prasavGraph: Android based Labour Monitoring

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Abstract: The simplified Partograph is a concise charting mechanism used by skilled birth attendants for recording and communicating the important parameters and developments during the labour process. Compliance and correct plotting of partographs may be significantly improved with the use of technology. This paper reports the development of an Android-based smart phone/tablet application to plot the partograph. To date such a complete application is not available. We envisage that over a period of time, systematic plotting of partographs will encourage providers to use it as a decision-making tool and thereby reduce morbidity and mortality both of mother and foetus/newborn arising out of complications during labour and its sequelae.

1 INTRODUCTION

The Millennial Development Goal 5 (MDG 5) targeted a 75% reduction in maternal mortality and a two-thirds reduction in child mortality. MDG 5 was formulated following a 1987 WHO conference where the Safe Motherhood Initiative was announced, of which the adoption of the partograph was an integral part (Hogan et al., 2010). An outcome of this Initiative was a comprehensive manual on preventing maternal deaths (Royston and Armstrong, 1989). A review in 2000 (Raleigh, 2000) cited areas for improvement such as increased use of manual vacuum aspiration for the management of incomplete abortion, as well as the education of midwives in the use of the partograph, and training traditional birth attendants.

Maternal mortality worldwide stood at about 343,000 in 2008. Studies showed that the main causes of maternal death were anaemia, post-partum haemorrhage (PPH), sepsis, malaria, delay, and eclampsia. “Delay” was cited as a primary cause relating to *obstructed labour*, i.e., the failure of fetal descent despite healthy uterine contractions, which accounted for 8% of maternal deaths worldwide (though often misreported as PPH or merely as “delay”). Obstructed labour is also the major cause of maternal morbidities such as obstetric fistulae which are thought to afflict an estimated 10-20 million women worldwide. It can be prevented by better trained attendants, timely monitoring and emergency intervention.

The simplified *partograph* is a concise charting mechanism used by skilled birth attendants for recording and communicating the important parameters and developments during the labour process (WHO, 2015). This single page sheet is prepared for collecting and recording all important information over a 12-hour period starting with the onset of labour through to delivery. It acts as a decision-making aid in that it indicates when labour is proceeding at a normal rate and when doctors should prepare for carrying out interventions.

Compliance and correct plotting of the partograph has been a major issue in its widespread use and in research based on the data collected. The adoption and accuracy of partographs may be significantly improved with the use of technology. The ubiquity of relatively inexpensive smart phones/tablets provides an opportunity, with a well designed electronic Partograph significantly increasing use and correct recording of the labour processes. This paper reports the design and development of an electronic version of the simplified partograph. This mobile/smart phone application – *prasavGraph* (Figure 1) enhances the simplified Partograph by recording events at the time of admission and during the active phase of labour up to 30 minutes after delivery.

The partograph may be considered to consist of three sections, each of which has different inputs

- the fetal record
- the progress of labour record
- the maternal record

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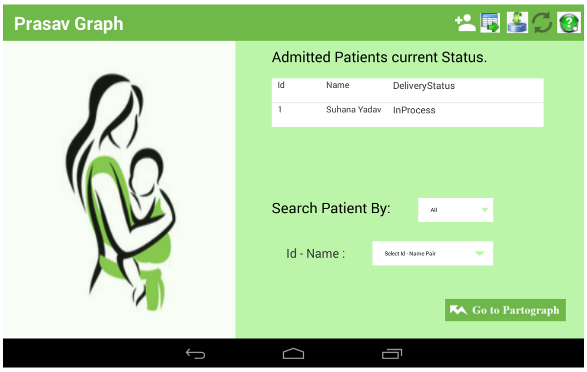

Figure 1: prasavGraph.

The fetal record tracks fetal heart rate and the condition of amniotic membranes and colour of liquor. The labour record tracks cervical dilation against time, charting it with pre-printed *alert* and *action* lines. The maternal record captures contractions, blood pressure, pulse, urine output, temperature, and drugs administered including those used to help uterine contractions. This information is a concise summary of the birth process and indicates when further interventions are necessary.

