TICUM: An Approach to Tele-Medicine for Rural ICUs in Developing Countries

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Abstract— **Highly trained medical staff in the Intensive Care Unit (ICU) need to interpret the high volumes of noisy data generated from the monitors attached to their patients. However, in rural ICUs there is shortage of specialist critical care staff to manage the highly complex patients safely and efficiently. One solution is to use tele-monitoring to allow medical staff in another location to receive ICU data over the internet to enable them to provide remote assistance to rural ICUs. In this paper we propose an architecture for tele-monitoring to provide enhanced decision support to rural ICUs in order to improve the quality of patient care by giving accurate summaries.**

Keywords- ***Telemedicine, tele-monitoring, tele-ICU, MVC***

I. INTRODUCTION

The Intensive Care Unit (ICU) is a specialist ward in a hospital where critically ill patients reside for the management of their severe illnesses. These patients are connected to monitors to display their vital physiological signs in real-time - this data enables medical staff to assess the state of the patient. Our particular area of interest is the cardiovascular (e.g heart rate and blood pressure) and respiratory (e.g partial pressure of oxygen and partial pressure of carbon dioxide) data produced by the monitors.

The ICU monitors generate large quantities of high-frequency and noisy data which must be analysed to inform clinical decisions. However, in rural areas in developing countries there is shortage of trained medical staff to interpret this complex data.

We therefore believe that medical staff in rural ICUs in developing countries could benefit from remote assistance in the interpretation of ICU monitor data to decide which interventions are appropriate, particularly if such a decision has to be made in the absence of more senior staff. Indeed it has been proven that technology-enabled remote care can be used to provide continuous ICU patient management and to achieve improved clinical and economic outcomes when on-site intensivist coverage was not available [1].

To assist in the delivery and quality of critical care we propose a low-cost telemedicine system called TICUM (Telemedicine Intensive Care Unit Monitor) for receiving and transmitting data from the monitors of a rural ICU in a developing country for purposes of remote assistance. Telemedicine is the use of telecommunication networks for the delivery of healthcare and medical education across a distance to mitigate issues of misdistribution of healthcare resources [2]. ICU Telemedicine expands the geographic range of ICU staff and also allows a single specialist to simultaneously monitor multiple patients on a continuous basis [3]. The goal of TICUM is to provide a multi-media tool to receive rural ICU monitor data and to display the data graphically and to provide a textual analysis of the data to enable remote clinical decision support.

TICUM incorporates the following forms of telemedicine: tele-ICU and tele-monitoring. Tele-ICU is remote critical care telemedicine which is considered as an on-demand means of networking critical care consultants with facilities lacking intensivists. Tele-monitoring is the use of information technology to monitor patients at a distance [4].

The structure of this paper is as follows. Section 2 provides our analysis of the rural ICU in the form of an activity diagram and use case diagram in order to determine how TICUM will be developed. Section 3 discusses the architecture of TICUM system which is our approach to ICU Telemedicine for a developing country. Section 4 discusses the results we have obtained so far. Section 5 discusses related work. Section 6 gives a discussion of our approach and future work. Final conclusions are given in section 7.

II. ANALYSIS OF RURAL ICU USING TELEMEDICINE

Figure 1 shows the activity diagram of the rural ICU and the role of TICUM for remote assistance. It can be seen that there are 5 actors in the rural ICU who interact with other actors and play specific roles.

