Towards Providing Full Spectrum Antenatal Health Care in Low and Middle Income Countries

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Abstract: The provision of Antenatal Care (ANC) for pregnant women plays a vital role in ensuring infant and maternal health. Limited access to antenatal care in Low and Middle Income Countries (LMIC) results in high Infant and Maternal Mortality Rate (IMR and MMR, respectively). In this work, we propose a cloud-based clinical Decision Support System (DSS) integrated with a wearable health-sensor network for patient self-diagnosis and real time health monitoring. Patient assessment is performed by evaluating the human-input coupled with sensor-generated symptomatic information using a Bayesian network driven DSS. High risk pregnancies can be identified and monitored along with dispensing of consultant advice directly to the patient. Patient and disease incidence data is stored on the cloud for tuning probabilities of the Bayesian network towards improving accuracy of predicting anomalies within the epidemiological context. The system therefore, aims to control IMR and MMR by providing ubiquitous access to ANC in LMICs. A scaled-up implementation of the proposed system can help reduce patient influx at the limited tertiary care centers by referring low-risk cases to primary or secondary care establishments.

1 INTRODUCTION

Every year over 210 million pregnancy cases are reported worldwide (Shah and Åhman, 2004). About 2.6 million of these pregnancies conclude in stillbirths with 98% of these deaths occurring in Low and Middle-Income Countries (LMIC) (Hogan et al., 2010, WHO and UNICEF, 2012, UNICEF, 2012, May 2014). Nearly 800 women lose their lives every day as a result of pregnancy related complications with 99% of all maternal deaths occurring in developing countries. The high fertility rates amongst LMIC women (Sathar et al., 1988) predisposes them to an enhanced risk of pregnancy related complications. The resource-limited health-care infrastructures in the LMICs further aggravates the situation, with women from remote poverty-stricken areas being the most disadvantaged.

Antenatal care (ANC) has been proven to be a key determinant of infant and maternal health (Inam and Khan, 2002). Provision of the most basic ANC has been shown to significantly reduce the astronomical IMR and MMR in LMIC countries (Inam and Khan, 2002). A simple but timely measurement of high blood pressure can help pre-empt several complications including but not limited to preeclampsia, ectopic or molar pregnancy, placenta previa, placental abruption, miscarriage, hyperemesis gravidarum, preterm labour as well as problems with the foetus itself (Burrow et al., 2004, Norbeck and Tilden, 1983, Sattar and Greer, 2002, U.S. Department of Health and Human Services, September 2010.). In Pakistan, like other LMICs, the leading causes of maternal mortality include haemorrhage, followed by eclampsia and sepsis (Jafarey, 2002). Regularity in ANC can pre-empt such obstetric and postnatal complications thereby averting major emotional and financial stress for the patients and their families.

The major impediments in provision of ANC in

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LMICs include poverty, illiteracy, inadequate governmental healthcare support, obstacles in timely access to available services and cultural barriers. Moreover, with the absence of health insurance safety nets in LMICs accessibility to ANC becomes directly proportional to the economic status of the patient and her family. Besides the non-availability of essential health information, ill-equipped primary care centres and under-trained primary health care workers also contribute to the high IMRs and MMRs. (Penfold et al., 2013, Bloom et al., 1999, Ransom et al., 2002, Titaley et al., 2010). As a result, a large number of patients in developing countries fail to access, obtain and implement ANC, essential for the welfare of both the foetus and the mother.

In this work, we propose a cloud-based ANC DSS for an assistive medical diagnosis and monitoring of pregnant women. The salient features of the system include: (i) patient self-diagnostics; (ii) automated monitoring; (iii) patient prioritization; (iv) real-time case tracking and intervention by patient-opted tertiary care consultants; and (v) on request consultant advice dispensation. The structural components of our clinical Decision Support System (DSS) include a multilingual tablet and smart phone front-end application that is usable by both patients and consultants; a wearable health sensor suite interfaced with front-ends via Bluetooth (Miller and Bisdikian, 2001); a web application for dealing with PC-based patient requests; a desktop application for hospital administration and a backend database server for storing patient and doctor incidents data.