The Android-based application *prasavGraph* emulates the simplified paper Partograph and also provides additional features. The digitization of the record keeping process during labour can help build applications for decision support to reduce morbidity and mortality both of mother and foetus/newborn arising out of complications of labour and its sequelae. To the best of the authors' knowledge, this is the first such application that is based on the Android platform, and which has been developed using a delay tolerant 3-tier architecture. The Partopen is the closest electronic aid that is available for recording labour. However, the Partopen is not as comprehensive as this effort (Underwood, 2013), although its design goals were to work with the paper partograph without changing the workflow processes.

The broad objectives of the *prasavGraph* application are

1. *Reducing data entry errors*, achieved by streamlining and simplifying the data recording process.
2. *Compliance with mandated/suggested procedures during childbirth*, ensured by making the application run in real time with the option of recording data "offline" too. However all such entries are logged and colour coded.
3. *Providing a Delay-tolerant Infrastructure*, to enable the application to work in low network connectivity areas.
4. *Analytics*, enabled by the availability of data in digital form. A server database is integrated to manage records of various devices in the same facility for better record sharing and visualization.
5. To act as a *training aid*.

In the next section, we describe the high level design of the *prasavGraph* application.

2 RELATED WORK

ICT has been seen as an enabler for better provision of healthcare. In particular, with the widespread use of mobile phones, mHealth technologies are seen as a means for low-cost and effective delivery of maternal health care, in particular by providing better training to caregivers, better access to specialist support and remote diagnosis, increased information about reproductive health, and greater awareness of diseases and their prevention and treatment. The deployment of ICT does not automatically lead to improved outcomes. This was seen in the case of the ClaimMobile project (Densmore, 2012), where the smartphone application did not replace the existing paper-based flows, but suffered from additional limitations of unreliable connectivity and power. The e-IMCI project in Tanzania achieved success in replacing bulky paper protocols with PDA-based IMCI workflow models (DeRenzi et al., 2008). Open Data Kit (ODK), an extensible set of phone based tools, supports the collection of data using smartphones, thereby reducing errors in data and providing timely feedback and decision support. While health-related ODK-based applications have reported a degree of success, major limiting factors include small screen size and concerns related to the security of data (Anokwa et al., 2012). CommCare is an open-source phone-based platform that has been used by community health workers in Tanzania for the care of pregnant women. Since CHWs could now be monitored, this intervention unfortunately resulted in a significant decrease in the number of CHW submissions (Svoronos et al.,). The MoTeCh project in Ghana (MoTeCH, 2011) also faced resistance in its use from CHWs. Both these experiences suggest that a greater participatory role involving users is essential for successful adoption. The Swasthya Slate (Swasthya, 2015) is a tablet-based platform interfaced with a collection of medical/diagnostic sensors that has been developed for CHWs and medical professionals in rural India. The most relevant work in addressing the labour process is the PartoPen (Underwood et al., 2013), where a pen-like device is used on specially printed partograph forms, while also digitally recording the inputs and providing timely audio reminders and feedback on a tiny screen on the device. The PartoPen approach is *not* to supplant the existing paper-based protocols, but to automatically extract information from the forms and *supplement* the process with feedback and reminders. The PartoPen has been used in teaching and clinical studies in Kenya, showing the device's robustness but also the limitations of such a hardware-software solution in that it is oriented towards successful filling of the partograph rather than on the quality of care (Underwood et al., 2014).

3 SYSTEM DESCRIPTION

As mentioned above, a key motivation for this activity is to enable the faithful recording of data during labour. Despite government and WHO initiatives, compliance in this aspect is low across the world (Ollerhead and Barriers, 2014). The paper-based approach is often prone to errors during data entry, both in relation to the time and also in the fidelity of the data being entered. The fact that in many settings the medical staff are overworked often causes data to be entered retrospectively. Most importantly, the data has to be manually (and often painstakingly) digitized for any sort of data analysis.

