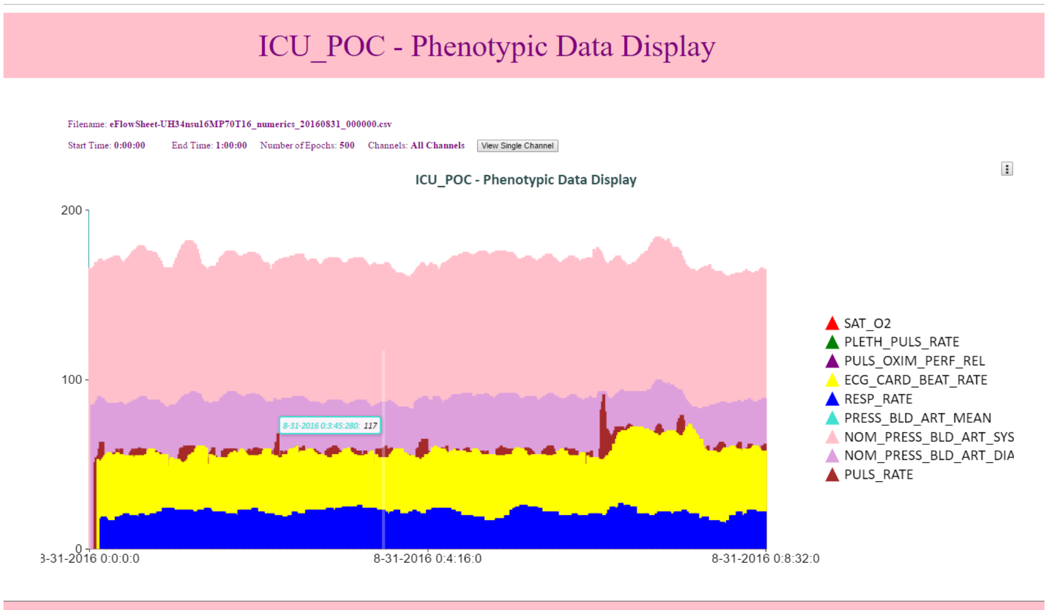

Figure 4.4i Phenotypic Data Visualization – All Channels

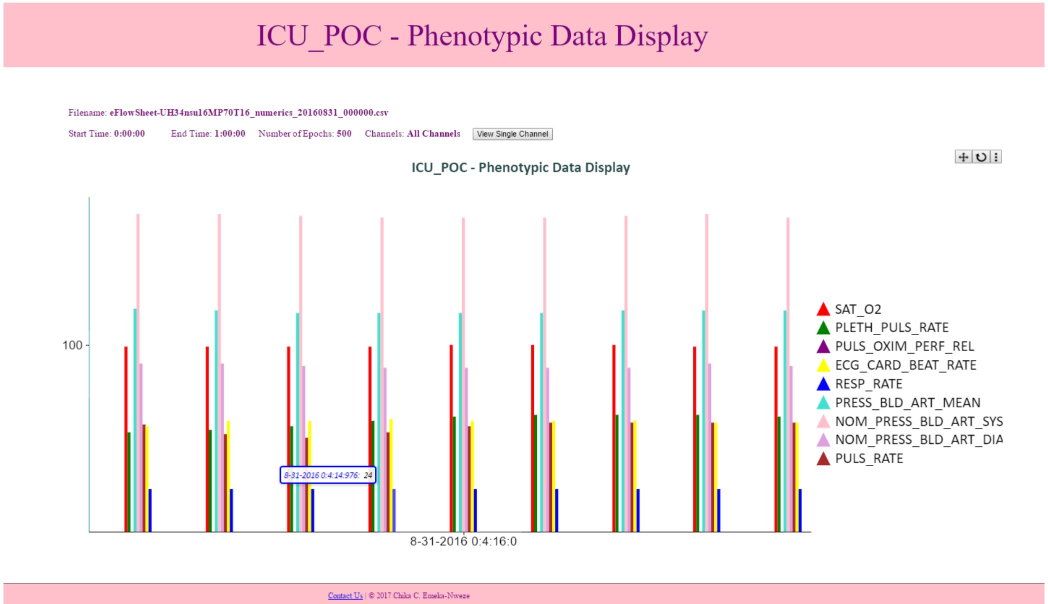

Figure 4.4j Phenotypic Data Visualization – All Channels (Zoomed)

4.5 Waveform Data Visualization

The waveform data visualization is like the phenotypic display except that it offers more flexibility for the user to select what he wants to see. It has a dropdown list of possible start-points in terms of epochs. It also allows the user to select how much epochs he want to display and finally the channel. These are all dropdown lists for easy processing. Once the desired parameters or criteria are selected, the refresh button fetches the chart and displays. The user can still zoom in as needed within the selected chart area. There is the name of the file in question as well as the Start time and End time of the displayed data on the page. The page also tells the number of epochs displayed on the screen.