At the heart of the system is a DSS which is compliant with the ANC guidelines devised by the Merck® Manual Professional Version (Merck, 2015) and is designed to emulate the decision making capabilities of a professional medical advisor. A total of 16 pregnancy-related abnormalities (Table 1) are included and elaborated by Merck along with their risk factors and symptoms. Pre-eclampsia has been selected and a probabilistic Bayesian network (Friedman et al., 1997) is constructed involving its symptoms (Figure 1). Clinical data from Shalamar Institute of Health Sciences (SIHS, Pakistan) is used to calculate the probabilities in the network. Patients may answer a series of systematically-posed questions, developed in accordance with the Merck® guidelines for self-diagnosis, in tandem with inputs from patient-worn sensors. Sensor-based monitoring can be performed in a continuous or periodic manner depending on the type of health marker to be measured. The probability of an abnormality is then progressively calculated by employing the Bayesian network and the patient provided symptomatic information.

The system can thereby keep track of and assess the health state of the respondent in real time irrespective of her physical distance from a hospital. Users can also choose to subscribe to certified consultants who are registered in the system, based on the tertiary hospital that they're working in. These consultants may then choose to participate and receive the patient's data followed by intercession in the recommendations dispensation process. On the basis of the diagnostic information, a health support or emergency response may be orchestrated at the primary, secondary or tertiary care centres. The system is currently being deployed at SIHS, where it is undergoing functional testing.

Taken together, the proposed system ensures a timely provision of optimal quality ANC to LMIC populace; thus, providing significant assistance in reducing the IMR and MMR.

Table 1: List of pregnancy disorders enlisted in the Merck® ANC guidelines.

1	Oligohydramnios	9	Abruptio Placentae
2	Preeclampsia and Eclampsia	10	Cervical Insufficiency
3	Spontaneous Abortion	11	Intra-Amniotic Infection
4	Pruritic Urticarial Papules & Plaques of Pregnancy	12	Hyperemesis Gravidarum
5	Pemphigoid Gestationis	13	Erythroblastosis Fetalis
6	Septic Abortion	14	Placenta Previa
7	Stillbirth	15	Ectopic Pregnancy
8	Vasa Previa	16	Polyhydramnios

2 RESULTS

2.1 Elicitation of Risk Factors, Symptoms and Diseases from Merck® ANC Guidelines

The comprehensive ANC guidelines provided in the Merck® Manual Professional Version were used to elicit pregnancy-related abnormalities, the risk factor to which a patient may be predisposed and the presented disease symptoms. A total of 16 abnormalities (Table 1) were extracted along with respective risk factors and symptoms. These included pre-eclampsia (MacKay et al., 2001) which is amongst the leading contributors to IMR (Basso et al., 2006) and MMR (Ghulmiyyah and Sibai, 2012). A

Table 2: Symptoms and Risk Factors Associated with Preeclampsia and Eclampsia.

Symptoms and signs	Risk factors
Proteinuria	Nulliparity
High blood pressure and hypertension	Pre-existing chronic hypertension
Severe headache	Vascular disorders
Visual disturbances (blurred vision, scotomata)	Pre-existing or gestational diabetes
Coagulopathy (Petechiae)	Age>35 or Age<17
Non-dependent oedema (facial & hand swelling)	Family history of preeclampsia
Hepatic ischemia (right upper quadrant abdominal, epigastric pain)	Preeclampsia or poor outcome in previous pregnancies
Enhanced reflex reactivity	Multifetal pregnancy
Nausea	Obesity
Confusion	Thrombotic disorders
Vomiting	
Dyspnea	
Cyanosis	
Stroke	
Serum > two times normal (AST, ALT)	
Thrombocytopenia	
Reduced urine output	

detailed tabulation of 10 risk factors and 17 symptomatic presentations associated with pre-eclampsia are provided in Table 2.

2.2 DSS for Pre-eclampsia using a Bayesian Network

All symptoms of pre-eclampsia are orchestrated into a Bayesian Network (Figure 1). Bayesian probabilities for each disease outcome are progressively calculated upon input of symptomatic information by the user and wearable health sensors. The probabilities in the Bayesian Network are populated in line with the diagnosis pathways in the Merck® Manual and will later be further tuned in light of regionally localized patient data (both manual and sensor inputs). The DSS encapsulates the Bayesian probability calculation engine and transforms user inputs into probable outcomes, thereby also prioritizing high risk pregnancies for evaluation by a remote clinical consultant. The output to the user includes primary care advice and recommendations while detailed user profile and assessment information is uploaded to the cloud for ready reference and intervention of the consultant.

2.3 System Architecture for Cloud-based ANC

A three-tier architecture is employed to construct the foundation of the proposed system (Figure 2). The first tier comprises of Graphical User Interfaces (GUI) for the targeted client audience. These GUIs include a smart phone/tablet app and a web application for patients, primary health professionals and, consultants. A desktop application is also provided for user administration by the hospital administrators. Middle tier is a subscription-driven Web API (Microsoft, 2014) which embodies the functional logic including the DSS and Bayesian network. The third tier includes a MySQL (MySQL, 2001) relational database server with a normalized schema of all system entities. User triggered operations and requests are transported in JSON (Peng et al., 2011) between the wearable sensors, GUI applications, the Web API and the database.