Android-based smart phones, which are ubiquitous today, are very good data acquisition devices. The portability of applications across different handsets and tablets is also very good. The design of the electronic Partograph has been targeted at such devices. The smart phone is used as the primary data acquisition device. The application residing on it essentially uses form-based entry with client-side data validation on each data entry field. Colour-coded text boxes and out-of-bounds warnings are built into each such field. The application is built assuming an opportunistic communication framework (Pelusi et al., 2006). It works as a standalone device but whenever it is in the vicinity of a laptop in the premises, it replicates the data that have been collected so far.

Figure 2: Architecture Diagram.

As shown in Figure 2, the tablet and laptop are connected via WiFi or USB. The data is maintained in a standard format (openMRS), and can be opportunistically uploaded to the central server (cloud) for analysis. The design architecture resembles a Client-Server model. The laptop containing the database and web-server is used for backup and background processing of the data. The laptop also provides the facility for making paper copies of the partograph.

The different modules of the Android application are:

- Static User Interface Module: This module is used for creating various user interfaces of the Android Application. Static UIs in Android are created in XML.
- Network Module: This module is responsible for interacting with the network either as a service or otherwise. APIs used herein are:
  - Network Android API
  - Network Service API
  - Web Connection API
- Database Manager Module: This module is useful for carrying out database-related functions, including backup and logging. APIs used herein are:
  - Database API
  - Database Connection API
  - Database Functionalities API
- Notification Module: Notifications play an important role in this Android application whereby it notifies users (using an alarm / colour changes) about the validity/correctness of the input data etc.

The partograph records the progress of labour. The key parameters that are tracked are cervical dilation, and the vital parameters of the foetus and the mother. The onset of active labour is indicated when the cervical dilation is measured to be 4cm and continues up to 10cm, after which delivery occurs. Medically, progress is normal if the rate of dilation is 1cm per hour. Partograph zones are colour coded, as shown in Figure 3, to indicate different monitoring modes for the birth attendant. Any time the cervix

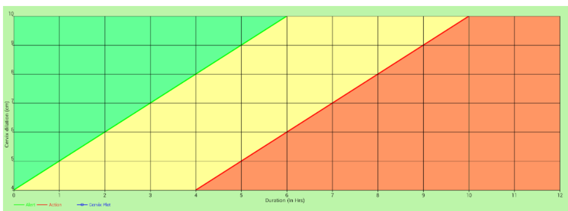

Figure 3: Partograph Zones.

dilation is in the red zone, *action* has to be taken. Provision for alerting the attending physician is (optionally) present in the system. The yellow zone indicates that labour is sluggish and alerts the attending staff for closer monitoring and/or augmentation of labour.

In the second and third stages a complete record of the medication as well as other physiological conditions of the mother is also maintained. On delivery, the details of the child(ren) need to be entered. This feature, coupled with opportunistic communication with the cloud/hospital, can be used effectively to automatically record births with municipal authorities. Popups and/or beeps are built into the application to serve as reminders to the attendant for recording the data. The use of the web server helps in making these data available on the central monitoring station.

4 DETAILED DESIGN

A significant part of the design activity is concentrated on the User Interface (UI). The UI is essentially composed of multiple forms which have been carefully designed to minimize the number of keystrokes. Multiple versions of the application have been validated by professionals, students, trainee doctors to evaluate and report on the ease of using the application. Figure 4 diagrams the application flow.

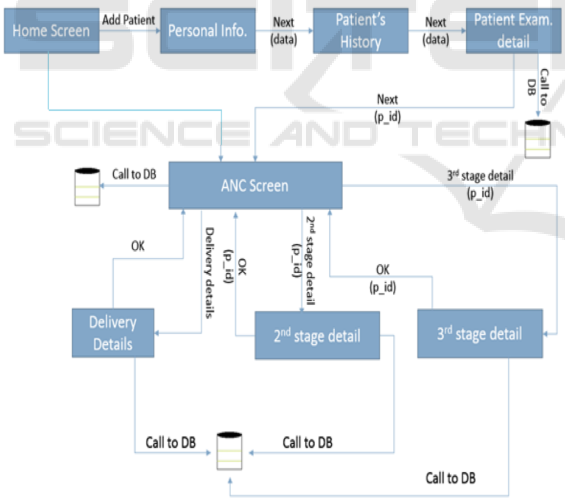

Figure 4: Flow Diagram of the Android application.