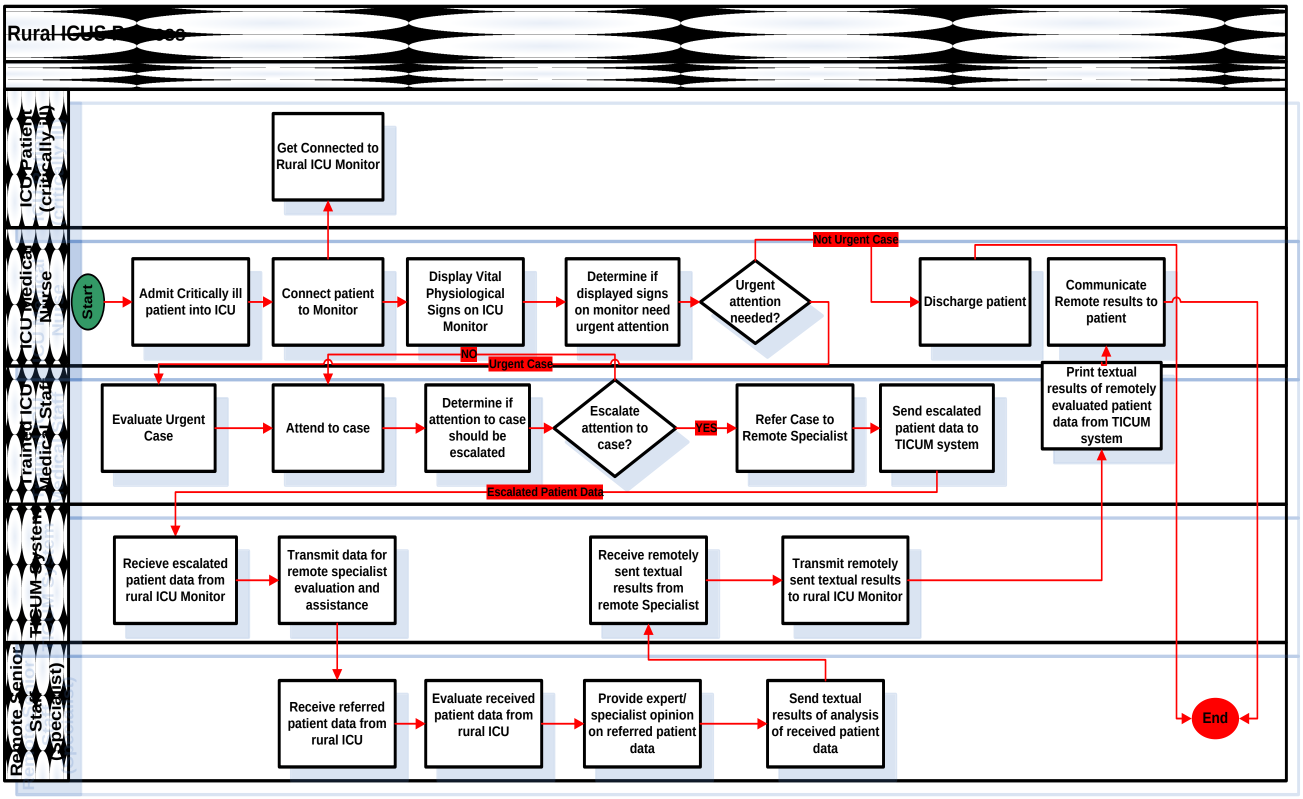

Figure 1 – Activity diagram of the rural ICU and the role of TICUM

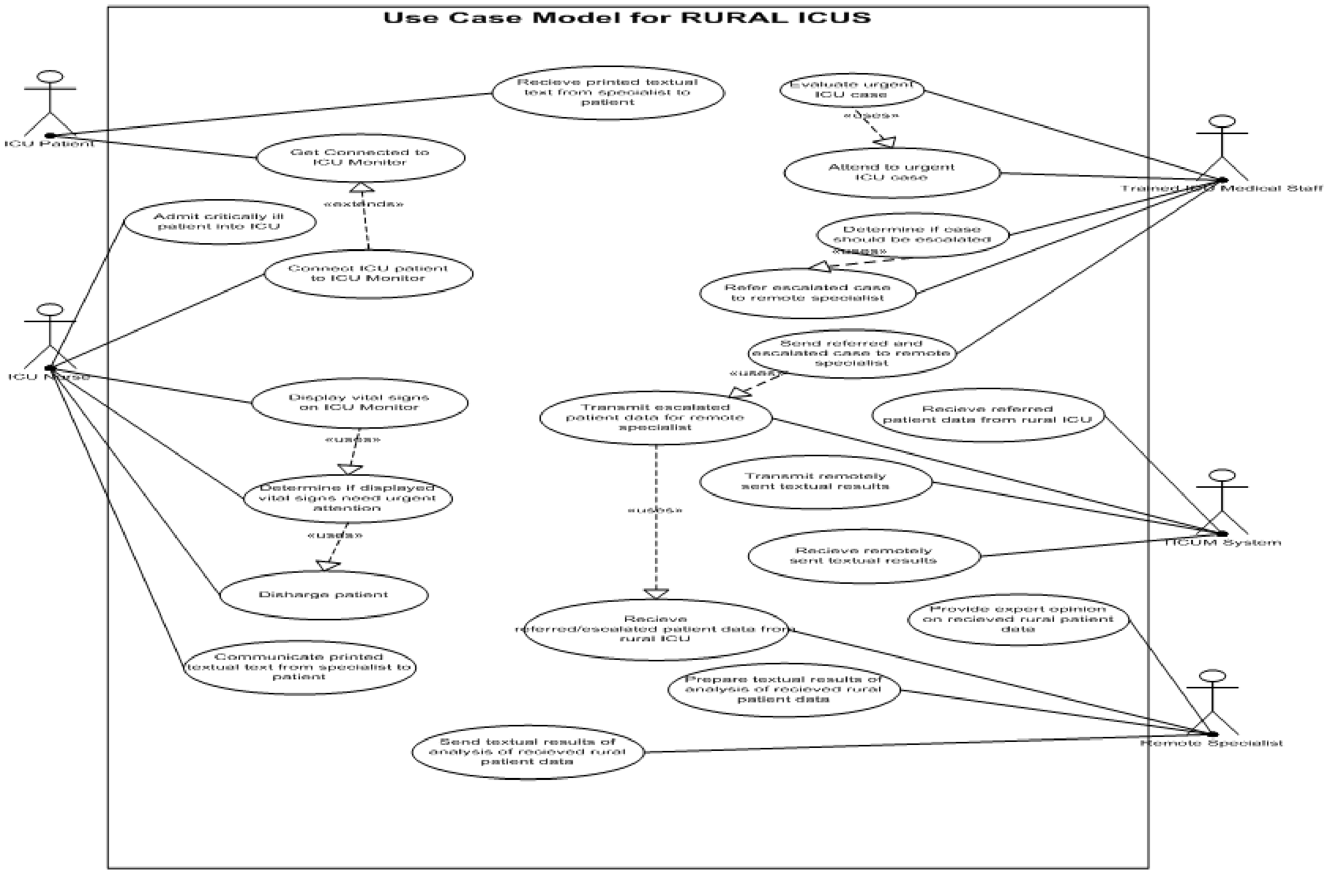

Figure 2 – Use case diagram for the rural ICU

The ICU patient is connected to the ICU monitors to display their vital physiological signs in real-time - this data enables medical staff to make patient state assessments either in the rural ICU or with remote assistance.

The ICU medical nurse is responsible for admitting, managing and discharging the ICU patient.

Trained ICU medical staff (doctors at various levels) make patient state assessments to determine what therapies and actions need to be taken to assist the ICU patient. If they require remote assistance then they can use the TICUM system

The TICUM system receives monitor data from the rural ICU patient and transmits it to a remote specialist for remote assistance. Likewise, TICUM receives textual assistance from remote specialists and transmits it back to the rural ICU for clinical decision support.

The remote ICU specialist receives rural ICU monitor data remotely and transmits back textual analysis of the data to the rural ICU for clinical decision support.

An alternative representation of the activity diagram is shown as a use case diagram in figure 2.

We need an architecture that is able to fulfill the role of the TICUM system for transmitting and receiving data at the rural ICU and the remote sites. The architecture should, therefore, be able to provides asynchronous communication

