

A Robust Remote Health Monitoring and Data Processing System for Rural Area with Limited Internet Access

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ABSTRACT

Emerging technologies such as Body Sensor Networks (BSN) and Remote Health Monitoring Systems (RHMS) allow for collecting continuous data from patients, providing clinical interventions to improve patients' physical and mental health, and to prevent medically adverse events. Although RHMS have shown promises in reducing healthcare costs and improving quality of care, designing a robust, flexible and portable RHMS that can adequately handle technological and environmental restrictions such as data communication disruptions caused by low-quality infrastructure is by large an open problem.

In this paper we present an end-to-end robust RHMS including body area networks for monitoring and management of patients with HIV/AIDS. The proposed system includes an Android application to be installed on mobile devices to collect and preprocess data from patients, a wireless body area network to handle data communication and transmission, and a backend cloud-based server coupled with a NoSQL database and web-portal for data visualization and analysis.

The proposed system addresses a number of serious challenges in RHMS design including data transmission and synchronization in a body area network with poor network connection (e.g. in a rural area with poor or unavailable internet connection). The proposed system is fully implemented and deployed in a large research study involving 600 women living with HIV/AIDS in rural parts of India. The results demonstrate the effectiveness, reliability, robustness, and accuracy of the proposed RHMS.

CCS Concepts

• **Social and professional topics**→ **Medical technologies**→ **Remote medicine** • **Networks**→ **Wireless access networks** • **Computer Systems organizations**→ **Embedded and cyber-physical systems**→ **Sensor networks**

Keywords

mHealth, Remote Health Monitoring Systems (RHMS), Body Area Networks, Remote Health Management, AIDS.

1. INTRODUCTION

With rapid increase in healthcare expenditures, there is a growing need for alternative and innovative approaches for chronic disease monitoring and management, which can help early diagnosis and adverse event prevention. Innovative technologies such as Body Sensor Networks (BSN) and Remote Health Monitoring Systems (RHMS) allow for collecting continuous data from patients or any person with special needs, and provide an effective platform for information integration and retrieval, data analysis, and predictive analytics for health conditions. They also enable clinical interventions to improve patients' physical, physiological, and mental health, and to prevent medically adverse events from taking place.

Rapid advances in many technological domains including mobile systems, wireless communications, internet, and sensors has led to the development of effective RHMS that can collect various physiological information including vital signs and other medical conditions through wearable/implantable body sensors, body area sensors, or digital questionnaires [1]-[17]. RHMS and BSNs can reform the healthcare structure by increasing the efficiency of healthcare systems, expanding the reach of healthcare services to all segments of the population, and reducing the costs of chronic disease management.

Although RHMS have shown promises in reducing healthcare costs and improving quality of care, designing a robust, flexible

and portable RHMS that can properly handle system restrictions such as data communication disruptions is yet an open problem. For example, most of existing RHMS have been developed based on the assumption that the RHMS always has access to a perfect internet, mobile, or landline connection. However, in many applications, specially for a portable RHMS in areas with poor internet connection, a robust and reliable system is needed to ensure reliable data collection and transmission with no damaged or missing data.

In this paper, we present an end-to-end, robust, portable, and distributed RHMS for monitoring of patients with HIV/AIDS. The case study focuses on Women Living with HIV/AIDS (WLHA) in rural India. This study is a collaborative effort between UCLA School of Nursing (Nyamathi, R01-MH098728-4), UCLA Computer Science department, University of California San Francisco (UCSF) School of Medicine, and All India Institute of Medical Sciences (AIIMS).

The rest of the paper is organized as follows: Section 2 describes the project motivations and specific aims, Section 3 provides the system architecture, methods, and the details of the proposed framework and components. In Section 3 we also talk about the challenges in data collection and transmission, and then provide technical details of the proposed approaches to mitigate these challenges. It also describes the details of the developed system including BSNs, frontend and backend, mobile app, webserver and web portal. Finally, Section 4 describes the results and conclusion.

2. MOTIVATION and SPECIFIC AIMS

This paper presents an end-to-end RHMS and BSN for monitoring of patients with AIDS. This study focuses on 600 WLHA residing in a rural area of India.

