Improving the Efficiency of Healthcare Delivery System in Underdeveloped Rural Areas

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Abstract—A low doctor-to-patient ratio in rural areas of underdeveloped regions results in an inefficient and expensive delivery of healthcare. Information and Communication Technology (ICT) could play an important role in improving the efficiency and making healthcare more affordable. In this position paper, we present an architectural framework to use ICT (specifically mobile technology) for efficient delivery of healthcare to masses. The proposed framework is (1) comprehensive to cover majority of critical diseases (2) sound from medical science point of view, (3) interfacing to Electronic Medical Record (EMR) system, and (4) self-learning in order automatically diagnose and predict future outbreaks. We present preliminary data and share social experiences from a pilot conducted for preliminary detection of Cardio Vascular Disease (CVD) in rural areas of Punjab, India. We also propose an outline for future study for diagnosing Leptospirosis in rural areas of Gujarat, India.

I. INTRODUCTION

Majority of population living in rural areas lack the access to basic and quality healthcare. In such areas, even for the diseases for which all of prevention, diagnosis and prescription is well standardized (based on decades of medical research), lack of awareness has resulted in large-scale spread and the deaths thereof. A few of these most common diseases (such as Diabetes, Malaria, Tuberculosis and Flu, among others) have been the major cause of deaths in these areas.

With limited number of competent medical experts and ever increasing number of patients, only a small number of patients can be treated directly by these proficient medical experts. Even in these small cases, there is usually a constraint of large physical distances between the patient (from rural environment) and the doctor (typically in urban environments) that further increase the cost of quality medical healthcare and makes it less accessible. In addition to small number of competent medical experts and physical distances, another critical challenge is lack of information about prevention and diagnosis (even if it is using the locally available herbs as practiced in other similar environments).

In this paper, we explore how ICT can be used to fill in the gap of providing quality healthcare to those who can be easily diagnosed with known symptoms and can be prescribed corresponding medicines as per their disease state. Early detection and diagnosis using the standardized procedures and using known prescriptions can go a long way in significantly reducing the number of severely infected people. Non-medical experts can be easily trained to use such procedures wherein technology can help (and in certain cases also perform automated procedure) in differentiating between those who can be treated without having to go to the medical expert and those who are severely ill or can’t be diagnosed and hence should be seen physically by the medical expert. Such a simple system based on standardized forms will be complementary to complex telehealth based systems by further filtering the people who can be easily diagnosed using automated procedures as well as providing collated information to the doctor to aid in telehealth delivery.

Further, with technology in place, records (EMR) and statistics about the disease and diagnosis can be maintained. Efficient algorithms and modeling can then be developed, combining the medical information with other relevant information (such as geographical location and weather condition) to predict the outbreak of a disease or to further the dependency of a disease on such factors in an automated way. Such algorithms and models will further help improve the efficiency by treating more patients at the initial level through standardized procedures.

We first outline the efficient healthcare delivery process using technology at different steps. We then present our experiences of currently undergoing field trials of CVD risk detection in the Bhatinda district (in the state of Punjab in India) and our plans for the proposed Leptospirosis study that we plan to undertake in the state of Gujarat, India.

II. RELATED WORK

Somani Patnaik et al. [1] compared Short Messaging Service (SMS), voice and electronic forms to empirically evaluate the different methods for collecting data using mobile phones. They also specified on how to increase accuracy and efficiency while health care worker is collecting data. However, we focus on different tools that can be used on mobile phones (such as forms on standardized procedures) that can further improve the healthcare delivery. Agarwal et al. [2] discussed remote monitoring of diabetes and hypertension using mobile phone and web interface. Their application collects desired data such as blood pressure using mobile phones and sends it to a central server. We further propose extending such a system to train a healthcare worker with limited education to diagnose people without involving an expert. Onur et al. [3] proposed a solution to put low cost microscopic modalities into mHealth architecture so that data can be sent to laboratories. Such an
III. IMPROVING EFFICIENCY IN HEALTHCARE DELIVERY

A typical healthcare delivery process would involve a person visiting the doctor whenever he feels sick (marked as A in Fig. 1). The primary challenges in such a delivery process are:

1) Lack of access to relevant information and reactive diagnosis: Initial symptoms of disease are often ignored or are unknown thus making the disease more severe before the patient visits the doctor (rather than the disease being treated at the very early stage, not requiring very competent medical experts and with simple medications had the symptoms and diagnosis being known).

