E-MEDISYS 2008
2nd International Conference: E-Medical System
October 29-31, 2008 – TUNISIA

Using Telemedicine as an Enabler for Antenatal Care in Pakistan

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Abstract: Pakistan is a developing country with more than 60% of its population residing in rural areas with insufficient health care facilities. The recent advancements in telemedicine provide a significant opportunity to the developing countries to develop a health infrastructure that addresses the needs of the rural population. In this paper, we discuss our model of a **remote patient monitoring system** (RPMS) that aims to provide a cost efficient yet effective health care system to the patients residing in the remote areas of Pakistan. In particular, we have initially selected the domain of antenatal care because of an alarming mother mortality rate of Pakistan. This system will augment the existing health care infrastructure.

Key words: Antenatal care, Remote patient monitoring system, Telemedicine

INTRODUCTION

Advancements in Information and Communication Technology (ICT) have brought about a revolution in providing cost efficient, on-line e-services to the people around the globe. Researchers are now focusing on providing critical health care services to the patients at their door steps in real-time by utilizing the services of modern wireless networks and the Internet. Consequently, we see that in many developed countries such systems are planned to provide health care to the aging people at their homes [Demongeot et al. 02]. But in the developing countries the importance of network-based medical system is manifolds because they could act as a catalyst for providing basic health services to the patients who live in underprivileged/underserved rural areas, where health care facilities are either non-existent or of extremely poor quality. The patients in these areas have to travel great distances over a highly inefficient transportation system to reach the nearest health care center. Consequently, a large number of patients die mostly in emergency scenarios. This phenomenon is particularly evident by a very high Maternal Mortality Rate (MMR) and Infant Mortality Rate (IMR) in Pakistan. The current medical statistics clearly indicate that the situation is catastrophic. The gravity of the problem is further aggravated due to the scarcity of skilled health care staff. According to the 'World health statistics' by WHO for 2007, Pakistan has one physician for 1351 people, a nurse for 3225 people, a midwife for every 6666 people, a pharmacist for 20000 people and a dentist for every 20000 people. Only 31% of the total births are attended by the trained birth attendants [WHO 07].

This leads to an infant mortality rate in Pakistan being highest among SAARC countries standing at 70 deaths per 1,000 live births [SPARC 06]. Moreover Pakistan also has the highest maternal mortality rate in South Asia [Dawn 07]. This situation is totally in contrast with the scenario in the developed countries. For example, in comparison to MMR of 350-500 per 100,000 live births in Pakistan, MMR in UK is only 0.6 on the same scale.

The prevailing situation clearly indicates the failure of the current health infrastructure of Pakistan. There is a dire need of revamping this infrastructure by utilizing ICT as an enabler. For attaining millennium development goals of reducing IMR and MMR [UNDP 00], it is necessary to provide universal access to clinical services in a cost effective manner at the primary care level [Adam et al. 05]. So healthcare programs and systems are needed which must ensure effective health measures and inexpensive community based interventions in public and private sectors [Sule & Onayade 06]. Many private and government sector organizations have been thinking on these lines to provide telemedicine facilities to overcome this deficiency in health care in remote areas. Therefore, we propose a **remote patient monitoring system** for

antenatal care in Pakistan. This project has been approved by the National ICT R&D fund, which is interested in supporting research and development initiatives focused at e-health related systems for increasing the effectiveness of services delivered by current healthcare infrastructure in rural areas [ICTRDF 08].

In Section 1 we will briefly review the research and development work going on in different countries and universities regarding telemedicine. Section 2 will highlight the motivation and the objectives to be achieved by our system. Then in Section 3, we discuss the basic architecture of our system. This is followed by a description of the development process model in Section 4. An effective evaluation strategy for the testing of this system is discussed in Section 5. Finally we conclude the paper in Section 6 with an outlook for our future work.