The application starts with the Home Screen, which has options to either add a new patient and to go to a pre-existing partograph, given a patient id or a patient name. Clicking on the *add new patient* button takes the user to a screen which records the patient's name and other attributes. The next form, in Figure 5, allows the user to input the patient's medical history and examination details at the time of admission. Some of the fields are mandatory while others may be left blank. This is an important feature because the state in which the patient is admitted is not always completely known, e.g., all the test results may not be known at that time. Many of the field values (e.g., date and time of entry) are either set automatically from the machine settings or set to default values. The right side of Figure 5 shows some of the

Figure 5: Form Based Entry.

physiological parameters of the patient that need to be entered at admission. All these fields are checked for validity and bounds, with alerts popping up on incorrect or out-of-range values. The attending medical staff has the option to override the flagged exceptional values (e.g., a very high systolic BP value) but any such value is (colour) coded and stored.

After the user inputs these data, the main partograph screen is displayed. The cervical dilation value is noted and the partograph "starts" recording in real time only if the value is greater than or equal to 4 cm. Once the details at admission have been entered, the partograph is presented as shown in Figure 6. All subsequent entries are made in this page. Note that the top of the partograph continues to display admission time entries.

This screen has three different input modes: 1^{st} and 2^{nd} stages and the 3^{rd} stage with delivery details. The 1^{st} stage requires recording cervical dilation values periodically and the cervical dilation value vs time graph gets updated automatically. During 1^{st} and 2^{nd} stages, the recording of data such as foetal heart rate, duration and frequency of uterine contractions, pulse, BP etc. is done at predefined intervals (30 or

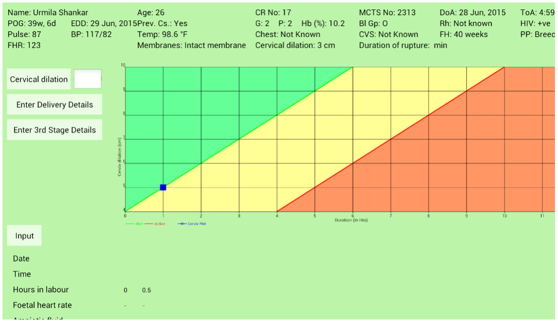

Figure 6: Cervical Dilation.

15 minutes). The tabular display gets automatically time-stamped and hence only the actual time at which data are entered gets noted. The first column of left half of the figure shows a partial list of the parameters that are monitored at regular intervals of 30/15 minutes depending on the stage of labour. The values are displayed in the table below the graph aligned with the time axis of the cervical dilation graph (CDG). As mentioned earlier, this application is used for monitoring all the 3 stages of labour. In Figure 7, we show one of the forms that needs to be filled in the 3^{rd} stage. The right side presents the data regarding the neonate(s) post delivery.

In case the data input from the 2^{nd} stage in the CDG shows some abnormality, the application notifies the user by an alarm. Similarly during a 3^{rd} stage

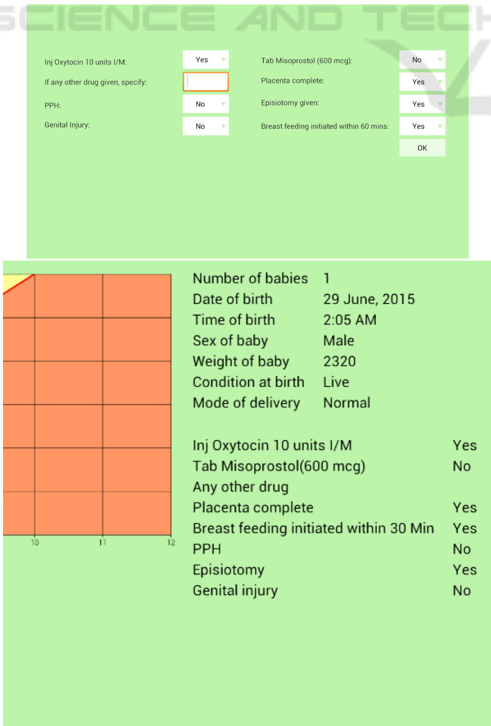

Figure 7: Third Stage.

input procedure, if any parameter is found to be abnormal, the user is immediately notified about it. The application also suggests possible precautionary measures that can be undertaken. Delivery details of the patient such as number of babies born, date and time of birth, sex etc. are fed in the third part of the partograph. The data collected are periodically synced with the mysqlite database residing on the tablet and the laptop.