Microsoft® MVC (Masound and Halabi, 2006) has been employed to develop the Web API. Agile Development (Martin, 2003) methodology is used to incrementally develop the system's overall software manifestation. The system has been tested and verified using white-box testing at the component level. Integration testing has been performed to validate the functional coupling of the overall system.

2.4 Security and Privacy

Confidentiality of patient data is ensured by controlled access and its on-demand availability from isolated logical data storages at hospital level. It can be further enhanced by continuous risk assessment and updates to the security policies. Furthermore, we are considering to deploy Health Level-7 (HL-7) Healthcare Privacy and Security Classification System (HCS), and Role-Based Access Control Healthcare Permission Catalogue (RBAC). Towards implementing data segmentation for access across distributed systems, we are also considering to use HL-7 Data Segmentation for Privacy (DS4P) as a standard.

2.5 ANC System Software Prototype

2.5.1 Smartphone and Tablet Application for Patients and Consultants

A smartphone application is developed for users including patients, primary care operatives, doctors

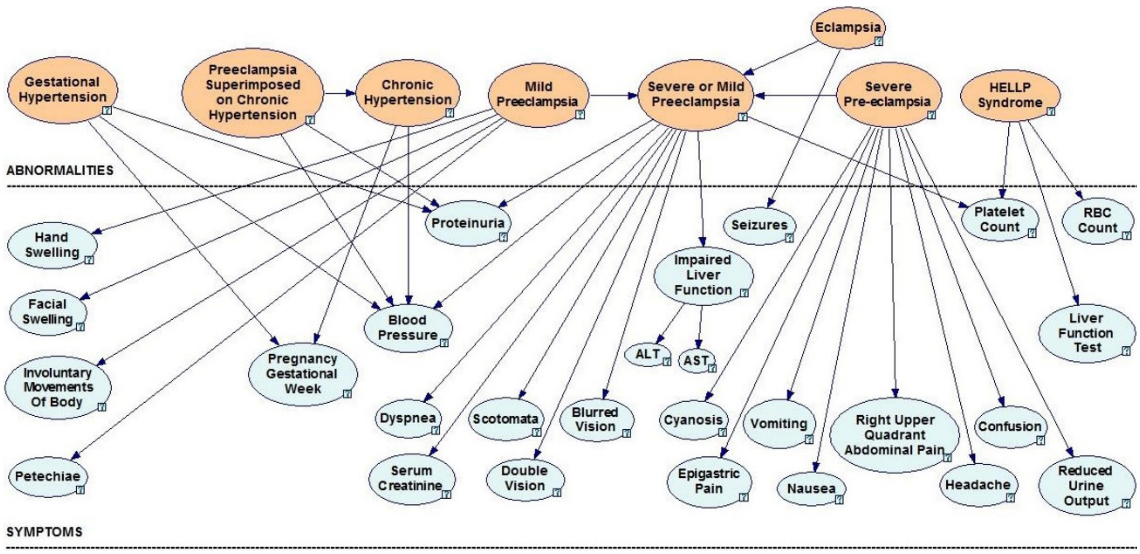

Figure 1: Bayesian Network of Symptoms Leading to Pre-eclampsia and Eclampsia.

and consultants (Figure 3B). Heuristic evaluation for user interfaces has been undertaken and the smart phone app has been localized to rural locales along with a text-to-speech feature in the DSS. Furthermore, elicitation of potential users' characteristics such as reasoning ability, gender, age, spatial memory and learning style is underway towards creating an enabled user experience. Windows Phone Development Kit (Microsoft, 2013) is used to develop the application and XAML (Schmidt, 2010) is used to construct the user interfaces. The application encompasses features such as user registration, profile creation, patient self-diagnosis using a multi-lingual GUI, consultant subscription based on patient choice, and public forums for discussions and sharing ANC experiences.

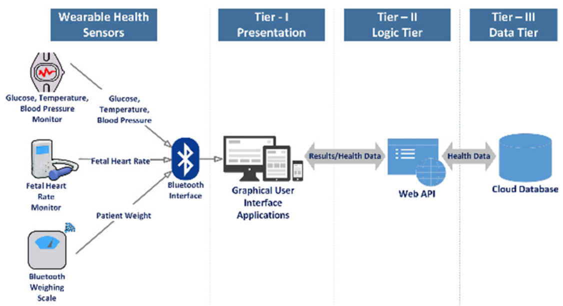

Figure 2: Overall System Architecture.