III. THE TICUM SYSTEM

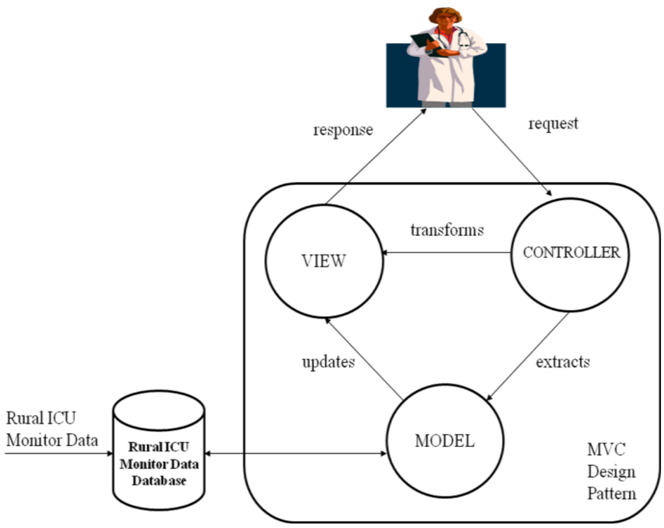

Figure 3: Architecture of TICUM

The goal of TICUM is to provide a multi-media tool to receive rural ICU monitor data and to display the data graphically and to provide a textual analysis of the data to enable remote clinical decision support. TICUM will allow remote medical staff to choose particular patients together with time ranges of their ICU monitor data to display and analyze from an interactive interface.

Figure 3 depicts the general architecture of the TICUM system for displaying and analyzing rural ICU monitor data in a developing country for the purposes of remote assistance. TICUM is based on the Model-View-Controller (MVC) design pattern. In software design, a design pattern is a general solution to a re-occurring problem - it is a description or template for how to solve a problem that can be used in many different situations. They extract the high level relationships and interactions between objects and reuse their behaviours from application to application without specifying the final application classes or objects that are involved - they are effectively a skeleton or framework for which an application will be built.

The MVC design pattern separates objects into 3 processes: the *Model* for maintaining data; the *View* for displaying all or a portion of the data; and the *Controller* for handling events that affect the model or view. Due to this separation, each category can be changed or replaced independently without affecting the others. The MVC is commonly used by applications that need the ability to maintain multiple views of the same data - in our case we wish to have 2 views of the ICU monitor data: graphs of the data as well as a textual analysis of the data.

We will describe each of the processes of the MVC design pattern and describe how they have been adapted for the TICUM system for receiving and presenting rural ICU data for remote analysis.

The *Model* is the domain-specific structure of the data on which the application operates as well as the application-specific operations on those data – it is effectively the database system. In TICUM, the model receives data in real-time from the rural ICU monitors and stores it in a database to enable the display of the data to medical staff around the world for analysis.

The *View* manages the display of the data from the model into a suitable form to an end-user. The View can present data in many forms. In TICUM the View will output the remote ICU monitor data in graphical form and provide textual analysis for clinical decision support - this will be done on an internet browser.

The *Controller* interprets user actions (e.g mouse clicks and keystrokes) and user input into application function calls to change the model, or view, or both. Whenever a controller changes a model's data, all dependent views will be automatically updated. Similarly, whenever a controller changes a view, the view gets data from the underlying model to refresh itself. In TICUM, the Controller interprets the choice of patient together with the range of data points to view

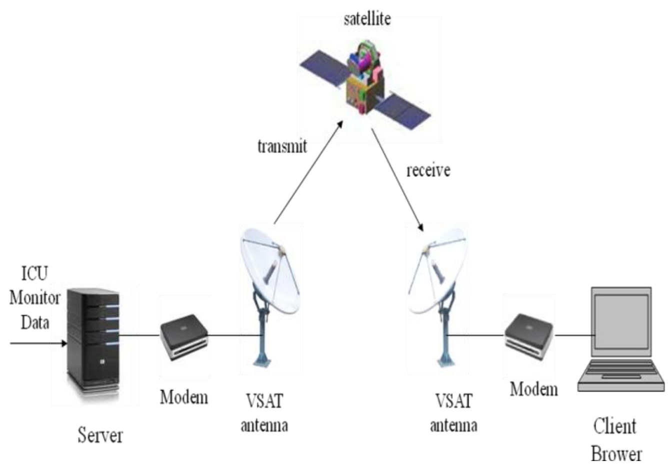

Figure 4: Architecture for TELE-ICU

and extracts the data from the Model and transfers the data to the View process for it to display the data.