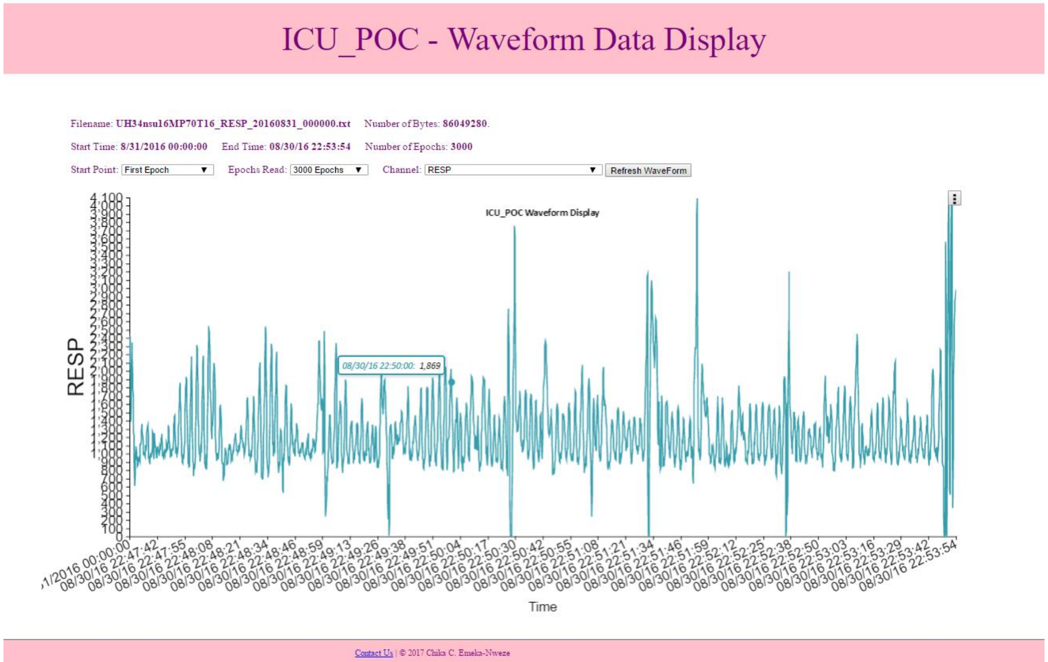

Figure 4.5a Physiological Waveform Data Visualization – RESP

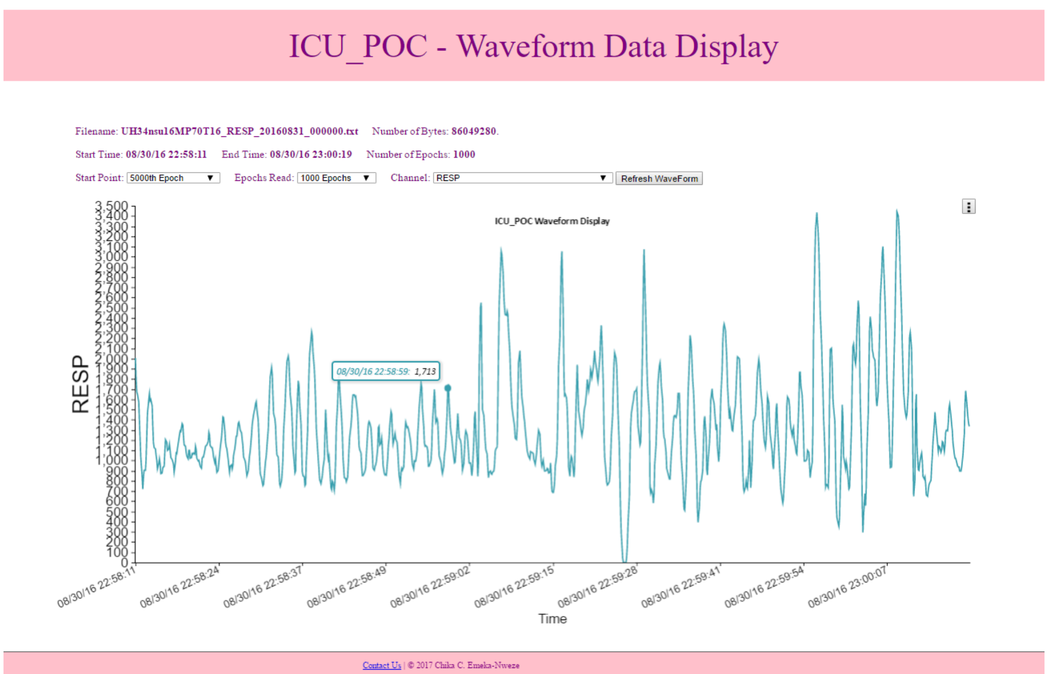

Fig. 4.5b Physiological Waveform Data Visualization – RESP (Zoomed)

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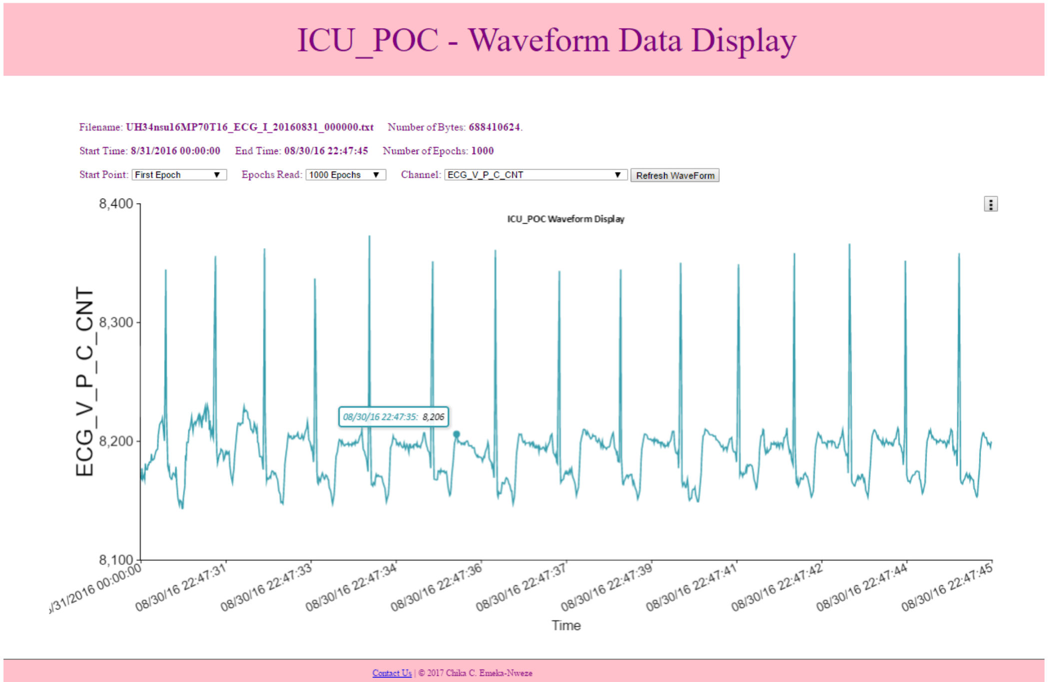

Figure 4.5c Physiological Waveform Data Visualization – ECG_V_P_C_CNT

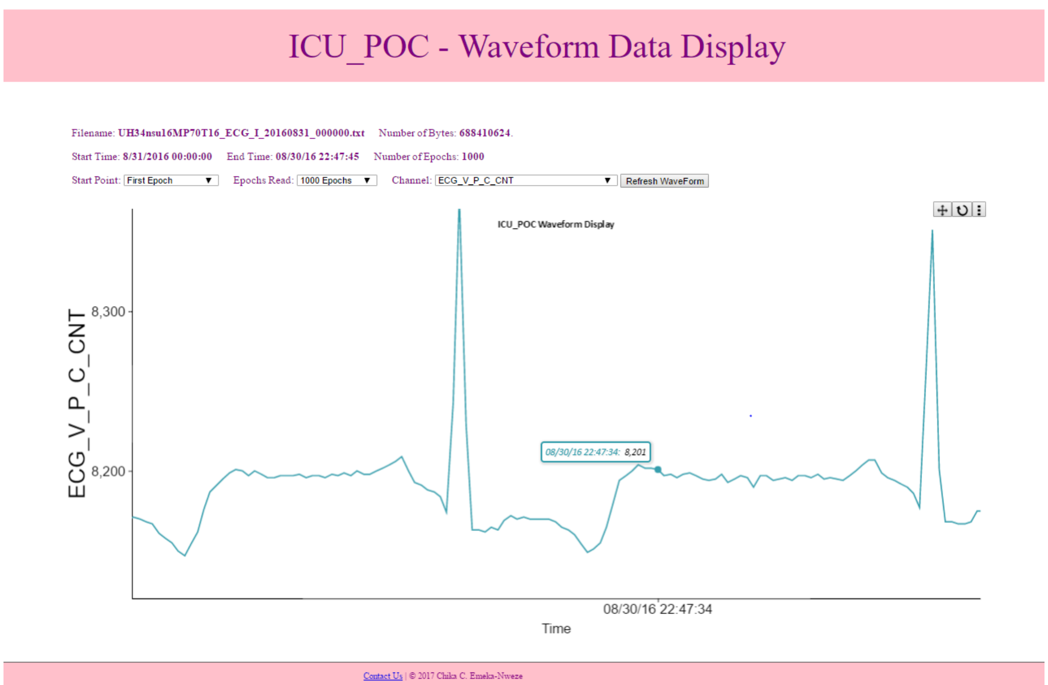

Figure 4.5d Physiological Waveform Data Visualization – ECG_V_P_C_CNT (Zoomed)