To increase the reliability of the software and to avert data loss due to malfunctioning of the device, two approaches have been developed. First, the data are replicated on an external SD card on the tablet. Second, data are replicated over a network to the server after a fixed time or done manually by the user. In case of device failure, the SD Card is removed from the tablet and inserted in another tablet and all the Partograph data captured by previous device are restored. Also, data captured at the server end can be copied to an SD card and inserted in another tablet to restart operations in case of device failure. Thus, the Partograph can be seamlessly migrated from one tablet to another (Figure 8). The use of this application

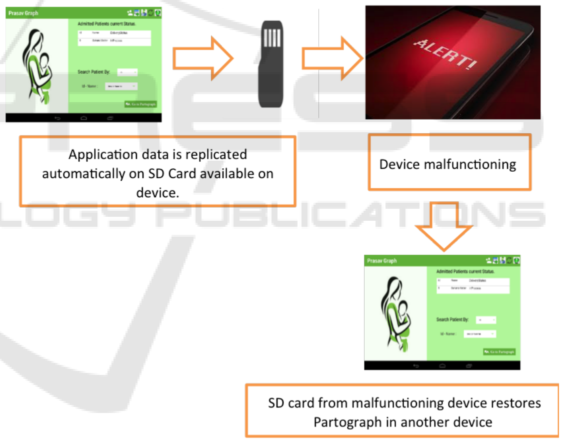

Figure 8: Restoring Partograph data from one device to another.

in a field setting required making the application robust, and the tablet safe from accidental mishandling. Accordingly, the tablet where the application runs is kept in a casing that has been made using Rapid Prototyping. As shown in Figure 9, the device can be screwed to the nurses' trolley conveniently to prevent it from being misplaced/mishandled in a field setting.

At the control station, doctors can view the partograph(s) of the currently admitted patients arranged in a grid pattern according to current cervix dilation of the patient(s). On clicking any partograph, complete details of patient are displayed. The criticality of various patients can be assessed remotely and simultaneously priorities to attend to cases can be decided

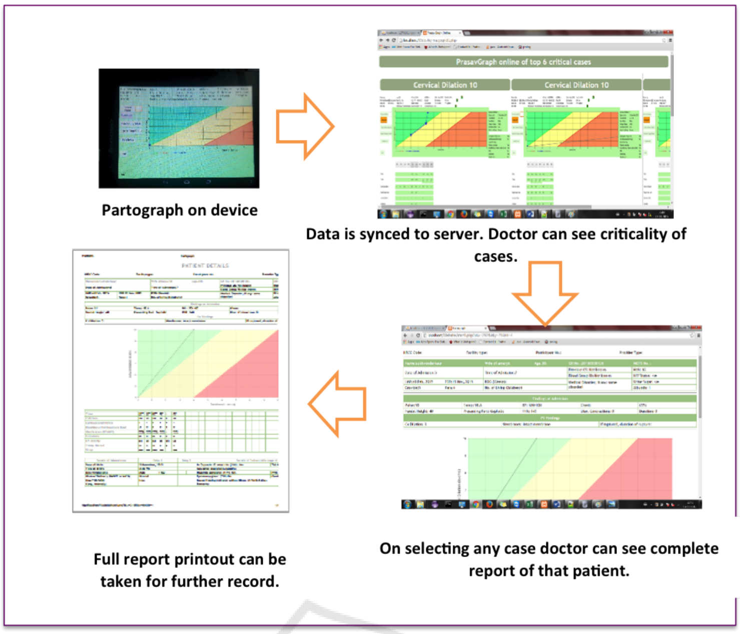

Figure 10: Information Flow from attending technician to Clinician.