2) Limited accessibility of competent medical experts: With only a small number of competent medical experts available, (at geographically remote locations) directly approaching a good doctor, mostly in urban areas, is often expensive.

We envision that simple technologies can go a long way in overcoming the constraints of the typical healthcare system. Such an improved healthcare delivery process is marked as B in Fig. 1. Next, we discuss how different technological solutions can be put in place at each stage across the improved healthcare delivery process.

A. Rural clinics for pre-screening

Screening camps conducted in rural areas can filter those who need immediate care by competent medical experts (potentially located in urban areas) while treat those who are at an early stage with known standardized procedures. A case in point is famous Aravind Eye Hospitals. From January 2006 to March 2007, a total of 1793 screening camps were conducted by the Aravind Eye Hospitals screening a total of 505,621 patients of which 112,825 underwent surgery in their urban hospital1. Pre-screening to decide patients who need surgery together with an efficient management system at their hospitals helps reducing the overall expenses incurred while still providing quality healthcare. Simple technologies like forms on mobile phones or electronic medical records facilitate the operations of such screening camps. We present an example of using phone based forms for pre-screening of patients potentially suffering from CVD in Section IV. These patients are then told about their potential CVD risk (low/medium/high) and those suffering from medium/high risk are recommended to visit the rural clinics (setup by our collaborators - Electronic Health Point2) for detailed checkup.

B. Forms for standardized procedures

Several simple forms have been proposed for initial screening of a lot of common disorders such as Cardio Vascular Disease (CVD), Diabetes, and various type of Cancers3, among others. These forms are created after extensive empirical studies on data from real patients and there is comprehensive medical research on improving them further and increasing their efficiency as compared to expensive lab test based screening. Such standard forms can be easily converted into electronic format on devices such as mobile phones/computers; field health worker can be trained to screen patients by filling up these forms; and the analysis based on filled up form can be put as computing logic in the program running on the electronic device. Not only will such an approach help perform quick and quality screening with minimal human expertise required, it will also ensure that the health information for the people are stored in electronic format for further analysis and ensuring better health services in the future. We present an example of CVD risk analysis using mobile phone based forms in Section IV.

Even for those who are screened to visit the medical expert, such a process can further improve the efficiency of healthcare delivery. When the patient visits the expert doctor, all his health information can be made available electronically to the doctor and he can (after any additional information required) quickly get on to his job without wasting much of his valuable time. Such an increase in expert doctors’ productivity (due to the quick access of information with most of pre and post-op stuff performed by the nurse) was evident at Aravind Eye Hospitals where the average number of surgeries per doctor per year is 2600, as compared to all India average of 400. Efficient technology can help further improve this efficiency with easy access and monitoring of patient information electronically. In Section IV, we also illustrate this procedure in our CVD risk assessment case study wherein we created multiple forms integrating the complete cycle from pre-screening to post-lab-visit assessment.

C. EMR

EMR systems are currently being used across the world, including even several large and medium scale hospitals in India for end-to-end streamlining of the healthcare process. In contrast with the paper based records (that are mostly prevalent across India) such EMR systems make the healthcare process more efficient and affordable by collating information from multiple locations, allowing on-demand access to the information for both expert doctors and Community Healthcare Workers (CHW), maintaining historical records for efficient

1http://www.aravind.org/community/types.asp

2http://globalhealthpoints.com/water-in-golewala/

3www.who.int/
treatment of diseases in the future and appropriate accountability of the allocated resources by a central agency. Such benefits make EMR systems key to scalable, affordable and quality healthcare services.

Several such EMR systems exist both as open source software applications (maintained by an active volunteer community of developers) such as openMRS, openEMR, patientOS as well as commercially available applications (owned and maintained by a private organization) such as cureMD EMR, DoX Systems and SuperEMR. The cost for commercially available EMR systems can be prohibitively large thereby limiting the adoption of such systems across all healthcare service providers.