1. Background

We now briefly summarize the projects that are related to our RPMS project; however, none of them is comprehensive enough to meet the requirements to be utilized as RPMS. Various projects and research activities are in progress in the developing countries like China, India and Egypt [Jiehui & Jing 07] [Mishra et al. 06] [Mechael 05]. Many institutions around the globe are carrying out research activities in the field of telemedicine including University College Cork (Ireland) [Donoghue et al. 06], University of Notre dame, Brunel University, University of Miami [Bauer et al. 06], Harvard and Boston University [Malan et al. 04] [Gao et al. 05], University of Virginia [Virone et al. 06], Imperial College London [Thiemjarus et al. 05], The Johns Hopkins University, University of Texas [Hande et al. 06] etc.

Researchers in [Bauer et al. 06] have identified that remote patient monitoring consists of three core components: (1) sensor nodes that monitor the vital signs of the patients, (2), patient level node (usually PDA) for transmission of data to a root node and (3) the root node (server) for gathering information from patient level nodes and maintaining the records. These ideas have been inspired by the latest research reported in [Jiehui & Jing 07] [Mechael 05] [Lin et al. 04] [Kogure et al. 05]. The heart of the system is a server in which electronic medical record or central patient database maintains patient's general information and medical history [Jiehui & Jing 07] [Donoghue et al. 06][Bauer et al. 06][Virone et al. 06].

2. Current state of health in Pakistan

We will now briefly introduce the current health system that is deployed to provide health care to the rural population of Pakistan.

2.1. Role of Lady Health Workers

Lady Health Workers (LHWs) are the primary health care providers in the rural areas of Pakistan. LHWs can provide preventive, curative and rehabilitative services to the community. They also educate and provide family planning methods. The selection criterion for LHWs is that they should be at least educated till 8th grade and be the local residents of their targeted villages. Over 30 million people are receiving services from the LHW system in their village at an average cost of Rs. 26,500 per LHW per year over the life of the program. This low cost solution is now having negative impact on the motivation level of LHWs and the effectiveness of the system is gradually reducing [PHC 06]. We believe that with the introduction of our remote patient monitoring system the performance of LHWs network will significantly improve that will consequently result in providing a better quality of service to the patients.

2.2. Current Telemedicine scenario

In Pakistan the field of telemedicine is relatively new. Elixir Technologies introduced the concept of Telemedicine first time in Pakistan in 1998 in the form of a philanthropic project, TelMedPak [TeleMedPak 07]. The organization has done some pilot projects namely Taxilla and Gilgit projects. The methodology used in Taxilla project was "Store and Forward Teleconsultation" through email, while in Gilgit project voice chat was also included [Zafar 07]. These projects showed that telemedicine can be used successfully for provisioning of specialist care in remote areas of the country. Telemedicine provides the inexpensive way of delivering specialist healthcare facilities to the large population residing in rural areas. However, the people still need to travel to nearest health centers where the facility of video conferencing was made available. Consequently, women population mainly did not use this facility due to the prevailing culture and the socio-economic factors related to taking a day off from their routine job.

3. Project theme

The goal of our project is to design a generic remote health care system with an initial focus on the antenatal care but it must be scalable to revamp the complete medical infrastructure. Our aim is to use advancements in Information and Communication Technology (ICT) to develop a monitoring system that could enhance the quality of health care provided by the LHWs. This would help in saving lives of mother and child; reduction of MMR and IMR. This can be done by creating an automated patient monitoring system for antenatal care of pregnant women in remote areas.

Presently, antenatal care is being provided by little-educated LHWs who manually perform all the steps of patient care. They take readings of the patient's physiological data using instruments which are difficult to handle and require manual tuning etc. Then, they manually record this data into printed forms. Finally, the collected forms are sent to a doctor who goes through all of them looking for any symptom of abnormality. The doctor then takes decision regarding the patient's treatment.