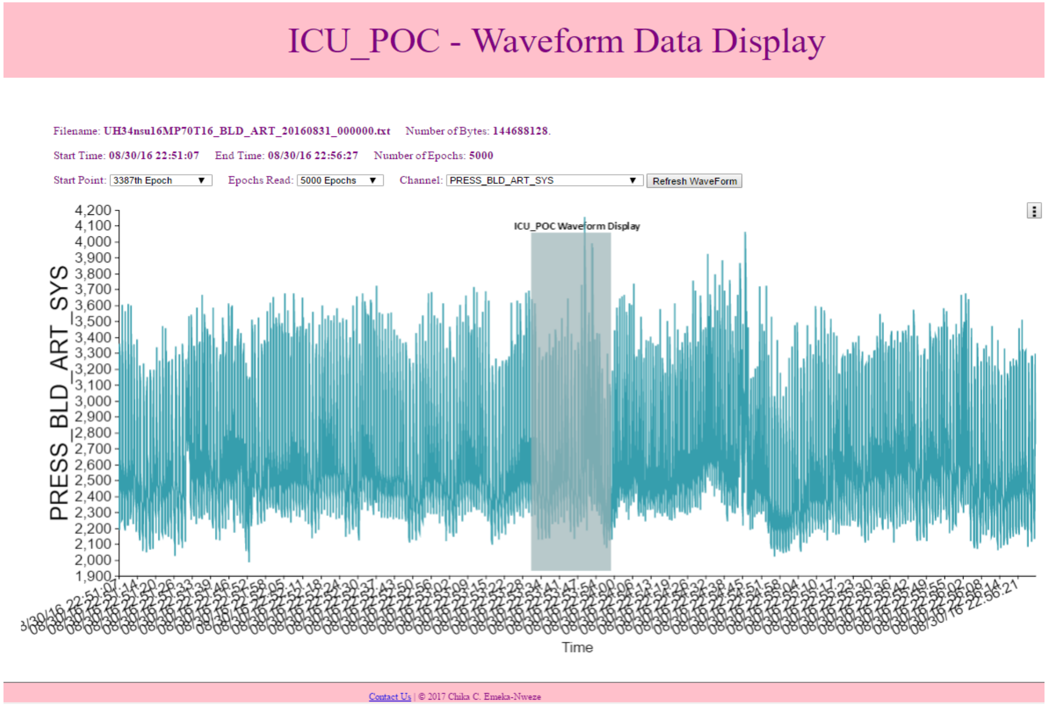

Figure 4.5e Physiological Waveform Data Visualization – PRESS_BLD_ART_SYS

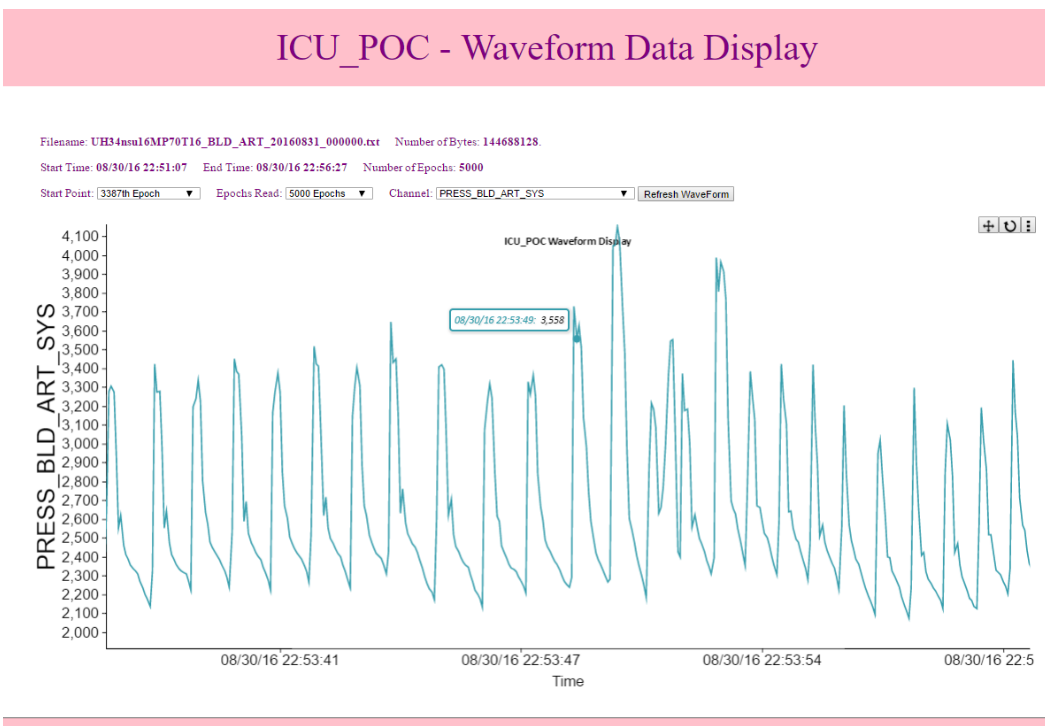

Figure 4.5f Physiological Waveform Data Visualization – PRESS_BLD_ART_SYS (Zoomed)

4.6 ICU_POC Query Engine

The query engine is interfaced with the OpenEMR database. Each query is with regards to the approved and transferred records from the ICU_POC application to the OpenEMR. The query interface can be opened from the link created within the OpenEMR or from the ICU_POC such that the physicians do not have to go far in obtaining the needed information. The query engine has the query interface that captures the criteria for the query. There are several parameters as described below which the user should capture before a good query can be executed. The list can be expanded as the need arises. The query is made for a patient as well as for several patients with the same. Below is a few of possible query criteria we can use to make inquiries on the EMR database.

Patient ID {E.g. 12345677}: This takes the patient ID number. It is an optional field in which a blank field means the query is based on all patients of the selected parameters. Start Date {MM/DD/YYYY}: * - The start date takes the approval date of the data. End Date {MM/DD/YYYY}: * - The start date takes the approval date of the data.

SAT_02 Range {E.g.: 90-100}: * - The channels have different range of values that can be inquired about and can be guided by the example on the page.

NONINV_SYS Range {E.g.: 100-150}: * - The channels have different range of values that can be inquired about and can be guided by the example on the page.

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NONINV_DIA Range {E.g.: 50-70}: * - The channels have different range of values that can be inquired about and can be guided by the example on the page. Parameters marked with * are required. – The fields marked with asterisk (*) are all required to make a successful search.

With a successful query, the output result is displayed in a tabular form showing the count of the records as well as the search criteria that were used. The page also has a link with which to generate a visual display of the phenotypic and physiological wave form data. On clicking the “Generate Image” button, it gets the raw files stored in the database and regenerates the charts as desired.