The Joint United Nations Program on HIV/AIDS reported that India has the third largest population of individuals living with HIV/AIDS in the world, with 1.7 to 2.6 million affected with HIV/AIDS [23]. Rural women living with HIV/AIDS (WLHA) in India face serious challenges in accessing and following treatment regimens, caring for family members, and maintaining positive mental health [19][20]. They experience ongoing barriers to HIV testing and treatment [19]. Furthermore, they are generally underweight and malnourished, with very low adherence to antiretroviral therapy (ART) [19][20]. The Indian Government designed a successful approach to address the health requirements of the rural population by training local social workers as ASHA (Accredited Social Health Activists) to help enhance the physical and mental health condition of rural WLHA [19][20].

The UCLA School of Nursing, in collaboration with UCSF, AIIMS, and Indian Council of Medical Research (ICMR) designed and implemented a novel three-year study (Nyamathi, R34-MH082662) focusing on rural WLHA in India, with the main goal of enhancing their adherence to antiretroviral therapy (ART) and improving their physical, mental, and psychological health. In this study, the intervention and support was delivered by rural village women trained as HIV-focused care providers (ASHAs) partnered with nurses. These ASHA support WLHA by providing care, mental and physical support, and assistance to WLHA by decreasing barriers to ART adherence. Findings from this pilot study

revealed significant improvement in adherence to ART, depressive symptoms, internalized stigma and avoidant coping, as well as weight gain and increased lean body mass, among the ASHA-intervention women compared to those in usual care [19][21][22].

The subsequent five-year longitudinal study, initiated in 2013, utilizes a 2x2 factorial design, specifically, 1) ASHA support alone for WLHA, vs. 2) ASHA support for WLHA + nutrition (food-based) training, vs. 3) ASHA support for WLHA + food supplementation, vs. 4) ASHA support for WLHA + nutrition training + food supplementation, to test the effects of nutrition training and/or food supplementation on anthropometric parameters and immune status of the WLHA at 6-, 12- and 18-month follow-up.

This five-year study also aims to examine the effects of the intervention on ART adherence of WLHA at baseline and 6-, 12- and 18-month follow-up, changes in psychological health of the WLHA over 18 months, measured by improvement in CES-D and stigma scores, the effect of the intervention on nutritional adequacy of the WLHA over 18 months, measured by comparisons of vitamin, mineral and macronutrient intake, lipid normalization of WLHA (triglycerides and cholesterol), and anthropometric parameters and psychomotor development of the index children at 6-12-, and 18-month follow-up.

In this study, we designed and developed a RHMS to collect and transmit data from and to patients. The collected data includes physiological information, vital signs, demographics, contextual information, social and physical activity, psychological and mental health information, medication adherence, and nutrition information. It also includes lab data such as blood and urine test results. The system wirelessly transmits the collected data to the backend cloud-based database. This data can be later visualized and analyzed by authorized experts through the system web portal. In next sections, we discuss the technical details of the system design and architecture.

3. METHODS

3.1 System Architecture

Figure 1 shows the overall architecture of the proposed system. In this study, we designed and developed an Android based application to be installed on tablet devices provided to the research staff, supervisor, project manager, data manager, and the administrator. The mobile app is responsible for collecting data from patients, preprocessing the collected data, visualizing the data, and transmitting it to a backend server. The mobile app has been designed to support two different languages: English and Telugu. By switching to the Telugu language setting, all questionnaire forms, as well as all app items, menu bars, and buttons will change into Telugu language.

After collecting patient's data, the app wirelessly and securely transmits this data to the backend cloud-based server through either WiFi or 4G internet connection. Several research staff carry the tablets to visit patients simultaneously and independently; therefore, it is very important to synchronize the tablets on a timely basis to have the updated status of all patients in all tablets to avoid data overwrite or repeated visits and interviews. Since the internet connection can be poor or unavailable in rural areas, where most of the patients are located, it is very challenging to transmit the data and synchronize the patients' status in real-time. In the next section, we discuss the details of the network and the best approaches to deal with internet connection problems.