We have developed an automated system that will replace all this hectic activity. Using the handsets provided to the LHWs, applications are developed for them to increase the knowledge and skills of LHWs. This would motivate them to improve the quality of their service because they would get an increase in salary for opting to work on an ICT solution and this would also give them the opportunity to learn the cutting edge technologies. The major challenge, however, is that this system must be designed keeping in mind the skill level of LHWs, cost and effectiveness. Our system is able to gather the physiological data, transmit it, store it and find any abnormality and then assist the doctor in the decision making process.

4. Proposed architecture

In this Section, top-level architecture of our system is described. First, we introduce the overall architecture of the system and then it will be followed by the description of different modules of this architecture.

4.1. Overall architecture

The overall architecture of the system consists of wearable medical sensor modules, a Data Gathering Module (DGM), a PDA, a remote server providing Clinical Decision Support System (CDSS) and Electronic Medical Record (EMR) management, and any web enabled remote terminal (e.g. doctor's laptop) which could be used to access services provided by the web-server. This overall architecture is shown in Figure 1.

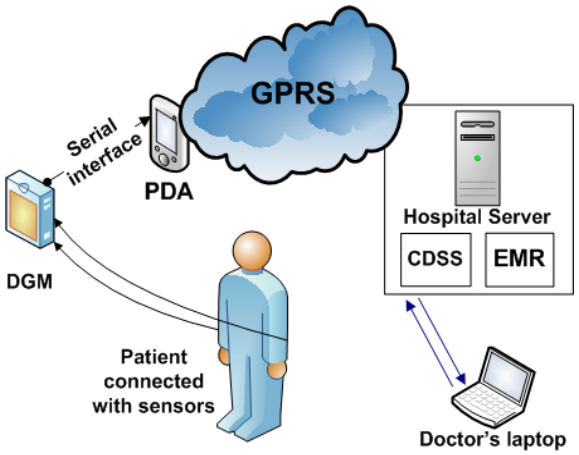

Figure 1. *RPMS system architecture*

The interaction and flow of the information among these modules defines the execution model of the system. The LHW is required to attach the medical sensor modules to the patient's body. The modules record the patient's data, gathered by DGM, which is then forwarded to the PDA through a wired channel (e.g. USB or serial port). The PDA contains an application for local monitoring of patient's data that display the current readings. When all the readings have been taken, the PDA connects to a remote server through GPRS and transmits the data. The remote server processes the data, invoke CDSS to perform analysis of data and invoke EMR service to record the readings in the patient's history. The specialist doctor can examine this record on her/his computer or laptop and give her/his specialized opinion about the patient by monitoring her condition. The feedback can be displayed on the PDA screen, notifying the decision of the doctor.

4.2. Detailed architecture

4.2.1. *Sensors and Data Gathering Module (DGM)*

The sensor modules gather physiological data from the patient. The design of these modules is determined by the type of measurement required but it has three necessary restrictions: small size (for ease in mobility), low energy expenditure (to enhance the battery lifetime) and most importantly safety for the patients (i.e. no harmful radiations etc.). Preference is given to the non-invasive techniques of data gathering through sensors.

A typical sensor used in our system consists of electrodes, protection circuitry, signal sampling, filtering, amplifying and preprocessing blocks and an output interface which is usually an ADC. Figure 2 shows a typical biosensor.

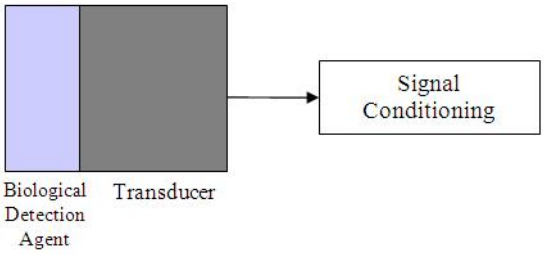

Figure 2. *A typical biosensor*

The consultant gynecologist suggested that the major causes of maternal death are hypertension and anemia [MedicineNet 08a] [MedicineNet 08b]. So for antenatal care, we need to develop the sensors for measuring following signals:

- Pulse
- Temperature
- Blood Pressure
- Heart Beat
- Hemoglobin
- Blood Sugar
- Albumin

DGM consists of a central microprocessor that controls the operation of a number of medical sensor modules. The central microprocessor gathers data from the sensors and passes it on to the PDA through a serial or USB interface which then passes the data to the hospital server.

