Wearable Sensors: A Step Towards Smart Monitoring Of High Risk Pregnancies

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Abstract: Maternal and infant health is a global healthcare problem affecting developing and developed countries alike. Pregnancy complications increase the risk of maternal and infant death, and are associated with adverse outcomes such as miscarriage, stillbirth, and preterm birth. Women going through high-risk pregnancies may require complex care involving lifestyle modifications, pharmacological and technical support and even hospitalization. Recent advances in wearable sensor technologies offer new opportunities to accurately monitor the high risk pregnancy cases as the demand for wearable and remote patient monitoring systems is increasing worldwide. In this paper, extensive literature review was carried out related to the monitoring of high risk pregnancy and use of wearable sensors related to childbirth. This enables authors to close the information gap regarding feasibility of using wearable sensors for monitoring mother and child health to ensure a safe delivery. Further based on the information collected and collated a theoretical framework is proposed for the use of wearable sensors in remote monitoring of high risk pregnancy. Thus the integrated system enables healthcare worker to do continuous monitoring of vital parameters of pregnant women through wearable sensors. This will improve timely communication between relevant stakeholders and help in reducing maternal mortality occurring due to lack of timely help.

Index Terms: maternal health care, maternal risk factors, remote monitoring, sensor integration, child birth, wearable body sensor network

1. INTRODUCTION

The fact sheets of World Health Organization (WHO)contain the real situation of the present maternal mortality status worldwide (Say et al 2014).Dr. Lale Say (2014) states that an estimated 287 000 maternal deaths occurred worldwide in 2010, most of which were in low-income and middle-income countries and were avoidable. Under the umbrella of Sustainable Development Goals and the Global strategy for Women's, Children's and Adolescent's' Health, countries have now united behind a new target to reduce maternal mortality even further. The maternal mortality ratio in developing countries in 2015 is 239 per 100 000 live births versus 12 per 100 000 live births in developed countries (Say et al 2014).According to the UN report, maternal deaths have witnessed 45 per cent drop globally since 1990 — from 5.2 lakh in 1990 to 2.89 lakh in 2013 (Tabassum 2014).Pregnancy-related and infant deaths in India have declined significantly from a few years earlier but there is not much to cheers in the numbers. Despite the Launch of Janani Shishu Suraksha Katyakram (JSSK) in 2011 aim to strengthened maternal health initiatives by entitling free deliveries and Caesarean-Sections to every pregnant woman coming for deliveries at government health facility, India is lagging behind the target of 103 deaths per live births & bringing a 75 per cent decline in the MMR to be achieved by 2015 under the United Nations- Millennium Development Goals (MDGs). (Tabassum 2014). The major challenge faced by India is lack of accurate information about births and deaths, particularly when women give birth at home (Lale Say 2014).Rural areas of poorer states of India has the highest MMR (397) compared to the lowest MMR in urban areas of richer states (115). Three-quarters of maternal deaths are clustered in rural areas of poorer states whereas most maternal deaths are attributed to direct obstetric causes (82%). There is no difference in the major causes of maternal deaths between poorer and richer states. Two-thirds of women die seeking some form of healthcare, most seeking care in a critical medical condition. Rural areas of poorer states have proportionately lower access and utilization to healthcare services than the urban areas (Montgomery et al 2014). During pregnancy, it is highly probable both the expecting mother and the developing foetus are exposed to adverse health conditions that might endanger their life (Rylander, Odland, & Sandanger, 2013). The leading causes of maternal morbidity and mortality in the developing world are preeclampsia, a condition characterized by maternal hypertension (i.e., increased BP) and proteinuria (i.e., increased protein in the urine). (Ref: Roberts & Gammill 2005). Such conditions when monitored properly (BP, fetal growth etc) and provided timely adequate care have been shown to greatly reduce maternal mortality and improve health outcomes for both the mother and baby. Adverse birth outcomes including preterm delivery, low birth weight, and perinatal mortality have been linked to lack of prenatal care (Ghanem et al 2012). Rural population are face greater health disparities than people living in urban or suburban areas due to lack of health care resources (preventive health care services, health insurance etc), difficult and inaccessible geographic access, lack of infrastructure (transport, connectivity etc) and are more difficult to reach with regards to their health (Eberhardt, Ingram, & Makuc, 2001; Sinha& Varghese, 2015; Eberhardt & Pamuk, 2004). A portion of this disparity can be attributed to demographic and socioeconomic factors (Eberhardt & Pamuk, 2004). These are further complicated due to demographic, socio economic and cultural disparities. A high risk pregnancy is one that threatens the health or life of the mother or her fetus. It often requires specialized care from specially trained providers. Some pregnancies become high risk as they progress (pre-eclampsia, gestational diabetes etc), while some women are at increased risk for complications even before they get pregnant for a variety of reasons like existing health conditions (High BP, diabetes, AIDS), age, lifestyle factors, conditions of pregnancy. Early identification of high-risk pregnancies through wearable sensors can facilitate smart monitoring and initiation of therapy. Recent advances in mobile health (also known as m-health) and wearable sensor technologies provide new possibilities for accessible forms of healthcare and health status tracking and monitoring (Majumder et al 2017; Casselman et al 2017). Recently, together with advances in sensor techniques and wireless communication, wearable sensor systems have enabled the creation of a new generation of constant health monitoring for pregnant mothers. While wearable technologies for general lifestyle monitoring are on the increase, there are very few wearable health solutions that are pregnancy specific. Wearable