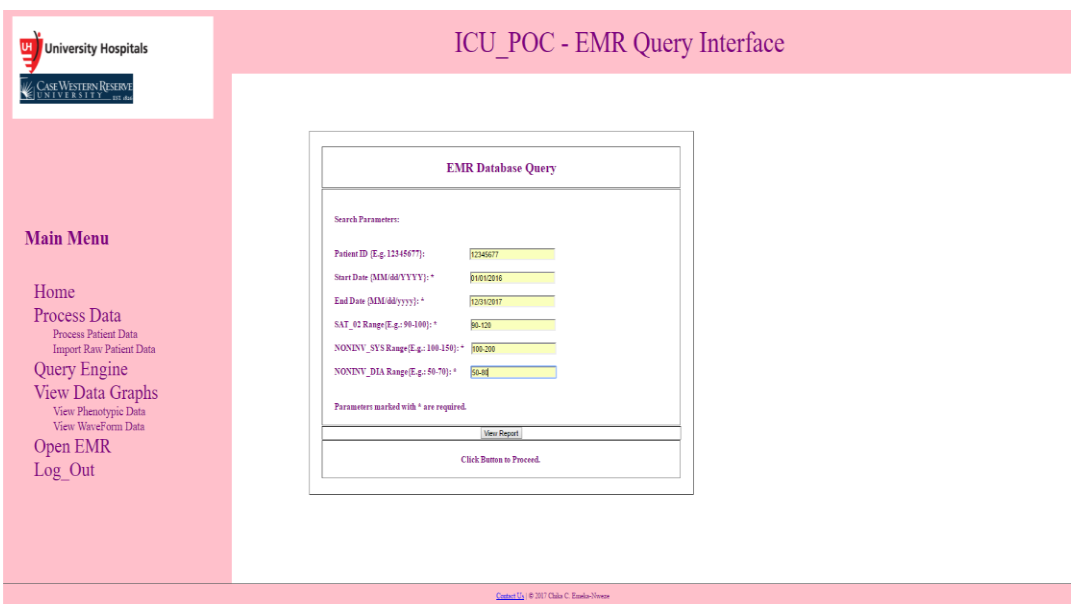

Figure 4.6a ICU_POC Query Page for a Specified Patient

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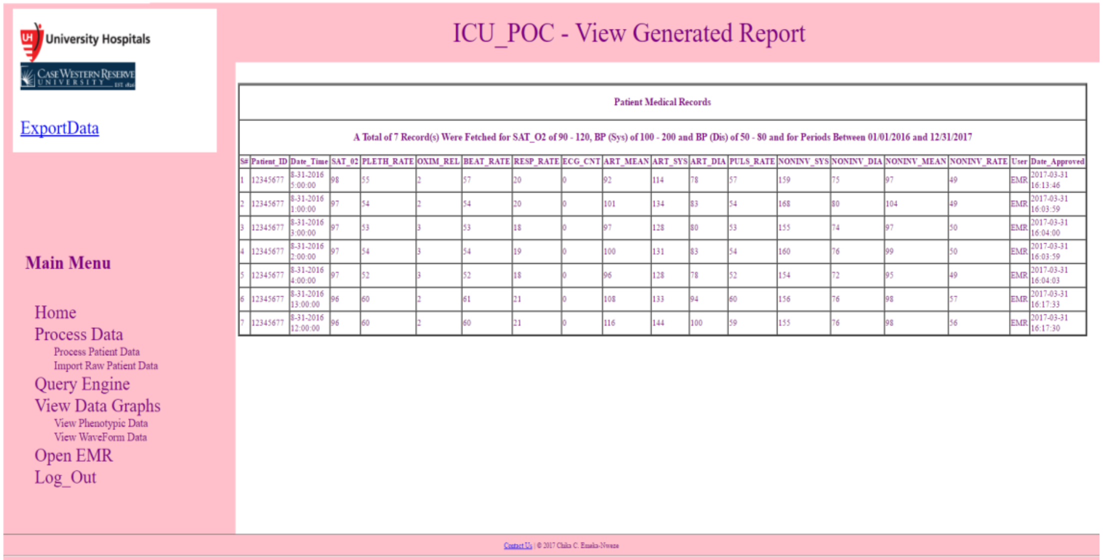

Patient Medical Records

A Total of 7 Record(s) Were Fetched for SAT_O2 of 90 - 120, BP (Sys) of 100 - 200 and BP (Dis) of 50 - 80 and for Periods Between 01/01/2016 and 12/31/2017

S#	Patient_ID	Date_Time	SAT_02	PLETH_RATE	OXIM_REL	BEAT_RATE	RESP_RATE	ECG_CNT	ART_MEAN	ART_SYS	ART_DIA	PULS_RATE	NONINV_SYS	NONINV_DIA	NONINV_MEAN	NONINV_RATE	User	Date_Approved
1	12345677	8-31-2016 5:00:00	98	55	2	57	20	0	92	114	78	57	159	75	97	49	EMR	2017-03-31 16:13:46
2	12345677	8-31-2016 1:00:00	97	54	2	54	20	0	101	134	83	54	168	80	104	49	EMR	2017-03-31 16:03:59
3	12345677	8-31-2016 3:00:00	97	53	3	53	18	0	97	128	80	53	155	74	97	50	EMR	2017-03-31 16:04:00
4	12345677	8-31-2016 2:00:00	97	54	3	54	19	0	100	131	83	54	160	76	99	50	EMR	2017-03-31 16:03:59
5	12345677	8-31-2016 4:00:00	97	52	3	52	18	0	96	128	78	52	154	72	95	49	EMR	2017-03-31 16:04:03
6	12345677	8-31-2016 13:00:00	96	60	2	61	21	0	108	133	94	60	156	76	98	57	EMR	2017-03-31 16:17:33
7	12345677	8-31-2016 12:00:00	96	60	2	60	21	0	116	144	100	59	155	76	98	56	EMR	2017-03-31 16:17:30