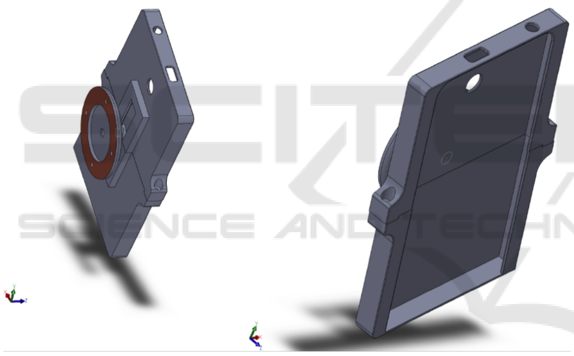

Figure 9: Rapid Prototype Model of the device holder.

as illustrated in Figure 10. This application paves the way for timely delivery of medical services in remote/rural areas. A paper record of the partograph can be obtained at any time from a browser, as a webserver running on the laptop serves the page. As shown in Figure 11, the webpage has been designed to print on an A4 size printer and shows all the data captured during labour.

The partograph has been tested initially by a resident doctor at Safdarjung Hospital, New Delhi. This phase helped us identify crucial gaps in the implementation with respect to actual field use. A version of this application underwent field testing in the District Hospital, Panchkula. Currently the application is being used by student nurses and resident doctors at two tertiary care centers in Chandigarh and New Delhi. Additional trials are planned at primary, secondary and tertiary facilities including 23 district hospitals across 13 states of India to understand scalability and other system issues. Data collected from these studies will be analyzed for reporting in a medical journal.

5 OBSERVATIONS

In this section, we report some of the findings that *prasavGraph* as a Data Collection and Reporting application can provide. We would like to inform the reader that, in this paper, we do not attempt any analysis or even comment on the data that have been collected – only the potential of such an infrastructure for officials planning healthcare activities and for people working in health care analytics is illustrated.

The preliminary data collected on *prasavGraph* from hospitals give an insight into trends in cases of pregnancy and its potential complications. The interface of *prasavGraph* is user friendly and feeding data in various columns of the app are kept simple so that medical staff attending patients can send reports without any glitches. Data obtained on *prasavGraph* from various hospitals were centrally recorded and analyzed to study patterns among patients. The medical/pathological evaluation of the patients blood sample takes some time and the medical condition of the patient may not allow the medical staff to fill all the details on the *prasavGraph*. In this situation, the staff has to rely only on the readily available reports. Recording cervical dilation is a reliable option for the