For our system to be operational, rural ICUs only need to use VSAT to transmit the monitor data. VSAT (Very Small Aperture Terminal) is based on the TCP/IP network protocol with a very broad spectrum of applications. VSATs access satellites in orbit to relay data to various remote stations around the world. VSAT technology is used for two-way satellite internet provisions – this allows medical staff around the world to receive rural ICU monitor and to transmit information back to rural ICU medical staff for remote assistance. Apart from a terminal and a little dish antenna, no other infrastructure is required.

Figure 4 depicts the general architecture of the TELE-ICU system for transmitting and receiving rural real-time ICU monitor data in rural ICUs for a developing country for the purposes of remote assistance. The real-time data generated from the ICU monitors are recorded in a server and, using a transceiver in a modem, the data is transmitted using a VSAT antenna to an orbiting satellite for a client anywhere in the world to receive. Using the transceiver in their modem, the client will receive the data through their VSAT antenna and present it on a browser for remote assistance. The advantage of this wireless network architecture is that distance will not hamper data transmission.

IV. RESULTS

Figure 5 shows the output of TICUM. The interface is partitioned into 3 frames: a main frame to display the rural ICU monitor data in graph form; an input frame (top right) to choose the patient and the range of data points to view on the main frame; and an analysis frame (bottom right) to output a textual analysis of the data displayed in the main frame. The input frame is effectively the controller that controls the output (view) of the main and analysis frames by taking requests from the users and interrogates the model by running the requested event.

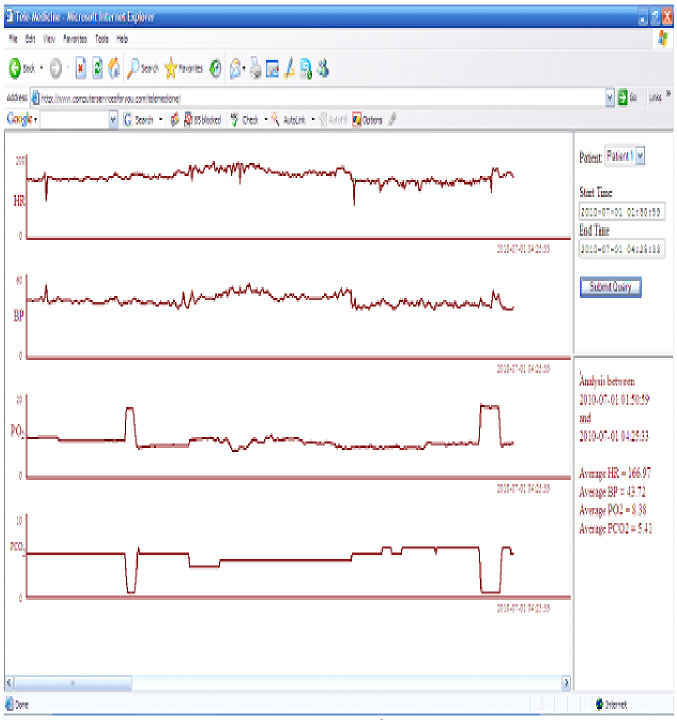

Figure5: Output of TICUM

Given ICU monitor data taken from a neonatal ICU in the UK, figure 5 demonstrates the TICUM system. In our example, the main frame displays 4 signals - note that in the graphs *HR* represents the Heart Rate, *BP* represents the mean Blood Pressure, PO_2 presents the Partial Pressure of Oxygen and PCO_2 represents the Partial Pressure of Carbon Dioxide. In the input frame medical staff can choose the patient they wish to remotely analyse together with the time range of the patient's ICU data - this data determines the graphical output of the main frame and the textual analysis in the analysis frame.

V. RELATED WORK

A common architecture for telemedicine monitoring is the 3-tier architecture. [5] propose a framework where vital signals are collected and processed using a 3-tier architecture. Likewise, PPMIM [6] uses a remote medical monitoring 3-tier architecture with a GSM/GPRS peer-to-peer channel.

The 3-tier architecture is similar to TICUM's MVC - however, topologically they are different. The 3-tier architecture is a client-server architecture which consists of 3 tiers: a *presentation* tier which is the user interface for a client; a *logic* tier which controls the application's functionality by performing related processing; and a *data* tier which consists of database servers to store and maintain the data. A general rule in 3-tier architectures is the presentation (client) tier never communicates directly with the data tier - all communication must pass through the logic tier. Conceptually the 3-tier architecture is linear whereas the MVC architecture is triangular; the View sends updates to the Controller, the Controller updates the Model, and the View gets updated directly from the Model. Moreover, the 3-tier architecture is a system architecture pattern, while MVC is an application architecture pattern.