Figure 4.6b ICU_POC Query Result for a Specified Patient

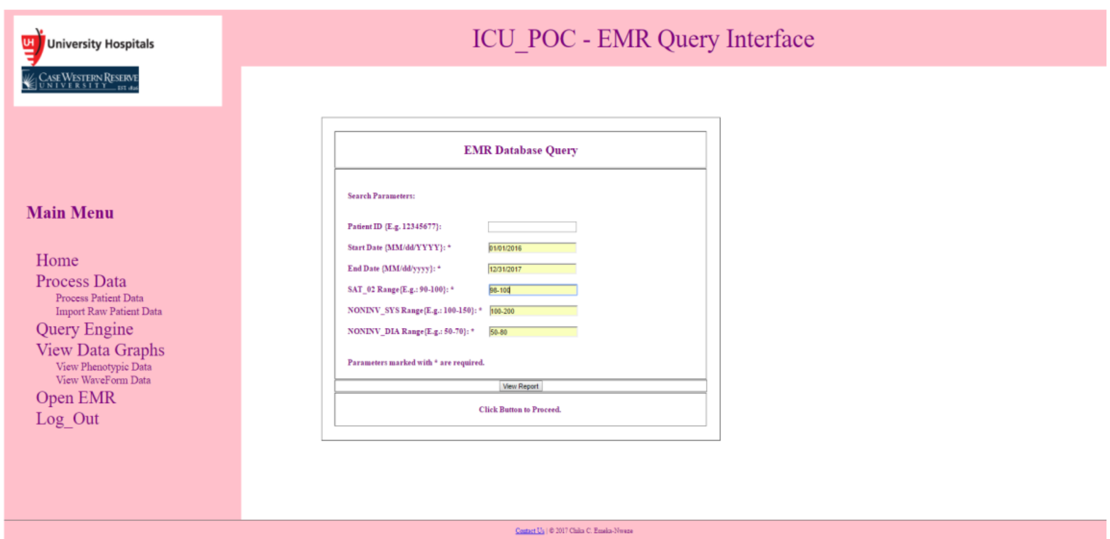

Figure 4.6c ICU_POC Query across All Patient

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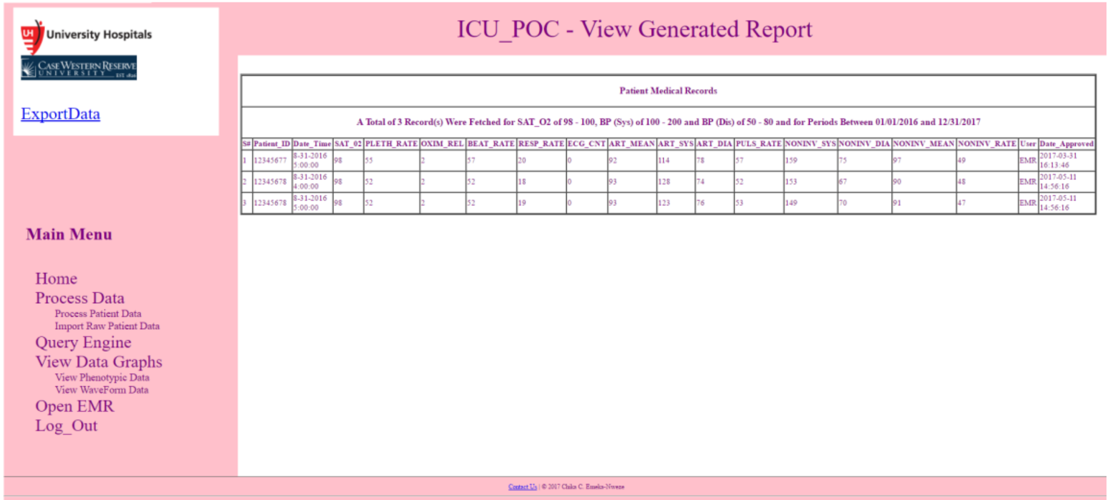
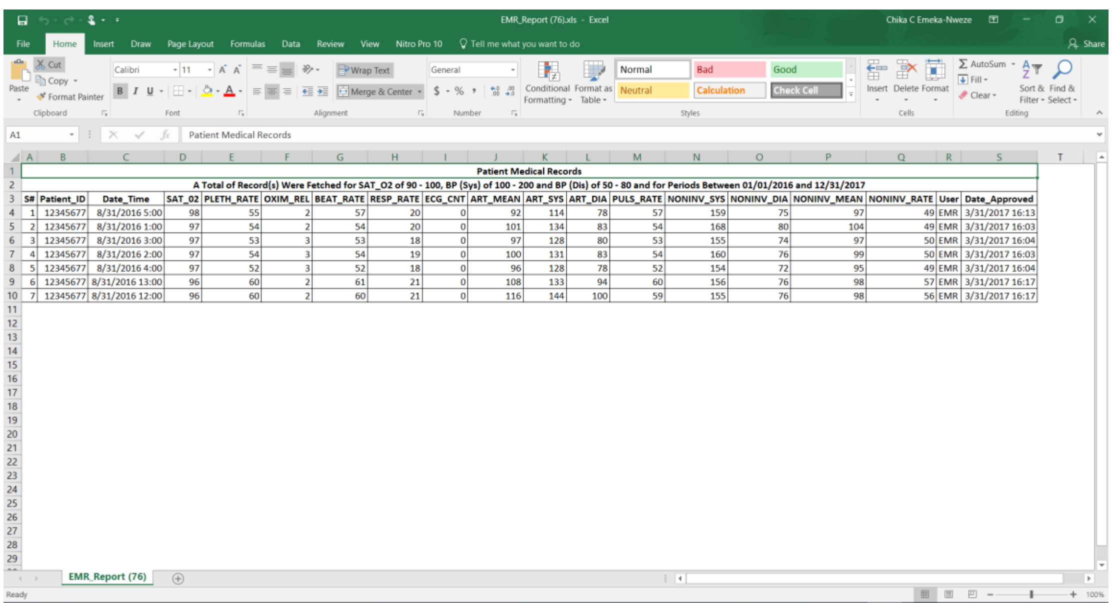


Patient Medical Records

A Total of 3 Record(s) Were Fetched for SAT_O2 of 98 - 100, BP (Sys) of 100 - 200 and BP (Dis) of 50 - 80 and for Periods Between 01/01/2016 and 12/31/2017

S#	Patient_ID	Date_Time	SAT_02	PLETH_RATE	OXIM_REL	BEAT_RATE	RESP_RATE	ECG_CNT	ART_MEAN	ART_SYS	ART_DIA	PULS_RATE	NONINV_SYS	NONINV_DIA	NONINV_MEAN	NONINV_RATE	User	Date_Approved
1	12345677	8-31-2016 5:00:00	98	55	2	57	20	0	92	114	78	57	159	75	97	49	EMR	2017-03-31 16:13:46
2	12345678	8-31-2016 4:00:00	98	52	2	52	18	0	93	128	74	52	153	67	90	48	EMR	2017-05-11 14:56:16
3	12345678	8-31-2016 5:00:00	98	52	2	52	19	0	93	123	76	53	149	70	91	47	EMR	2017-05-11 14:56:16

Figure 4.6d ICU_POC Query Result across All Patient



Patient Medical Records

A Total of Record(s) Were Fetched for SAT_O2 of 90 - 100, BP (Sys) of 100 - 200 and BP (Dis) of 50 - 80 and for Periods Between 01/01/2016 and 12/31/2017

S#	Patient_ID	Date_Time	SAT_02	PLETH_RATE	OXIM_REL	BEAT_RATE	RESP_RATE	ECG_CNT	ART_MEAN	ART_SYS	ART_DIA	PULS_RATE	NONINV_SYS	NONINV_DIA	NONINV_MEAN	NONINV_RATE	User	Date_Approved
1	12345677	8/31/2016 5:00	98	55	2	57	20	0	92	114	78	57	159	75	97	49	EMR	3/31/2017 16:13
2	12345677	8/31/2016 1:00	97	54	2	54	20	0	101	134	83	54	168	80	104	49	EMR	3/31/2017 16:03
3	12345677	8/31/2016 3:00	97	53	3	53	18	0	97	128	80	53	155	74	97	50	EMR	3/31/2017 16:04
4	12345677	8/31/2016 2:00	97	54	3	54	19	0	100	131	83	54	160	76	99	50	EMR	3/31/2017 16:03
5	12345677	8/31/2016 4:00	97	52	3	52	18	0	96	128	78	52	154	72	95	49	EMR	3/31/2017 16:04
6	12345677	8/31/2016 13:00	96	60	2	61	21	0	108	133	94	60	156	76	98	57	EMR	3/31/2017 16:17
7	12345677	8/31/2016 12:00	96	60	2	60	21	0	116	144	100	59	155	76	98	56	EMR	3/31/2017 16:17

Figure 4.6e ICU_POC Query Result Exported to Microsoft Excel Sheet

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4.7 Phenotypic vs Physiological Data Visualization

There is the ability to compare patients observed data using the phenotypic and physiological visual displays. ICU_POC application allows the user to generate the phenotypic chart sis by side the physiological and the physicians can observe and analyze the two charts side by side with a bit to make possible inferences. This comparison is very necessary as that will give the physician a thorough understanding of the entire patient's body system at any specific time. The rest of the figures (Figures 4.7a though Figure 4.7e) will be looking at different visualization comparison, zooming in to a particular section of the phenotypic and trying to view same epoch in the physiological waveform chart.