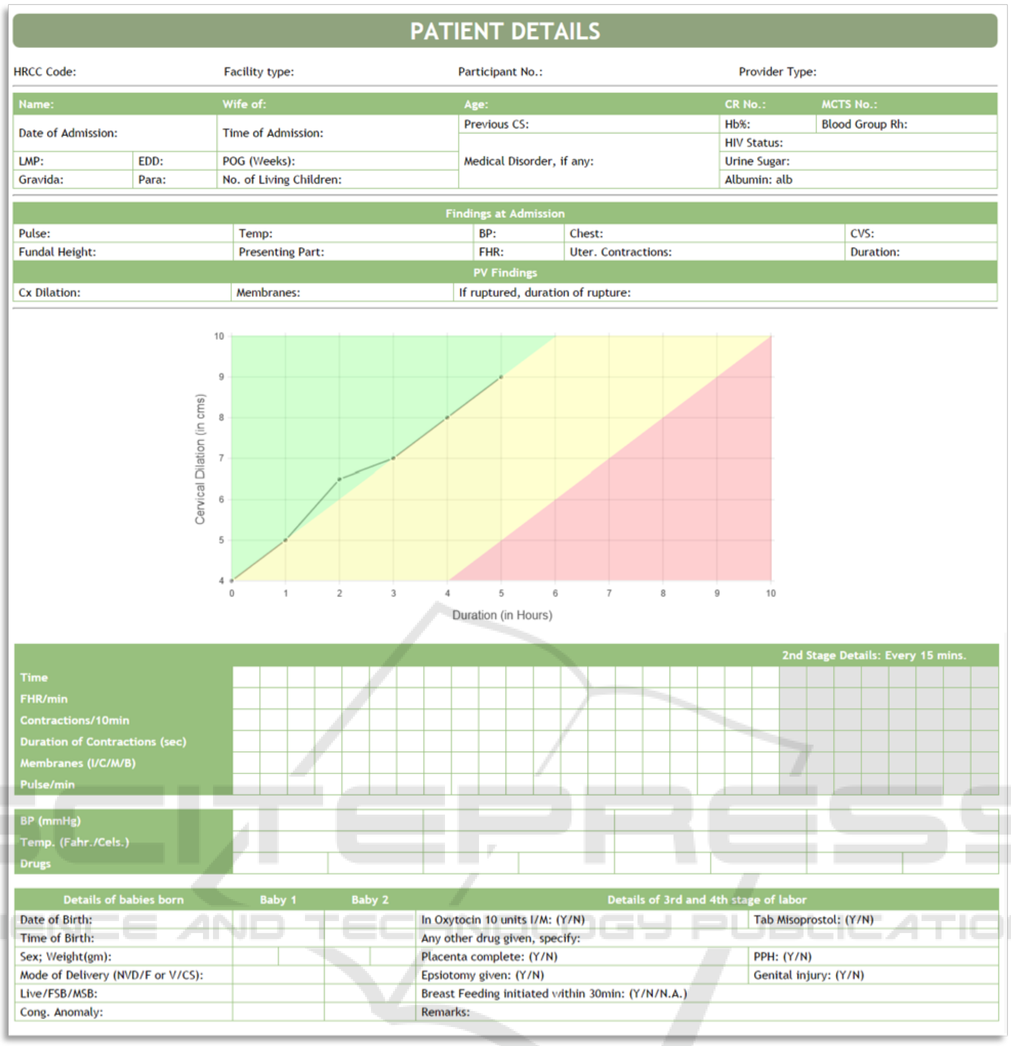

Figure 11: Partograph.

medical staff in determining the stage of labour, especially in cases with very little reaction time.

Figure 12 displays some of the admission time parameters of patients admitted in this particular hospital during the period of survey. Green and red portions of the bar represent normal and "out of normal" ranges of medical/pathological parameters respectively. The data were analyzed for about 200 entries available on *prasavGraph*. The haemoglobin bar shows that 46.55% of patients had lower than normal blood haemoglobin value. The number of patients who were detected HIV positive can also be seen. 10.61% patients had abnormal urine sugar levels and 25.95% patients had abnormal urine albumin. The patients history of pregnancies also helps the doctor to prudently scrutinize the case. In *prasavGraph* we take values of gravida (number of times a patient got pregnant), para (number of times a patient give birth to a premature baby of gestation age greater than six months) and number of live child(ren). Clearly these data can identify potential areas where intervention is required.

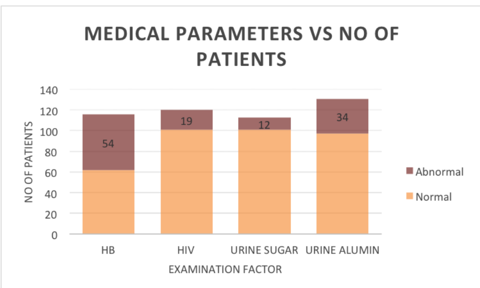

Figure 12: Data Captured at Admission time.

Figure 14 shows some of the medical parameters whose values can potentially fluctuate during active labour. The figure shows the number of patients with

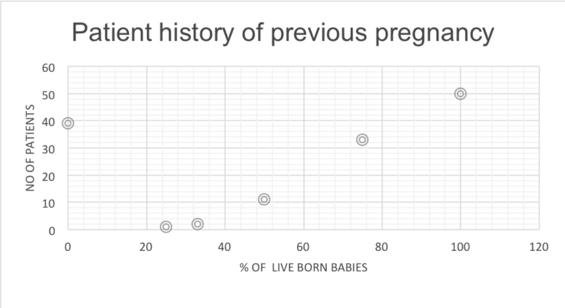

Figure 13: Previous Pregnancy Data.