In addition to the high associated cost, some of the major limiting factors against adoption of EMR systems in Indian context are:

1) Low penetration of computers both due to affordability and ease of usability
2) Lack of good quality communication infrastructure for syncing the data remotely

Massive penetration of cellular services together with availability of very low cost programmable mobile phones make them excellent devices with capability to revolutionize the delivery of affordable and quality healthcare services to remote areas. Fig. 2 illustrates a typical architecture of an EMR system with mobile phone interface as well. Data can be collected from multiple sources, stored in a remote database and a server on the cloud can be used to perform compute intensive tasks. Records from past diagnosis can be easily accessed on-demand to make decisions on cases with similar symptoms. With critical health related information being communicated across multiple locations physically separated from each other, integrity, accountability and availability of the data form key components of data security of the communication channel.

Thus, a CHW can input the information into a remote database using mobile phones and cellular connectivity. Based on availability, several communication modes such as SMS, General Packet Radio Service (GPRS) or WiFi can be used for syncing the local information to a remote database. Further, several healthcare sensors can interface over local interfaces such as Bluetooth and infrared to collect the health related information for a patient. This information can then be accessed by an expert doctor for diagnosis, similar to any other EMR system. Such an architecture seamlessly integrates a mobile phone as a low cost computing and communication device in the well studied (and well tested across the world) EMR systems. Sana is one such mobile phone based EMR system that we are currently using for the CVD risk analysis case study (discussed in detail in Section IV).

With the healthcare information being available in digital format, these EMR systems can be easily enhanced further to provide affordable and efficient personalized services as well. As an example, a simple reminder can be sent to the patient when he is due for his next visit to the doctor based on the records maintained in the database.

D. Use of GIS and AI techniques for improving and automating diagnosis

It is well known that diagnosing an infectious disease with 100% accuracy involves pathological tests. As per field studies, it is possible to diagnose it with 90% sensitivity using scientifically proven methods, e.g., WHO’s algorithm for Leptospirosis. Currently, WHO’s algorithms do not use any knowledge of spatial and temporal spread of disease, e.g., Leptospirosis spread through contaminated water bodies. In our proposed system (discussed in detail in Section V), with the use of cellphone and GIS systems, we expect to improve the accuracy of diagnosis by accounting for spatial and temporal data analysis.

Current spatial disease surveillance techniques fall into two distinct categories [4]: one using spatial statistics to analyze and detect disease clusters through post-hoc analysis of collected health information, and another to model disease dynamics using temporally explicit models. The first method emphasizes the detection of disease clusters for identifying emergent infections [5], [6]. A classic example to detect spatial and space-time disease clusters is SatScan, a software developed specifically for disease surveillance in the US and funded by the US National Institute of Cancer. This technique is based on the hypothesis that certain types of diseases (particularly cancer and emerging infectious diseases) can show spatial clustering, and therefore can be detected by a higher than normal variance to some background level of information. The key benefit behind the development of such tools is the idea that disease clusters identified from precise geocoded information can be spatially correlated with sources of pollution (as in the case of Cancer) or mechanisms of infectious disease transmissions [7].

The second method focuses on spatially-explicit agent-based models from AI. An agent-based model simulates interactions between biological individuals and their landscape through the use of computer code to represent each individual as an
agent in a virtual environment stored within a GIS. Further, the computer code representing an individual must possess the following four properties [8]: (a) autonomous behavior, (b) ability to sense its environment and other agents, (c) ability to act upon its environment alone or in collaboration with other agents, and (d) possession of rational behavior. Additionally, researchers have pointed out that intelligent agents should not only be able to respond to, but also learn from, their environment. Humanistic characteristics such as beliefs, desires, intentions, and emotions and trust also could form a part of agent behavior [9]. Computational models of boundedly rational decision-making behavior are available to develop computer code that fulfills the criteria of autonomy, awareness, reactivity, and rationality.

IV. CASE STUDY I - CVD RISK DETECTION

Cardiovascular Disease (CVD) is becoming a critical problem all across the world with a report from World Health Organization (WHO) estimating nearly 17 million deaths every year due to CVD. In low-middle income countries (where more than 80% of the cases happen [10]), deaths occurring due to CVD are double than that caused by HIV, malaria, and tuberculosis (combined) [11]. Early detection and economic burden from getting sick and deaths thereof motivates the need to develop cost effective methods for low-middle income countries. Several methods have been proposed in the literature to calculate CVD risk score [12], [13], [14], [15]. However, there is little work on calculating CVD risk cost effectively i.e. without lab testing or costly equipments. Most of these CVD risk prediction approaches require blood testing in laboratory, which may not be available in rural healthcare settings.