In a 3-tiered system, it is expected to have different hardware for each tier whereas with MVC everything will most likely be on one system – therefore, with the MVC architecture we save costs making TICUM an inexpensive system.

Telemedicine projects commonly use wireless technologies. There are a number of technologies that are used in telemedicine projects.

PPMIM [6] and AMON [7] uses GSM. GSM (Global System for Mobile communication) is a wireless technology that is capable of voice and data transmission. GSM is not suitable for our application because it has limited bandwidth and is infrastructure location dependent.

MobiCare [8] employs Bluetooth for transmitting data. Bluetooth is a wireless technology that uses low power and short range radio frequencies to communicate between two or more devices. This technology is not suitable for our application because of its limited distance coverage and inadequate security of transmitted data.

In [9] data interchange is done using the TCP/IP network protocol which allows operations over several communication means including POTS. POTS (Plain Old Telephone Service) is a voice-grade service associated with PSTN (Public Service Telephone Network). POTS is restricted to low bandwidth and has no mobile capabilities. It is, therefore, not suitable for our application.

For our system we need to only use VSAT. VSAT is a two-way satellite system with a little dish antenna. The VSAT system is based on the TCP/IP network protocol with a very broad spectrum of applications. VSATs access satellites in orbit to relay data to various remote stations around the world. VSAT technology is used for two-way satellite internet provisions – this allows medical staff around the world to transmit back information to rural medical staff. Apart from the terminal, no other infrastructure is required – therefore it is very useful in remote area data transmission since remote sites distance will not hamper data transmission.

In developing countries, the ability to bypass existing infrastructures with a private network will achieve substantial cost savings. In remote regions such as those in developing countries, the possibility of establishing a distance-insensitive, modest cost network, using a satellite transponder with VSATs and a hub station, enables many cost-effective applications. The broad generality of VSAT uses and applications makes VSAT cost effective.

VI. Discussion and Future Work

In remote regions such as those in developing countries, the possibility of establishing a distance-insensitive, modest cost network, using a satellite transponder with VSATs and a hub station, enables many cost-effective telemedicine applications such as TICUM. For TICUM to be operational we only need a modem and antenna at the rural site – this will make our system a cost-effective application.

Since we are not transmitting large data sets such as images, we do not need a bandwidth-on-demand network. However, for our application we do need the support of isochronous traffic that is time bound and time dependent. We require that our data must be transferred from the rural ICU monitors to the database within a specific time frame and have a low tolerance for delay and loss - this can be achieved using VSAT.

The MVC design pattern is very flexible. Since the data returned by the model is display-neutral - this way, a single model can provide data for any number of display interfaces. This enables TICUM to have a Flash interface or a WAP one; the same model can handle either. The MVC allow changes in one or more of the processes to be made with little or no impact to the rest of the system - this decoupling enhances maintainability, extensibility, and testability.

TICUM is currently a prototype and uses historical data for testing purposes. However, our architecture has great potential which forms the basis for future work.

To enhance TICUM's clinical decision support, the graphs could be filtered to clean up the ([10]) and superimposed with trends ([11]) to enable qualitative reasoning. This reasoning of trends will facilitate the removal of clinically insignificant events and the identification of clinical conditions and the outcome of therapies ([12]) which could be in the analysis frame. Another possibility is to generate textual summaries of neonatal data ([13]).

VII. Summary and Conclusions

We agree with [14] when they say that numerous challenges remain before ICU telemedicine systems become more broadly accepted and applied - these include cost of implementation of the system, resistance to the system by ICU medical staff, and the integration of data systems and clinical information into a remote electronic ICU model.

TICUM is a low-cost system which has potential and its results (though limited) are encouraging. Although not fully developed, we believe it to be a step forward in the development of multi-media telemedicine systems for receiving and transmitting of rural ICU monitor data for the purposes of remote assistance.

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