We have designed and developed a webserver and web portal to visualize the results to authorized people, and allow them to analyze the data, extract information, statistics and graphs, edit or revise the data, and export/download it in various formats. In section 3.1.1, we discuss the system accessibility and security, and how the users with various levels of authority can access or control the database. Also, in section 3.2.3, we provide more details about the webserver design and capabilities. As shown in Figure 1, the results can be analyzed by authorized experts, who provide feedback, comments, or new prescriptions, or recommend for specific interventions as how to improve patients' physical, physiological, and mental health condition.

3.1.1 System Accessibility

The proposed system allows for defining various levels of access to the data and control over the system. The users including patients, research staff, supervisors, selected research staff and selected research investigators may have various levels of access to the system. Here is the defined accessibility protocol:

- *Patients* have the right to *refuse to respond* to a question for any reason (either if they don't like to answer, or they don't know the answer). "Don't know the answer" is usually a selectable option in multiple choice questions. The interviewer can also mark a question as "refuse to respond" if a patient refuses to answer the question, no matter what the reason is.
- *Research staff* are not allowed to skip a question (unless it is a "refuse to respond" case). They can only upload the questionnaire one time when completed. The interviewer cannot go back to a previous section if it has already been completed, however, she can save the questionnaire partially, and complete it later.
- *Supervisors* can revise the data on the mobile device only before uploading the questionnaire. For security purposes, the database will keep all revisions of the data including the changes that have been made on the device side.
- *Authorized Research Principal Investigator/Co-Investigators* have full access/control over the system database. For example, they can manually add new data samples, or they can view, export, or revise the previously collected data.
- *Other Research Staff* may have limited access to the system database after getting permission from the Research Principal Investigator/Co-investigators to only view/export the collected data.

- All users including research staff, supervisors, and authorized research staff need to enter their unique user/password to be able to use the system. The system will then identify the user, and give him/her the proper level of access.
- Any changes in the data through the app or web such as revise, edit, or addition will be recorded in the database along with the date/time of change, and the name or user account of the person who made the change. The system always allows to recover the revised data.

3.2 System Components

3.2.1 Android Application

In this study, we designed and developed an Android application that can be installed on tablet or mobile devices. The mobile app is responsible for collecting data from patients on a timely basis including baseline round, and 6-month, 12-month, and 18-month follow up rounds, as well as laboratory results. The app supports two different languages: English and Telugu. By switching to Telugu, all questionnaire forms, app items, menu bars, and buttons change from default English to Telugu language. The app is also responsible for preprocessing the collected data, making a wireless connection to the internet network to transmit the collected data to a backend server, and making sure that the intact and full data is received by the server. The details of data transmission and network configuration is provided in section 3.2.2.

A more complete list of items that can be collected by the app includes: physiological information, vital signs, demographics, contextual information, physical activity, adherence measurements, stigma survey, adherence survey, social activity survey, psychological and mental health survey, medication compliance, and nutrition information. The app also collects lab data including blood and urine test results. We have designed and implemented specific pages in the app to collect each one of the aforementioned items.

The app also performs data preprocessing and basic data analysis including generating automatic alerts based on the collected data, reporting the alerts to the administrators by sending automatic emails, calculating depression score as a metric to measure patient's mental health (particularly depression), and enabling/disabling/revising questions in survey forms based on patients' responses to previous questions.

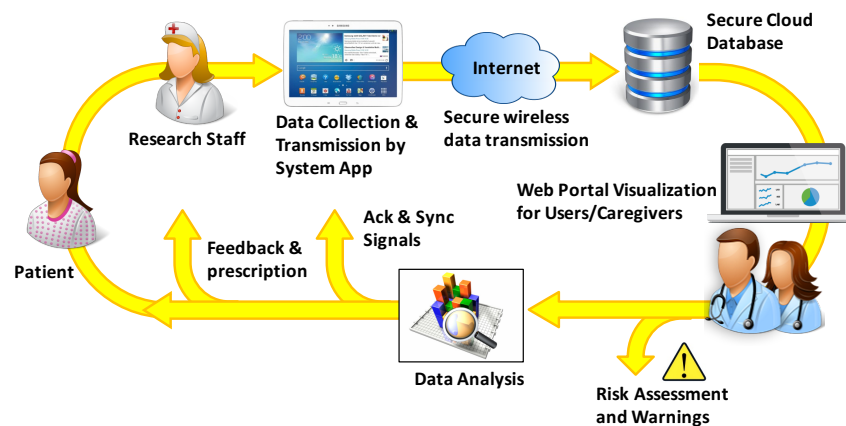


Figure 1. The overall architecture of the proposed system.