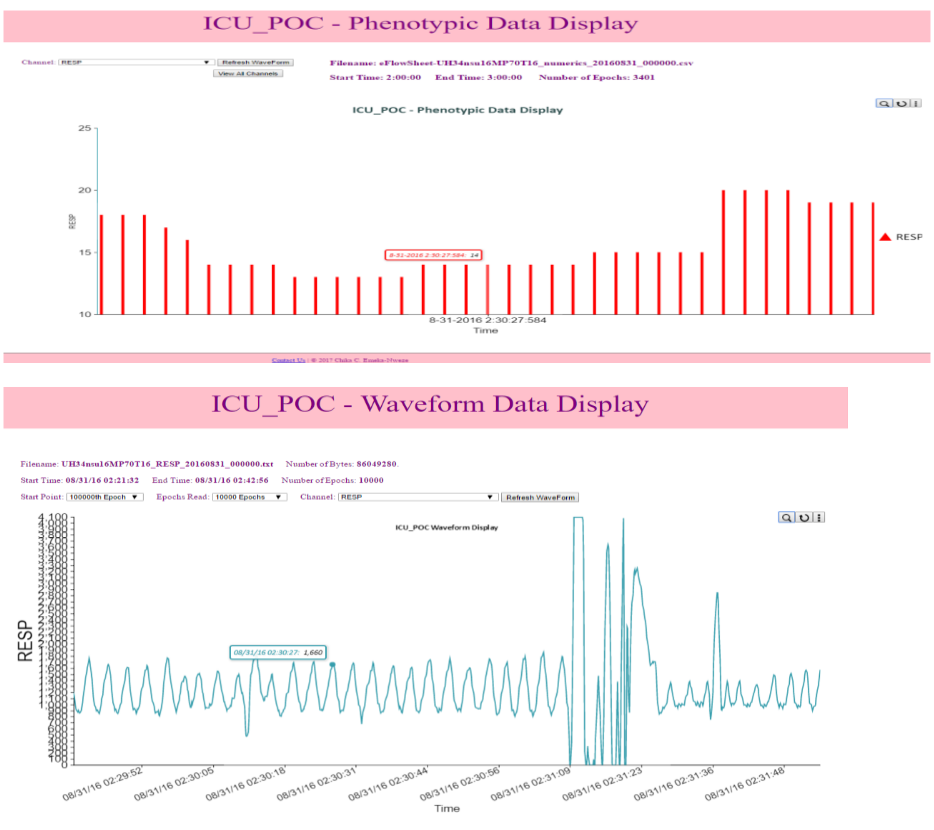

Figure 4.7a Visualization Comparison of the phenotypic vs Physiological Data

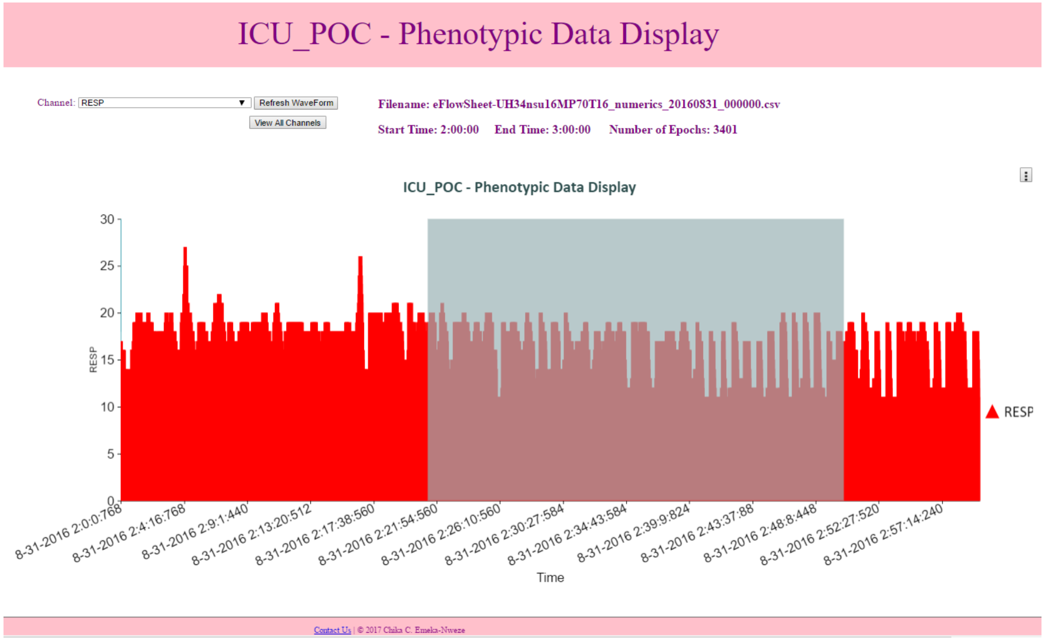

Figure 4.7b Visualization Comparison of the phenotypic vs Physiological Data Contd.

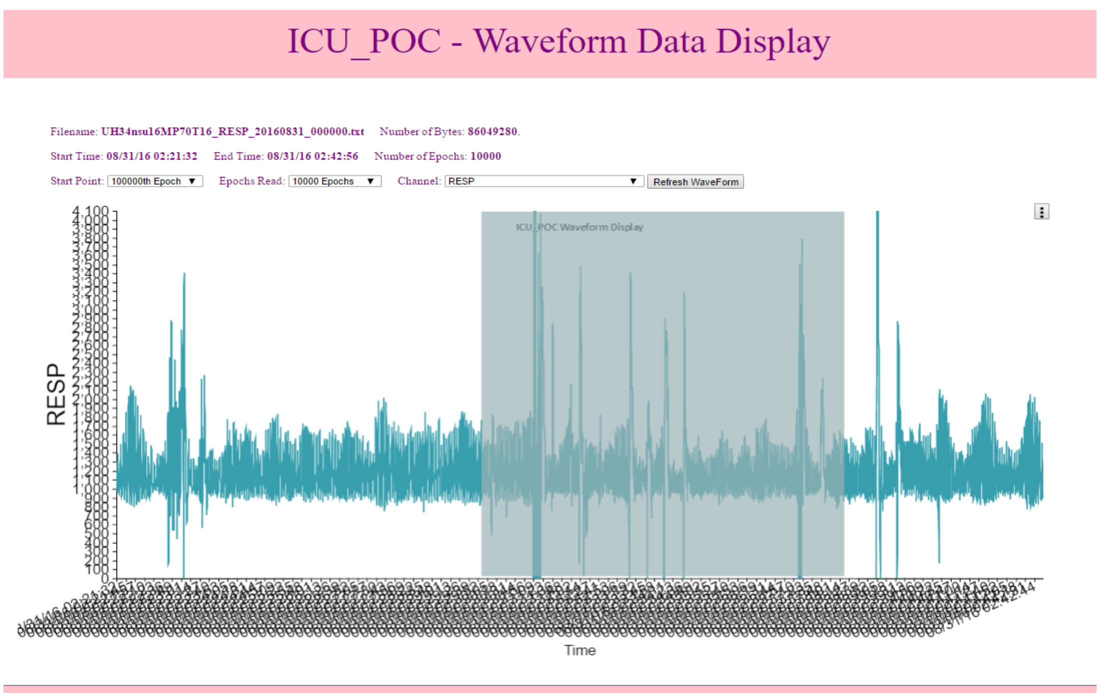

Figure 4.7c Visualization Comparison of the phenotypic vs Physiological Data Contd.