2.5.2 Web Application for PC-based Patient Assessment and Diagnostics

Since smartphone penetration is still low in rural and sub-urban localities of LMICs, the proposed system also includes a web application with the complete set of system features (Figure 3A). An extensive exercise for user interface design and development has been undertaken on the lines of the smart phone application interface (mentioned above). Microsoft® ASP.NET Web Forms (Sheriff, 2001) has been employed for the software. This application can be leveraged by using a personal computer with an installation of standard web browsers.

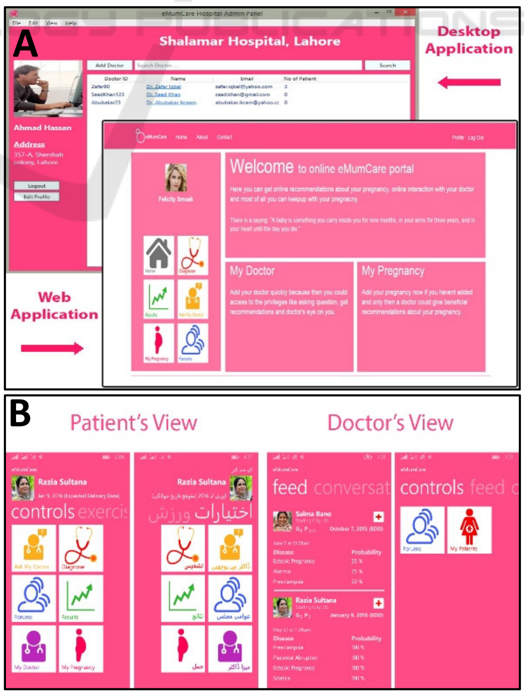

Figure 3: (A) Web Application and Desktop Administration Console, (B) Smart Phone App View.

2.5.3 Desktop Application for System and Data Administration

A stand-alone desktop application has been developed to act as the administration console (Figure 3A). Windows Presentation Foundation (WPF) (Chappell, 2006) has been employed to develop this component. Using this console, authenticated doctors and consultants are enlisted with the system by a hospital designated administrator.

2.6 Deployment of Prototype at Shalamar Institute of Health Sciences (SIHS)

The system has being test-deployed at clinical site in SIHS. Patient and consultant views are being acquired to fine tune the GUIs as well as the probabilities for pre-eclampsia's Bayesian network. A data warehouse has been established to act as patient and self-diagnostics registry.

3 DISCUSSION & CONCLUSIONS

The work outlines the design and development of a cloud-based ANC health support system which can be employed by patients for self-diagnosis and by clinical consultants to provide timely support to high risk cases. The salient objective of this project is to provide optimal clinical advice and support to pregnant women in LMICs. Towards its popular acceptance, limited financial resources of LMIC women limits affordability of prevalent smartphone devices and tablets. However, with a foreseeable drop in the device costs (Hamblen, 2014), a significantly improved affordability may be less than a decade away. Additionally, limited availability of 3G and 4G spectra for fast communication between the users and the cloud may be another impediment in scaling the system in rural and sub-urban areas of LMICs. The relevance of the system is however anticipated to improve with rapid penetration of communication technologies in LMICs (PTA, 2013).

Another significant challenge in wide-spread application of the proposed system may come from the inability of the potential LMIC users to read non-native languages. This has been catered for in this work by a multilingual support (English and Urdu) in the GUIs. For world-wide acceptance, an adequate design allocation has been made for supporting other native languages. Furthermore, the limited experience of LMIC women to execute software is also pertinent and may require tailored human-computer interaction techniques for ensuring an enabling user experience. Furthermore, hesitation on part of the patients can be circumvented by providing hands-on training to primary health care workers on the proposed system. Since primary healthcare networks are established in most LMICs, they can act as vehicles of delivery and execute the diagnostics in-tandem with the patient.

At the clinical end, a rapid increase in patient turn-over may lead to hesitation on part of the consultants to enrol in the system. However, an encouraging response has been received after the system's test-deployment at SIHS. It is envisaged that with due enhancements in GUIs, a streamlined patient-consultant communication, the proposed ANC system can gain wider subscription in Pakistan and worldwide.

In conclusion, the proposed system aims to use pre-existing clinical knowledge and employ communication technologies to deliver much needed ANC in LMICs towards reducing high IMR and MMR.

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