4.3. Main server at hospital

The main server located at a hospital acts as the brain of the whole system. This server receives different patients' data from the PDAs carried by LHWs. The server also analyzes the data for abnormalities using CDSS. The server then records the data into the patient's database using the EMR system. Feedback based on CDSS analysis is finally sent to the specialized doctor's laptop/PDA for approval/confirmation. The doctor's advice and instructions for the patient are forwarded to the PDA. The server also serves requests for reports based on patient's data and individual patient records requests from the concerned clients. The automated services provided by the server helps in reducing the workload of doctors and other hospital staff and increase their efficiency.

4.3.1. *CDSS*

The need of an automated analysis, decision and response in case of an emergency scenario lead us to the inclusion of a CDSS. CDSS is a piece of software, which analyses the patient's physiological data (e.g. ECG, blood pressure, body temperature etc.) in order to find out symptoms of any abnormality. These symptoms are used by the CDSS to estimate the current health situation of the patient. The decision support system is also capable of making decisions based on the diagnosis of estimated health situation.

In the architecture under discussion, we use a hybrid of model-driven decision support system and knowledge driven decision support system. Model-driven decision support system makes decisions based on the statistical model of the patient's data. Knowledge-driven decision support system provides specialized problem solving expertise stored as facts, rules, procedures, or in similar structures. A hybrid system simply augments the knowledge base with the statistical model to enhance the effectiveness of decision making process Thus, the resulting system is less vulnerable to 'false alarms' [Power 08].

Moreover, we also utilize a cooperative decision support system that helps in reaching at a diagnosis through our hybrid decision making model. Then, it presents the diagnosis as well as proposed decisions/actions to the medical consultant, through the user interface, who verifies the situation and decide whether or not the alarm is true. The CDSS model is shown in Figure 3. CDSS provides instantaneous medical analysis and feedback, thus reducing the doctor's workload.

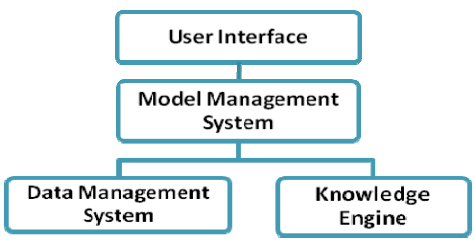

Figure 3. *CDSS model*

4.3.2. *EMR*

An EMR system keeps track of patient's history. Integrated with CDSS, it provides initial data (previous medical record of concerned patent) to the CDSS for comparison with current data. EMR stores the new data as well as the results of the analysis performed by CDSS.

4.4. User interfaces

As the end users of this system are humans, a user-friendly interface is provided. Graphical user interface is required at three points in the proposed architecture: the local application that runs on a PDA, an interface for the hospital's staff to register a new patient and an interface for the doctor's workstation.

4.4.1. *PDA applications*

A local application at PDA focuses on displaying the patient's information for local monitoring. As the system is to be used by not-so-well-educated LHWs, the information is displayed in a simplistic manner so as to minimize the level of training required to operate the application. The application also provides a configuration panel to adjust settings for the connection to the remote server located at the hospital. GPRS will be used as a mean of communication between different PDAs and the hospital server because GPRS is provided by all the mobile operators having wide coverage in remote areas as well. In future, we plan to introduce satellite connectivity to the system for use in areas where no other service coverage is available.

The local monitoring application also provides the facility to record the data offline in a file and transmit it later. If GPRS is not available in a region, this data file can be copied on a memory stick and uploaded to the server later from some other region or using a different medium e.g. Internet on telephone. Moreover, the LHW is also able to retrieve these saved records later if needed.