WHO released an approach for CVD risk detection, with or without the requirement for measuring blood cholesterol level, for different regions of the world. TA Gaziano et al. [16], also released similar CVD risk prediction approach without blood testing requirement, although with a few different parameters to consider. They also tested their approach for data on US population and results shown were very impressive. However, there is little evidence of usefulness of any such approach in Indian settings. We used both of these approaches, together with adding some more parameters based on our discussion with local doctors (hence forth in this section, we term the combination of the three as non-laboratory CVD risk detection approach) for CVD risk assessment in our study. This study is performed in collaboration with E-Health Point (EHP), a for-profit organization setting up rural clinics in Punjab and Sana Group, MIT who designed the basic system used by us in developing the forms for CVD risk detection. In our opinion, this is the first time such a non-laboratory CVD risk detection approach is being tested in Indian settings using mobile phone technology.

1) Designing the Study: While designing the CVD risk detection study, we focused on the following two parameters:

- Collecting appropriate health care indicators for rural settings: Non-laboratory based CVD risk prediction study by TA Gaziano et al. [16] requires collection of a few health indicators such as diabetes level, smoking addiction, blood pressure, among others, to categorize the patient to one of high, moderate or low CVD risk category. In collaboration with EHP, we discussed our approach with local doctors at EHP and further added more parameters based on their suggestions for detecting patient with high CVD risk. We plan to compare the different approaches with results from the lab tests to measure the efficacy of one or combination of such approaches for Indian rural setting.

- Improving healthcare worker efficiency: We partially automated the process of health care worker going door-to-door to enroll people, collect information about specific health indicators, calculate their CVD risk and if the person is found to be in high CVD risk then motivating them to visit the EHP clinic for further tests. We used mobile phone as a platform to create multiple forms (using Sana technology) for collecting the health indicators and autonomously computing the CVD risk detection.

2) Deployment Experience: We trained the EHP staff (field worker, IT professional and clinical staff) for using the Sana technology to perform the field deployment. Following are some of our experiences from the training session performed in July, 2010:

- Setting up and maintenance of the server end of the application: It was the first time Sana technology was installed in a professional organization with their own security concerns. Setting up the server end while working together with their network security mechanisms was challenging.

- Enthusiasm of the field workers and clinical staff: Since Sana runs on smart phones, we had our apprehensions about training the field worker to use the technology. However, both the field workers involved in the study showed a lot of enthusiasm, learned the technology and one of them even filled up the complete form correctly in her first attempt. We observed the clinical staff during our filed visit to EHP clinics, while they were being demonstrated with the new technology. They listened carefully and asked several questions making the entire process interactive. They were then trained on the forms developed for follow-up clinic visit of the patient (as discussed next).

3) Data Collection: We created multiple forms using Sana, collecting data about various dimensions related to this deployment, and perform extensive analysis in the future.

- Mobile forms: In addition to collecting the multiple health indicators required for the CVD risk detection, we are also collecting information when the patient visits the clinic for follow-up tests; survey on his satisfaction with the EHP services; and reasons for declining (if they refuse to participate in our study).

6http://www.who.int/cardiovascular_diseases/resources/atlas/en/
7http://www.sanamobile.org
Comparing multiple approaches: We plan to compare multiple approaches specified above for their efficacy in Indian setting. We plan to correlate the output from these indicators with the lab tests (for the patients coming for follow-up visits) and analyze if the addition of extra health indicators from the local doctors have any effect on increasing risk calculation accuracy.

Sana usability study: We are also collecting information on the usability aspects of Sana technology (time taken to fill up the form, mistakes committed, performance in regions with intermittent network connectivity). We plan to do extensive study of these aspects and their variability over time.