Figure 2 represents some sample pages of the android application: Figure 2-a shows the *patient list* page including the list of all patients along with brief status of each patient. Figure 2-b indicates the *profile page* of a specific patient that represents the details of previously collected data, and allows for starting, editing, or completing a new data collection procedure. Figures 2-c and 2-d show a sample *questionnaire* in *English* and *Telugu*. As shown in Figures 2-c and 2-d, we used a variety of icons and colors to indicate the status of a question in questionnaire forms. For example, *unanswered questions* are indicated with grey *U/A*, *refused to answer* items are indicated with red *RA*, and regular *answered questions* are indicated with green *A* icons.

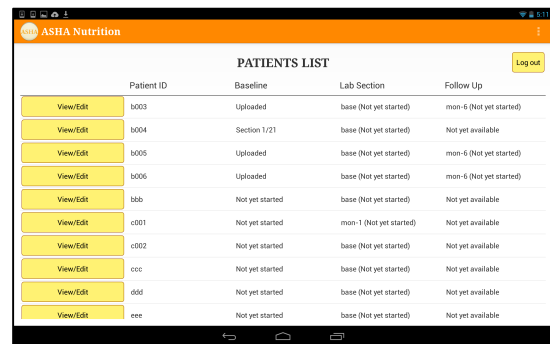
3.2.2 Body Area Network

The app may communicate (send or receive data) with the backend server for three main purposes: 1- To upload the collected data to the server; 2- To build a new user ID (add a new patient); 3- To synchronize the patients' status. As shown in Figure 1, the app can connect to the server wirelessly through either WiFi or 4G internet services. Since the internet connection can be poor or unavailable in many rural areas, where most of the patients are located, it is very important to design and utilize reliable protocols for data transmission.

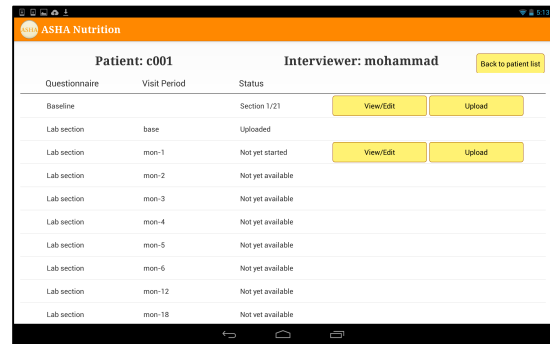
Figure 3-a shows an ideal scenario to upload the collected data. In this scenario, each one of the devices will connect to the internet network directly to transmit the data wirelessly and simultaneously. However, in practice, we needed to design and employ a more robust data transmission procedure to deal with internet connection issues. In this approach, the app will test network connectivity and internet bandwidth/speed before any transaction. If the network does not satisfy the bandwidth/speed requirements (based on the amount of data that is ready to upload at the moment), then the app will just save the data on local memory of the device and mark it as un-uploaded data. In this case, the app will notify the user about internet connection problems. The system will keep checking the internet connection on a timely basis and re-attempt to upload the stored data as soon as a satisfying connection is established. Furthermore, we have designed an acknowledge-based method between the app and the server to assure intact and perfect data transmission.

In this project, a number of ASHA and research staff visit different patients simultaneously and independently. When a research staff visits a patient for the first time, she needs to make an account for the patient in the system. In this case, the app needs to have access to the database to avoid making duplicate user IDs. If a patient is already visited by a another research staff, the new staff member needs to know the status of previous visits (including baseline or follow up visits) and data collection procedure to avoid data overwrite or repeated data entry. In any case, whether it is the first visit, or it is a follow up visit, or even if it is a visit to continue an incomplete data collection procedure, all ASHA need to have access to the latest status of all patients. To this end, it is required to synchronize the devices (e.g. tablets) on a timely basis by transmitting any new changes with the status of patients.