4.4.2. *Registration interfaces*

Every new patient's information must be added to a database in the hospital's server. This is accomplished by providing a software interface to the LHWs and the hospital's staff. It supports entry of a patient's complete information, medical history and unique id which is then used across the whole system to uniquely identify the patient.

4.4.3. *Remote monitoring application*

An interface for doctor is also developed that a doctor can use to view the detailed analysis of each patient's data. The doctor then makes a decision about patient's treatment on the basis of recommendations given by CDSS and can communicate her/his feedback via PDA through notifications.

5. Development process model

Our project is facing a unique challenge because of its multidisciplinary nature because it is to deploy ICT into existing social work places. Therefore, it is very important that research and development be done keeping in view the social requirements of the population and is intended to be consistent with existing healthcare facilities. This relation is shown in Figure 4.

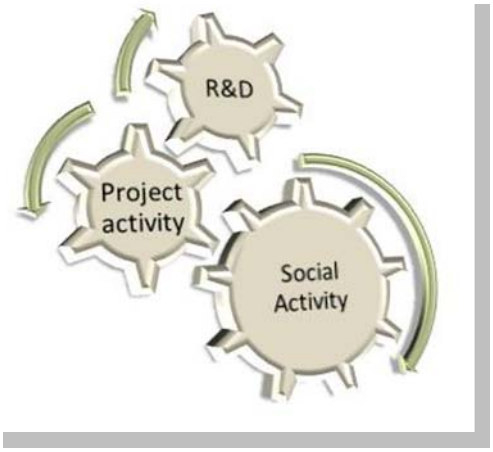

Figure 4. *Project activity deriving R&D and social activity side by side*

After a careful review, we have selected the development process model proposed in [Pressman 88]. It consists of following five phases.

Communication phase is the stage of project initiation and information gathering. In this phase investigation of the existing telemedicine systems in various countries is done along with the telemedicine activities in Pakistan. The rural health requirements are accessed through consultation with the private organizations working in the health sector and doctors and then an initial user-case model is evolved for this system. After that there is **Planning phase** in which the user-case project model is analyzed and supplementary requirements are defined along with the analysis model. Resource estimation, scheduling, and risk assessment are done in this phase. Then comes the **Modeling** and **Construction phase** in which the research and development activities are carried out regarding the project. Specialized project areas are identified and final design modeling and development of the system is carried out. In our case these specialized areas are:

- Hardware design of sensors and DGM
- PDA application development and secure communication infrastructure
- CDSS and EMR development for the hospital server

Usability analysis, development activities, test plans and procedures, support documentation and user manuals, identification and addressing of research problems are the prime activities of these phases. In the end comes the **Delivery** or **Deployment phase** in which the system is delivered and deployed for testing. Integration of the whole system is carried out and user's feedback is gathered which is used for evaluation process. Based on the user's feedback the system can be modified quickly and delivered again for evaluation. [TechMapp 98] provides an example of deployed system.

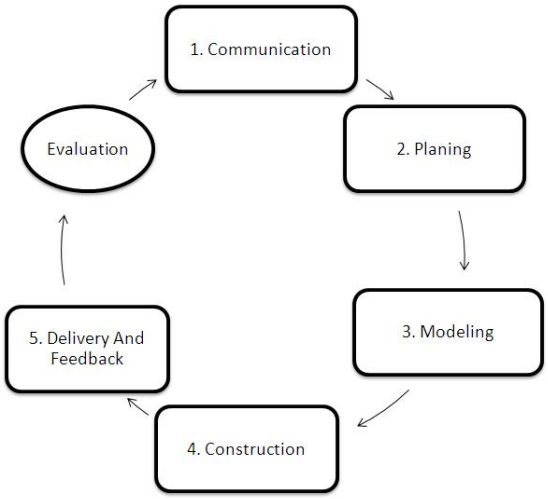

Figure 5. *Development process model* [Pressman 88]

6. Evaluation strategy

An evaluation strategy for testing the proposed system is planned that tests the system in a practical scenario. This practical deployment also helps in regular evaluation of the system and will lead to its further improvement. The evaluation framework for the proposed system is described below.