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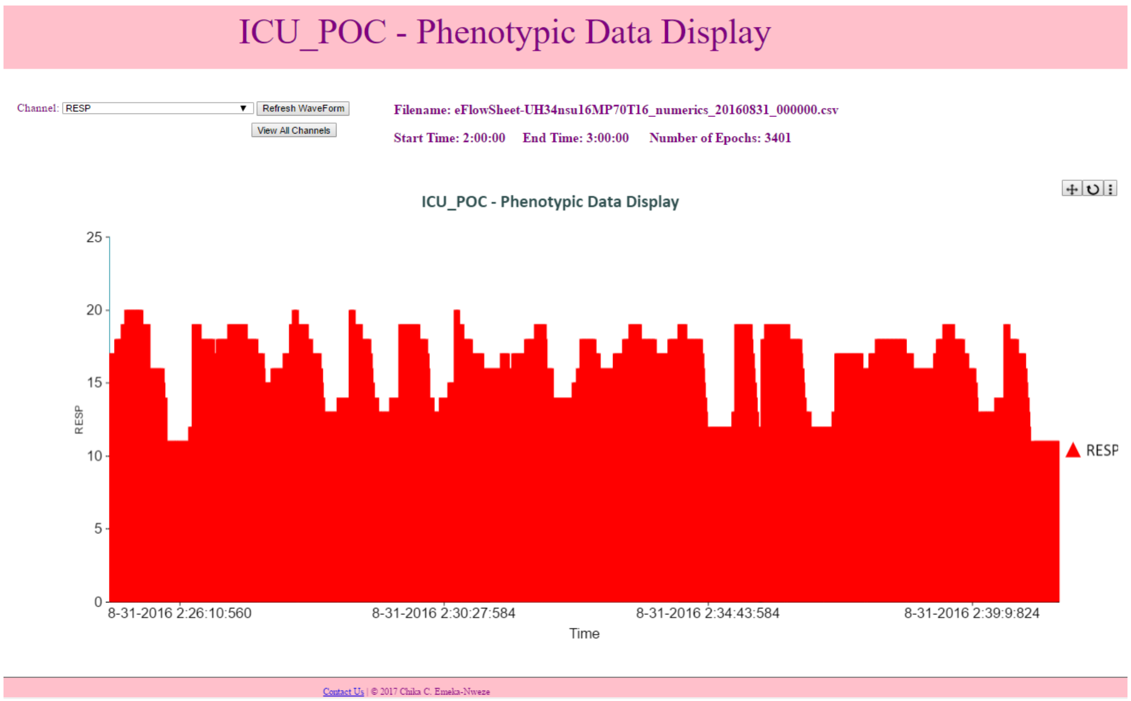

Figure 4.7d Visualization Comparison of the phenotypic vs Physiological Data Contd.

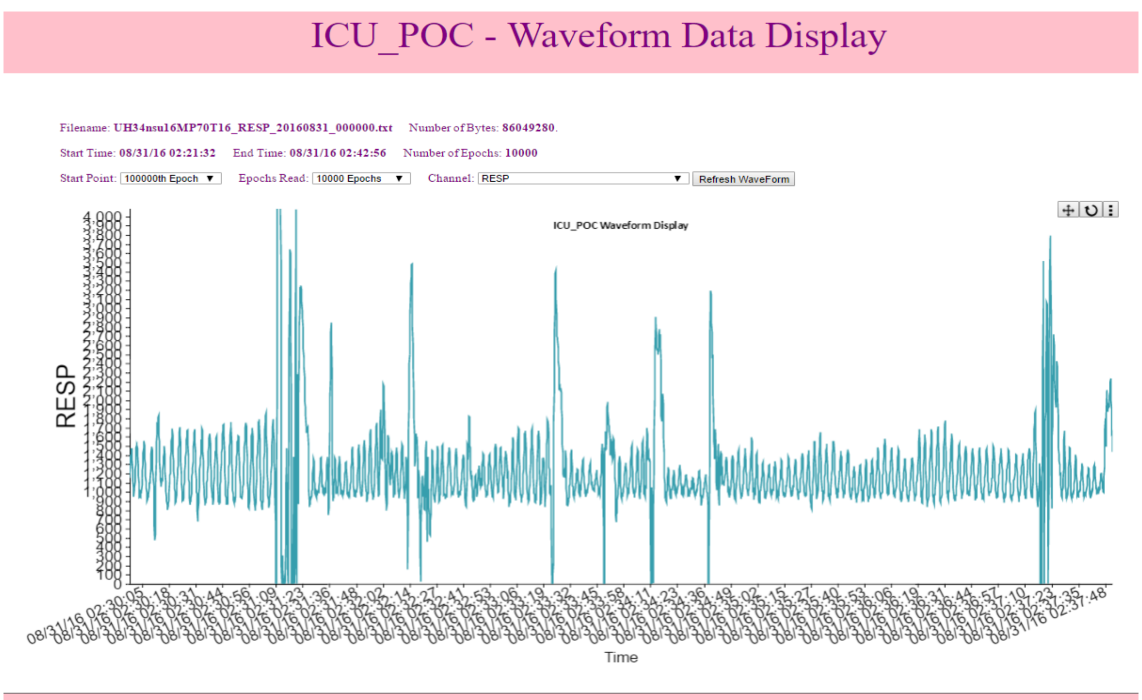

Figure 4.7e Visualization Comparison of the phenotypic vs Physiological Data Contd.

4.8 ICU_POC and EMR Bidirectional Data Flow

As earlier mentioned on section 4.5 above, ICU_POC can regenerate the phenotypic and physiological data visual display. This is achieved by querying the database for a patient or record. On finding the record of interest, clicking the "Generate Waveform" button on the record, fetches the raw files stored in the database and regenerates the charts as desired.

This is very important in that is saves the stress of saving all the generated images except for those of immediate interest. The rest of the records are left with saving only the parsed phenotypic and physiological files in the database and only regenerating the files when necessary.

In a nutshell, ICU_POC has the bidirectional capability of taking a raw file and processing it into hourly records and from the records go back to see the epoch data based on the images regenerated. A query to the OpenEMR will pool a set of interested records based on the criteria selected at the query page. From there one can go back to the visualization to view any interesting record.

ICU_POC processes has been demonstrated and the visualization overlaid. Having looked at the design and actual implementation of ICU_POC, Chapter five the gains, limitations, and suggestions on the possible future work that relates to this project. It will summarize what ICU_POC system is and bring this work to a completion.