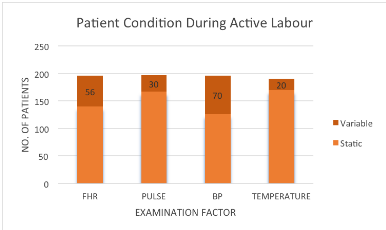

Figure 14: Parameters during Active Labor.

Table 1: Cervical Dilation at Admission Time.

Cervix Dilation (in cm)	No. Of Patients
4	86
5	32
6	19
7	15
8	22
9	3
10	23

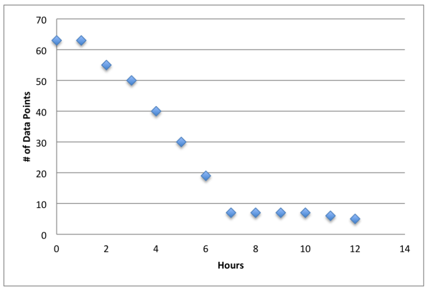

Figure 16: Measurements at Each Hour.

normal and “abnormal” values. Light and dark portions of the bar represent static and ”fluctuating” medical parameters respectively. For example, the FHR bar shows the foetal heart rate varied significantly in 56 patients out of 196. The Pulse Rate bar represents that 30 patients out of 197 had a fluctuating pulse rate. Systolic blood pressure varied in 70 patients out of 196. The body temperature was found to change in 20 patients out of 190 compared with admission time values.

The standard partograph is shown by the orange line in Figure 15 which assumes that the rate of increase in cervical dilation is 1cm/hour. The data obtained from *prasavGraph* shows deviations from this. It can be inferred that the observed rate of dilation was faster than this for dilation values upto 9 cm after which it progressed at a slower pace to reach the maximum level of 10 cm. In cases of prolonged delivery, the duration of full cervical dilation i.e. 10 cms was reached even in the 11^{th} and 12^{th} hours. Table 1 displays the number of patients with each cervical dilation value at the time of admission to the hospital. Analyzing data collected over 200 patients, it was

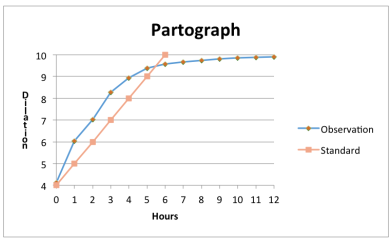

Figure 15: *prasavGraph* Summary of Patients.

found that 88.5 % patients were admitted in the first stage of labour, i.e., patients whose cervical dilation is below 10cm. 11.5 % patients were admitted in the second stage of labour i.e., cervical dilation is 10 cm. This is essentially the percentage of patients admitted to hospital at advanced stages of delivery/just after delivery. In 43.5 % cases, the data were properly filled on the device from the start of active labour i.e., cervical dilation 4 cm for the patient. Figure 16 shows the number of points of data recorded from the start of active labour, i.e., from hour 0 up to hour 12. In 11% cases, *prasavGraph* entered the red zone. A total of 1030 readings for each of the parameters (BP, Fetal Heart rate, Temperature) were recorded during patient examination. So, on an average, a patient was examined 5 times during active labour. This illustrates some of the ways that statistical properties of the data collected by the application can be analyzed for developing decision support systems.

6 CONCLUSIONS

This paper reports the first complete implementation of an Android application which enhances the traditional partograph to record the developments in the entire labour-to-childbirth process. The application has been built in a delay-tolerant framework, which enables it to be used in network deficient or poor network conditions.

Additional features like transferring the birth record to municipal authorities can also be incorporated into this application. A crucial feature that will improve the adoption of this application will be the integration of sensors to help semi automate the taking of readings. Another important feature that will be tested in the next trials will be to alert the supervising gynaecologist via sms.

With more trials being conducted successfully, the application can be adopted by the Government of India for monitoring labour especially in peripheral centres, for training providers and in promoting self learning etc. It is expected that the easy-to-use mobile/smart partograph will promote the practice of plotting partograph during labour by peripheral health workers which is currently very low. Over a period of time, plotting of partographs will encourage providers to use it as a decision-making tool and thereby reduce morbidity and mortality, both of mother and newborn arising out of complications of labour and its sequelae.

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