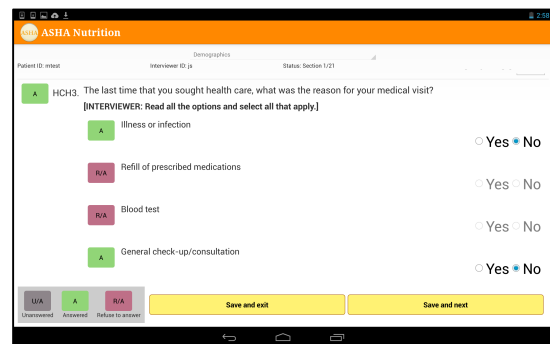
Figure 3-b shows an ideal scenario for synchronizing, where the server checks the status of each device, and then transmits the latest updates to the device. Since the internet connection may be unavailable for some devices, a more reliable approach is to take advantage of possible inter-communication among devices (e.g. through Bluetooth), so that an outdated device can get the latest changes from a previously updated device, as soon as they happen to be within Bluetooth range of each other. Figure 3-c represents this new scenario, where one of the devices that has been previously synchronized, will be later used as an interface device to synchronize other devices. In this approach, a set of devices can communicate with each other to eventually find a previously updated device as a source of data, and broadcast the updates over the network to synchronize other devices.



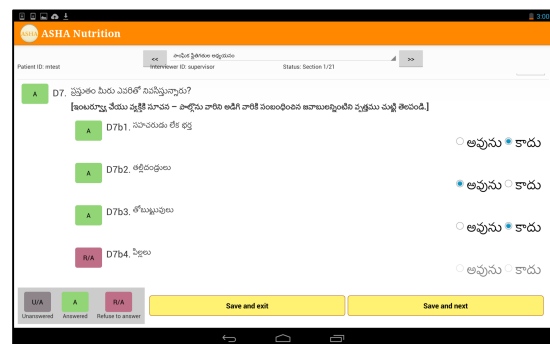
(a)



(b)

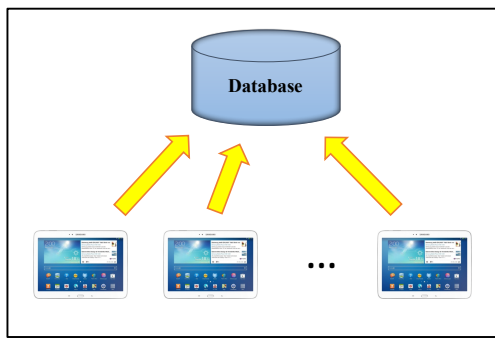


(c)

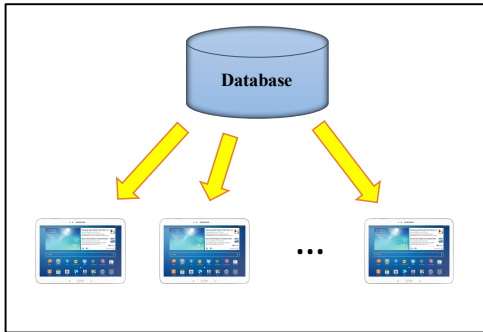


(d)

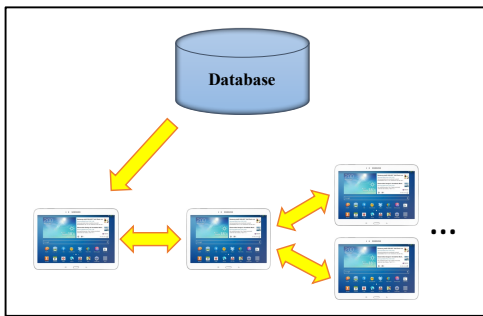
Figure 2. Sample pages from Android Application: a) Patient List page, b) Patient Profile Page, c) Questionnaire page in English, d) Questionnaire page in Telugu.



(a)



(b)



(c)

Figure 3. System network and data transmission: a) Wireless data transmission from app to server, b) Synchronization by transmitting data from the server to all devices (tablets), c) Device-to-device synchronization in the case of poor internet connection.

3.2.3 Webservice and Database

A cloud-based NoSQL database has been built to store and manage the data received from tablet devices. A webservice and web-portal have been designed and developed to visualize the results to authorized research staff, and allow them to analyze the data, extract statistics and graphs, edit or update the data, and export/download it in desired formats. As mentioned in section 3.1.1, various types of users can have various levels of access to the system to view, update, or control the database.