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Chapter 5.0

Summary and Conclusions

5.4 Summary

In summary, intensive care unit point of care application has been designed and developed to aid physicians in the analysis, diagnoses and treatment of patients with critical health condition at the intensive care unit. The physicians can treat patients in the hospital but having useful and well represented data will go a long way in helping to achieve more positive outcome, especially at the ICU where time is of great importance to the health of the patients.

The population of the older people in the United States is an ever-growing number that need the services of an intensive care unit to a great height. The number of qualified and certified intensivists to manage and care for these population on the other hand is not growing in proportion. Hence there is a need to address the present and future needs of our intensive care units. This piece of work, web-based ICU_POC will in no doubt create a positive effect in this regard by providing the necessary information that will help is fast decision making to reduce the patient length of stay (LOS) in the ICU. It will provide a remote opportunity for the intensivists. They can easily connect to this system and view / manage their ICU patient in a seamless manner.

It is interesting to note that this project has been able to generate visualization chats for the phenotypic and physiological waveform directly from numerical and binary data files respectively. That posed a huge challenge ab initio especially with the technology we have employed. ICU_POC also can recall the raw binary data and reproduce visualization charts by querying the EMR. The query engine can query the EMR system for a single patient enquiry or across many patients based on certain characteristics. This is a feature yet to be achieved with any EMR.

ICU_POC is designed to provide, accurate, fast and accessible data as at when needed. Accurate data collection will be assured since all the data are automatically generated directly from the Philips MP70 monitoring device unto the ICU_POC without any human intervention. Same data is analyzed, visualized and automatically transferred to the ICU for storage as historical and reference data. Data is managed very well and access to data is only clicks of buttons away. Data is useful only when it is accessible and well represented.

This application, will help the physicians to save time from going through numerous data sources available at the ICU before making diagnosis. They can connect to the EMR and as well visualize the phenotypic and physiological signals and make necessary conclusions promptly. It will increase their financial resources as well since medicine is rapidly moving from the traditional fee for services to improving patient outcomes by tying provider reimbursement to quality metrics and embracing electronic medical records as we earlier dealt with in chapter 2.0 above.

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ICU_POC is expected to shorten the time spent at the ICU by patients to a great number. Data will be accessible across different hospital facilities and as such removing the barrier created by distance in the medical treatment. Financially, this system will be beneficial in so many considerations ranging from hospital bills to the cost on relatives who take care of their ill members. As the patients spend less time in the ICU, more resources both technical and human will be made available to care for additional patients within a given period.

Conclusively, ICU_POC has been successful in being able to import data from the generated devices data, extract vital data and process them for analysis. Analysis have been made on the data as well as visualizing the phenotypic and physiological waveform data. Adopted data records could be approved and transferred to the OpenEMR for storage and accessibility by physicians for reference and historical archive. Above all it will grant the intensivists the remote capability in managing / monitoring ICU patients.

5.5 Limitations

Some obstacles were encountered during this project that created some limitations. The system was intended to have the data transferred to a live EMR but that was not achieved due to our inability to access the EMR from the University Hospital which we are using as a case study. However, an opportunity was utilized when we got an open sourced EMR – the OpenEMR. It was then used to simulate the actual live data transfer.

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Secondly, since we had no live EMR to connect with, it was not possible to implement the HL7 interface level of security regarding the data transfer. However, the messages were generated but needs some configuration details regarding whichever EMR ICU_POC will eventually connect with. OpenEMR, on the other hand has no HL7 interface engine to receive HL7 message in its design as at the time of this work.

5.6 Recommendations for future work

5.6.1 Health Level Seven International (HL7)

It will be worth pursuing with the hospital administration to see the possibility of interconnecting with their EMR system through their HL7 interface. This will create strong security feature to ICU_POC. Some level of collaboration will be involved with any interested hospital so that their EMR could be interfaced with this application.

5.6.2 Alarms

Alarms are auto generated signals telling a deviation from a normal observation of patient's physiological signals by a monitoring device [79]. Although the Data Acquisition System mentioned earlier in chapter 3 supports the collection of real-time physiological data, such as waveforms, numerics as well as alarm data, alarms were not part of the scope of this project. It is therefore important to furthermore carry out analysis on that aspect of data to understand the information and benefits that could be derived from the alarm data.

5.6.3 Implementation of ICU_POC Idea in other Hospital Units

The idea of integrating the other hospital systems with the EMR system will go a long way in helping the health industry. ICU_POC could be expanded to create an interface where doctor's comments as well as nurse notes could all be captured and attached to the patient's record for future reference. This will reduce the issue of having to use so many systems to manage a single patient. It will provide an all-in-one system for patient care management.

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Appendix

ICU_POC Code List

Name	**Function**
index.php	This is the main code that calls every other code within the application.
EMR_AddUser.php	To create a new user on the application.
EMR_Approve.inc.php	To Approve hourly records.
EMR_Data.inc.php	Aggregates the epoch records into hourly records.
EMR_Data_New.inc.php	Extracts good data from the parsed data file for processing.
EMR_Details.inc.php	Some sort of CSS features on the page.
EMR_DetailsPrint.inc.php	Some sort of CSS features on the page.
EMR_DirList.inc.php	Listing of extracted text files for processing.
EMR_Flowsheet.inc.php	Screen display of processed granulated data.
EMR_Footer.inc.php	Some sort of CSS features on the footer.
EMR_Form.inc.php	Drills down the hourly data into its granulated with the summary records both displayed.
EMR_HdrValues.inc.php	Some values for creating form headers.
EMR_Header.inc.php	Some sort of CSS features on the header.
EMR_JScript.inc.php	This has some JavaScript that runs on most pages.
EMR_Login.html	Login page for the application.
EMR_Logout.php	Logout page for the application.
EMR_Menu.inc.php	Main home page for the application.
EMR_Nav2x.inc.php	Navigation for the Form page
EMR_NewUser.inc.php	New User registration page.
EMR_Page.inc.php	Creates paging on the display pages.
EMR_POC.css	The CSS file for the application pages.
EMR_Prelim.inc.php	Preliminary HTML codes for the pages.
EMR_PrintSection.inc.php	Print codes for some pages.
EMR_PrintSection2.inc.php	Print codes for some pages.
EMR_Query.inc.php	Query engine that queries the EMR database.
EMR_Raw.inc.php	Displays extracted parsed data before processing.
EMR_RawList.inc.php	Lists the raw files for selection and extraction.
EMR_SelectAll.inc.php	JavaScript for Check All button on the pages.
EMR_Showimage.php	Displays images thumbnail.
EMR_Transfer.inc.php	Transfers data to the EMR database.
EMR_Transfer_HL7.inc.php	Displays generated HL7 message from the Transfer page.

EMR_Validate.php	Validates user login data.
EMR_View.inc.php	Displays result of data query from the database.
EMR_ViewExport.php	Exports the query report to an excel document.
EMR_ViewPhenoAll.inc.php	Visualization of multiple phenotypic channels.
EMR_ViewPhenoS.inc.php	Visualization of single phenotypic channels.
EMR_ViewWave.inc.php	Visualization of single physiological waveform channel.

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