sensors proposed for pregnant women capable of tracking physical activity, diet and weight management, sleep, and stress. Among pregnant women specifically, the technology needs to be comfortable and movable, as well as safe for the mother and the baby (Nitulescu et al 2015). Pregnant women tend to consider their baby first before themselves, so it is crucial to ensure that the technology be safe for the baby and that the mother should accept the technology for its effective use. This paper presents brief overview of use of wearable technologies for monitoring high risk pregnancies. Based on the literature it further attempts to put forth a simple theoretical conceptual framework for adopting the same in Indian context. For this purpose an extensive review of the academic and grey literature, as well as insights from wearable technology companies in the public and private sectors across the region have been considered.

2. Methodology

1. The primary purpose of this paper is to review the use of wearable sensor for monitoring pregnant mothers & foetal health and to provide conceptual framework for remote monitoring of high risk pregnancies using wearable sensors. A search on following publication database was conducted: PubMed Central (PMC), EBISCO, ProQuest, JGATE, and Google Scholar. Relevant articles in the past seven years (2010–2017) were collected. To seek out related articles, we target the following aspects: maternal health care, maternal risk factors, high risk pregnancy monitoring, sensor integration, wearable sensors + remote monitoring, remote monitoring + pregnant women, remote monitoring + child birth, wearable sensors + child birth. We have found 2630 articles from the search in the Google scholar and 53 in PubMed Central however, no article has been found in JGATE. Initial content analysis of abstracts of these articles, performed separately by each author and then jointly discussed, allowed us to discard articles found to be not immediately relevant, that is, not directly related to wearable sensors used for remote monitoring of high risk pregnancies. After the initial screening which consisted of removing duplicates, and non-technical articles 182 were found to be relevant related to use of wearable sensors and health. Finally excluding those that did not have any relevant information of monitoring high risk pregnancy, wearable sensors for high risk pregnancy and risk factors associated with high risk pregnant mothers that need to be monitored only 12 studies were found to be useful. Out of these, 5 articles examine the risk factors associated with high risk pregnancy, 4 analyzed wearable sensors technology solutions for monitoring pregnant mothers and 3 articles focus on the opportunities and future challenges of using wearable sensors.