The primary focus of this project is on providing an automated antenatal care system for population in remote areas. For this specific purpose, a controlled population group of pregnant ladies is taken along with the expert advice of doctors from a teaching hospital. For this purpose, the evaluation framework has a setup based on following two organizations: Human Development Foundation (HDF) which is a non-governmental organization (NGO) and Rawalpindi General Hospital (RGH) which is a teaching hospital for Rawalpindi Medical College (RMC).

6.1. HDF health model

Current health model of HDF has been designed to cater for the primary preventive needs of communities in particular and primary curative needs in general.

A Community Health Center (CHC) is the center stage of activities in a given community. One CHC delivers services to one HDF Unit i.e. 1000 selected households located in the neighborhood of CHC location. A public health experienced doctor (preferably a lady doctor) is usually the in-charge of regional health program, having the services of one Lady Health Visitor (LHV), four Lady Health Workers (LHWs) and two Trained Birth Attendants (TBAs) in each unit. The services of a dispenser cum vaccinator

are available for every two units. HDF health model is shown in Figure 6.

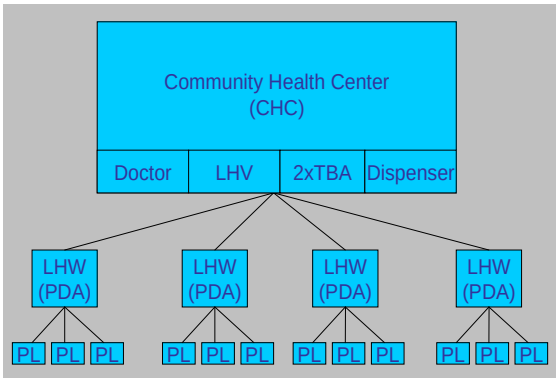

Figure 6. *HDF health model*

6.2. Teaching hospital: Rawalpindi General Hospital (RGH)

To provide expert advice on antenatal care issues, a consultant gynecologist from Rawalpindi General Hospital has been involved in the project. She provides assistance and an expert opinion in the development of medical sensors, clinical decision support system and issues related to the patients' health.

6.3. Controlled population setup

A group of one thousand pregnant ladies (PL) is divided into equal sized four groups, each one attended by one LHW. A doctor and a dispenser are also provided to the group. The whole system is connected to a teaching hospital for an expert medical advice.

The CHC of HDF in Islamabad rural region is targeted as it is nearest to the participating organizations. This CHC is looking after a unit (1000 households) selected from the poor population of rural areas of Islamabad. The services of CHC staff (Doctor, LHV, TBA and dispenser) are already obtained for the project.

6.4. Information flow in our evaluation framework

Among the different organizations involved, we use following evaluation framework. After reception of data from PDA, the main server in RGH generates and disseminates the results of CDSS, which are stored in EMR, to CHC and the LHW. The medical records of patients are made available to the CHC as well as the National Office (NO) of HDF. This information flow is shown in Figure 7. For this information flow, a dedicated server is setup in RGH, and dedicated terminals are provided to CHC as well as NO of HDF. The communication among RGH, CHC and NO is through the World Wide Web (Internet).

After the reception of information at NO the evaluation of RPMS can be done by defining and observing certain performance indicators.

6.5. Performance indicators

To evaluate the performance of our system, some performance indicators have been defined. The evaluation framework evaluates the system deployed in the controlled population group on the basis of these indicators. Some of these indicators are short term while some are long term. The short term performance indicators are:

- Number of correct patient referrals
- Number of complexities in birth process
- Amount and correctness of information available for emergency patients

The long term performance indicators are:

- MMR in controlled population
- IMR in controlled population

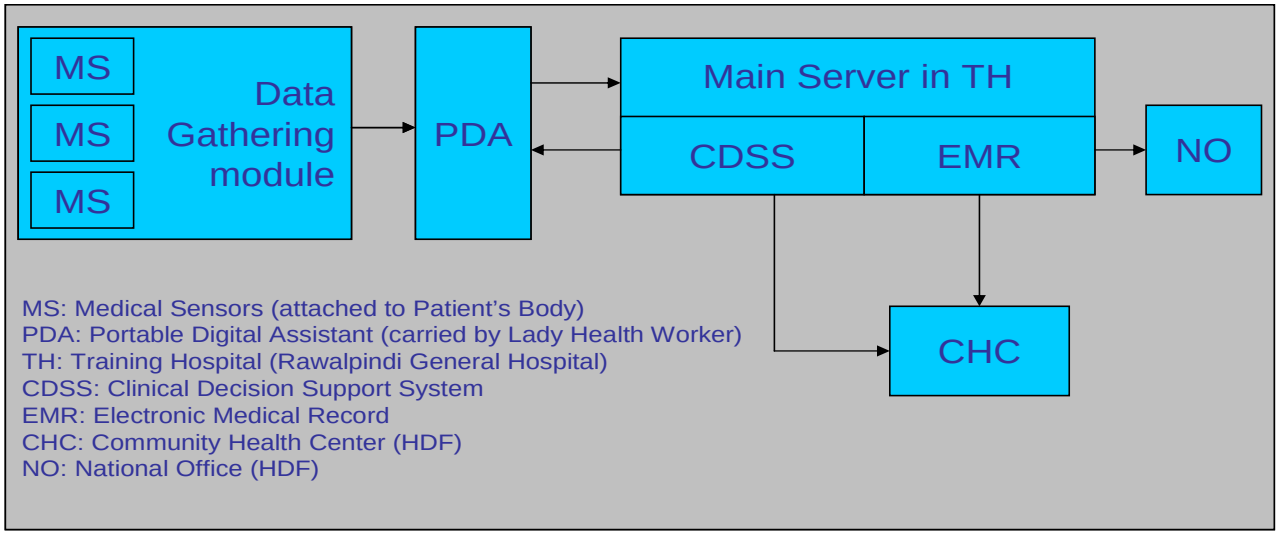

Figure 7. *Information flow in evaluation framework*

The system must improve the correct and timely referral of patients because majority of the deaths can be avoided by timely referral of the patients [Perera 06]. Timely referrals must also reduce the complexities in the birth process. The system must be capable of providing correct information and diagnosis in case of emergency, this would aid in timely referral and treatment of the patient.

We have explored some of the many possibilities of the design of the application. In order to come up with an effective solution, we have outlined the following categories against which the design must be evaluated:

1. Skill level of LHW:
    a. Language preference
    b. Extent of mobile phone usage
    c. Understanding of application usage
2. Effects on motivation of LHWs.
3. Usability of RPMS interfaces developed specifically for LHWs.
4. LHWs work load capacity.

For our proposed system the role of LHW is of prime importance so the development of the system is carried out keeping in view the requirements and ease of LHWs. The system should decrease the workload of LHW as she does not have to fill up the forms manually. We are currently in the evaluation phase and we believe that the outcome of this phase will be of great significance for our project.

7. Conclusion

In this paper, we have discussed our RPMS especially targeted at providing healthcare to remote areas of Pakistan. Based on advancements in ICT, this system enables specialist doctors to provide remote health care to the patients. Automation of monitoring and instantaneous medical analysis and feedback certainly improves the quality of care provided. This system is an important step towards providing better health care to population in rural and underserved areas where health facilities are virtually either non-existent or insufficient. The system has comprehensive development and evaluation strategy and it is intended to augment the existing healthcare infrastructure targeted at reducing MMR and IMR. It would also help in creating the wave of interest in R&D in the field of Bio-Engineering in Pakistan.

ACKNOWLEDGMENT

The authors are thankful to the staff and organization of HDF. We also appreciate the contribution of RGH doctors and staff. This project is funded by Ministry of IT, under National ICT R&D Fund. We will also like to thank Mr. Farid Zafar for his suggestions and review.

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