The authorized research staff and research investigators will analyze the results and extract useful information from the collected data. They can later provide feedback, comments, or prescriptions, or recommend

specific interventions in order to improve patients' physical, physiological, and mental health.

Figure 4 shows some sample snapshots of the developed web portal. Figure 4-a represents the *patient list* page including the list of all patients along with their basic demographics. This page allows the users to export desired data and statistics for all patients together in a single list in various formats. This page also allows the user to enter the patient's profile page by clicking on a patient ID. Figure 4-b represents a sample *patient profile* page, where the users can have access to all collected data from each patient. This page also allows the authorized users to manually add new data samples, or revise the previously collected data. Any changes on the original data through the app or web such as revisions, edits, or additions will be recorded in the database along with the date/time of change, and the name/user-account of the person who made the change to ensure accountability. This page shows all different revisions of the data in case a data sample is edited or updated manually. Figure 4-c illustrates a sample *graph* that is generated by the web portal. The graphs and plots can be really informative and helpful in this study since they can indicate the process of health condition improvement or deterioration.

Patient ID	Name	Gender	Ethnicity	Age	DOB
1005 update	1005 update	None	None	None	None
2000	Ella	None	None	None	None
aaa	aaa	None	None	None	None
8001	8001	None	None	None	None
8002	8002	None	None	None	None
8003	8003	None	None	None	None
8004	8004	None	None	None	None
8005	8005	None	None	None	None
8006	8006	None	None	None	None
800	800	None	None	None	None
800	800	None	None	None	None
0001	0001	None	None	None	None
0002	0002	None	None	None	None
000	000	None	None	None	None
000	000	None	None	None	None



Figure 4. Sample pages from Web Portal: a) Patient List page, b) Patient Profile Page, c) Sample Graph plotted in web portal.

4. CONCLUSION

Although new technologies such as BSN and RHMS have shown promises in improving quality of care, designing a robust and reliable RHMS that can deal with system restrictions such as limited internet connection or intermittent communication problems is yet an open problem.

This paper presented an end-to-end, robust, portable, and distributed RHMS for monitoring and management of patients living with HIV/AIDS. The proposed system includes an Android application to manage data collection and preprocessing, a wireless BSN to handle data communication and transmission, and a backend cloud-based server along with NoSQL database and web-portal for data visualization and analysis. The mobile app is responsible for collecting timely data from patients including baseline, 6-month, 12-month, and 18-month follow up rounds, as well as laboratory results. The proposed system particularly addresses a number of serious challenges in RHMS including data transmission and synchronization under limited network connectivity (e.g. in rural areas with poor or unavailable internet connections). Various techniques have been proposed to deal with network connection problems to assure full and intact data transfer, minimize the system delay and latency, and maximize the quality and efficiency of data transmission.

The proposed system has been implemented and is being used in a large research study to monitor 600 *WLHA* in rural parts of India. This study is a collaborative work between UCLA computer science department, UCLA School of Nursing, UCSF, and All India Institute of Medical Sciences (AIIMS).

The patients are split into 4 groups (150 patients in each group), and total 16 social workers are taking care of the patients (4 social workers per group). To date, the baseline data collection round has completed for 500 patients. The baseline round includes 426 data items (for each patient) collected and transmitted through the system. Also, the 6-month follow-up data collection round has been finished for 400 patients, the 12-month follow-up data collection round has completed for 300 patients, and the 18-month follow-up data collection round finished for 200 patients. The follow up rounds include 411 data items (for each patient) collected and transmitted through the system. Furthermore, the baseline lab data has been collected and transmitted through the app for 500 patients, as well as 1-month, 2-month, 3-month, 4-month, and 5-month lab data that has been collected and transmitted for 400 patients. The results prove the effectiveness, reliability, robustness, and accuracy of this system in satisfying clinician needs in collecting, transmitting, and managing the data, providing a powerful platform for data analysis.

The next step in this study is to include more wearable devices and pervasive sensors in patient's living space to monitor and track patient's physical activity, motions, and locations. Furthermore, we would like to add a backend Analytics Engine to analyze the collected data based on machine learning algorithms, and perform predictions about the study outcomes including patients' health conditions, adherence, and adverse events.

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