4) Preliminary Observations: So far, 55 people were visited to fill up the initial CVD risk assessment form. Fig. 3 shows the general distribution of people to high, medium and low risk categories. We then analyzed how the three methods of calculating CVD risk compare with each other (displayed in Fig. 4). Out of the total of 55 cases 9 cases are such that all the three methods for CVD risk calculation agree with each other (category 1). Then we compare the three approaches in pairs - There are 13 case in which additional method from our local doctors and TA. Gaziano et al. [16] matches while WHO conflicts (category 2), 10 cases are such that TA. Gaziano et al. [16] and WHO matches and local doctors approach conflicts (category 3), 6 such cases such that local doctors and WHO agrees, while TA Gaziano et al. [16] conflicts (category 4). Another interesting aspect is that two of the published studies, i.e. TA. Gaziano [16] and WHO risk prediction method conflict in 16 cases (category 5).

This preliminary analysis clearly indicates the need to perform extensive studies for coming up with a non-laboratory, cost-effective CVD risk detection approach for Indian scenario.

V. CASE STUDY II - LEPTOSPIROSIS

Leptospirosis is a potentially life-threatening infectious disease. For a non-medical professional, the symptoms of Leptospirosis resemble those of common flu or jaundice. Given the lack of proper Information, Education, and Communication (IEC) about the disease and unavailability of trained medics, the patient quickly progresses to complications such as failure of lung, liver, and kidney and finally death. It is not only prevalent in rural areas of India but also in metros, e.g. Mumbai and Chennai. Fig. 5 shows number of cases of Leptospirosis and corresponding deaths occurring in the state of Gujarat during 2007. The best method to put this disease under control is early diagnosis and prompt treatment or referral to a tertiary care centre.

Using our mobile-based system, we propose to efficiently identify suspected patients with a high probability, thereby improving the chances of getting them treated and hence their survival using our solution. At the grass root level, medical officers or peripheral workers can detect or suspect cases by identifying usual symptoms and assigning them with certain scores. These signs and symptoms are detected by simple examination and taking medical history of the patient into account. Once the score is above a certain threshold, the person is suspected to be suffering from leptospirosis and is treated as per the protocol. WHO has prescribed such a scoring system [17] which can be utilized. Fig. 6 shows the form containing the scoring system. The form can be easily ported to a mobile phone. Pre-diagnosis involves a sum of fourteen numbers. Studies have been undertaken to establish the validity (sensitivity and specificity) of this WHO scoring form [18]. The score form can be modified as per the local profile of the disease. If a uniform policy of its utilization at the field level is designed then this tool may help to tackle the high rate of fatality due to the disease. In addition to data entry and transmission, a smartphone can automate the tasks of measuring data for following two fields in the form:

(a) measuring the body-temperature of the patient using a...
Fig. 6: WHO’s form to pre-diagnose Leptospirosis connected sensor and (b) diagnosing conjunctival suffusion by taking a photograph of patient’s eyes and detecting redness in them.

Detection and Simulation: A two-step spatial approach
Once a disease probability in the form of secondarily sensed information has been identified using NLP and machine learning (AI) techniques, these probabilities will be tied back to the individual locations. Subsequently, the two spatially explicit techniques detailed earlier in subsection III-D will be used to (a) initially locate disease clusters in specific locations by identifying greater than normal variation above a spatial mean of disease occurrence using SatScan, and (b) set up an agent-based model to further simulate the probability of spread of the contagion.

Given the Leptospirosis similarities in the parameters leading to onset of disease with those of Malaria and Dengue, we expect that the same system can be tailored for the latter diseases. We will work on a version of our system for Malaria.

VI. CONCLUSIONS
In this paper we presented an architecture of using ICT to improve the efficiency of healthcare delivery using simple procedures that can complement advanced techniques such as using automated diagnosis and telemedicine. Such an architecture can be customized based on specific diagnostic requirements and local environment; collects data in electronic format that can be used for detailed analysis (and modeling); and has self-learning capabilities to automate the process of diagnosing so as minimize the role of doctors.

We presented a mobile phone based EMR architecture for healthcare delivery to use existing ubiquitous technologies for further improving the efficiency. We present a detailed case study of CVD risk detection in rural areas of Punjab, India to highlight how our proposed architecture can be put into use for technology enabled improved delivery of healthcare in under-developed regions. Our initial analysis clearly highlighted that any procedures or studies developed based on a different geographical region may not be directly applicable to a different context. The proposed architecture can then enable to perform standardized procedures quickly and effectively in new regions to understand their applicability. We propose to study the diagnosis of Leptospirosis in Gujarat using a similar approach while also developing some automated modeling approaches for further improving the efficiency of the disease diagnosis.

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