2.1 Risk factors

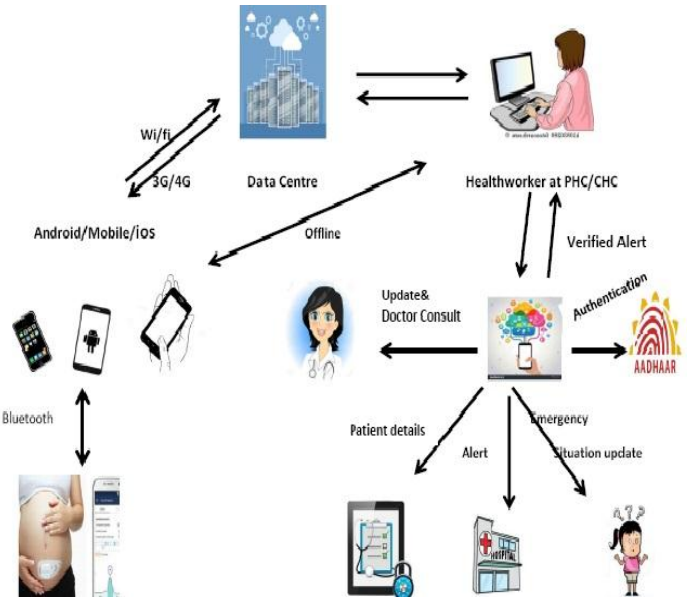
The majority of poor fetal or neonatal outcomes are associated with the following conditions: intrauterine growth retardation, prematurity, congenital anomalies, perinatal infections and meconium aspiration (Lowdermilk 2011).Other causes of neonatal death include disorders related to gestation and low birth weight, sudden infant death, respiratory distress syndrome, and the effects of maternal complications (Lyerly et al 2009). In the past, risk factors associated with neonatal death were evaluated only from a medical viewpoint but today, a more comprehensive approach to high risk pregnancy is used, and the factors associated with high risk pregnancy outcomes are divided in to broad categories based on threats to health and pregnancy outcomes. Deitra Leonard Lowdermilk (2011) categorized Pregnancy risks under the following four i.e: biophysical, psychosocial, sociodemographic and environmental. Biophysical risks include factors that originate within the mother or fetus and affect the functioning of either one or both (Lowdermilk 2011). Examples include genetic disorders which may interfere with normal fetal development, adequate nutrition, without which fetal growth and development cannot proceed normally, is one of the most important determinants of pregnancy outcomes. Some research has found that psychosocial risks consist of maternal behaviors and adverse lifestyles (Stephanie 2009). These risks may include smoking and alcohol (Miyazaki et al 2015).Other research found that the most serious complications – including stillbirth, premature delivery, and low birth weight – can be chalked up to the fact that nicotine and carbon monoxide work together to reduce fetus supply of oxygen whereas alcohol exerts adverse effects on fetus, resulting in fetal alcohol syndrome and fetal alcohol spectrum disorder (FASD) (May and Gossage2011, pp. 15-26). Pertaining to (Lowdermilk 2011, Lopez and Breart 2013) socio demographic risks arise from the mother and her family. These risks may place the mother and fetus at risk. Examples are lack of prenatal care, low income, adolescents, marital status whereas environmental factors include hazards in the workplace and women's general environment & may include environmental chemicals, radiation, and pollutants. There are many factors that can put women in the high-risk category during pregnancy including existing medical conditions, lifestyle choices and conditions that may develop with the pregnancy. Existing health conditions that affect pregnancy include: blood disorders, chronic kidney disease, depression, high blood pressure, HIV or AIDS, obesity, thyroid disease (Gardosiet al 2013). It's also possible to develop health problems for the first time during the pregnancy, even if a women usually fit and healthy. These sorts of problems include: Birth defects, gestational diabetes, growth problems, multiples, preeclampsia (Deitra Leonard Lowdermilk2011, chap.5). As the age of women falling pregnant increases, and the incidence of chronic disease escalates, so too does the risk of pregnancy and childbirth. Wearable sensor technologies become an invaluable tool to help reduce the risk of pregnancy and promote healthier lifestyle.

2.2 Wearable Sensors

Wearable devices can monitor and record real-time information about one's physiological condition and motion activities. The device allows individuals to constantly monitor their health without having to physically visit a doctor or other health care professional (Peck 2017). Wearable sensors have diagnostic, as well as monitoring applications (Majumder 2017). Their current capabilities include physiological and biochemical sensing, as well as motion sensing. It is hard to overstate the magnitude of the problems that these technologies might help solve. Physiological monitoring could help in both diagnosis and ongoing treatment of a vast number of individuals with neurological, cardiovascular and pulmonary diseases such as seizures, hypertension, dysthymias, and asthma. Home based motion sensing might assist in falls prevention and help maximize an individual's independence

and community participation. Recent advances in mobile and wearable sensor technologies enable seamless tracking of lifestyle parameters, and open new opportunities to accurately monitor the high risk pregnancy cases. Numerous wearable sensor systems and solutions have been reported for tracking health parameters. Andreoni et al. [12] designed a custom T-shirt and textile belts with embedded textile electrodes for monitoring ECG and HR. The electrodes were made from silver based conductive yarns. Instead of using any conductive gel, the electrodes relied on body sweat, an electrolyte medium, to improve the conductivity of the skin-electrode interface and signal quality and transmit the data over low power Bluetooth. Monitoring high risk pregnancy however presents additional challenges due to the specific maternal adaptations associated with pregnancy.Many wearable tech products use multiple digital health sensors that are typically integrated into sensor networks comprising other body-worn sensors and/or ambient sensors mostly in health monitoring applications of wearable systems. Peck, E (2017) [13] states that a wearable device called 'Ritmo' is designed for monitoring fetal health at home. Device has 13 sensors wrapping around the belly, including acoustic and ECG sensors to monitor the heartbeat, with motion sensors to track kicks, contractions and other movements. The information is sent to a cloud server for processing, and the results are sent back to the user's smart phone. Such monitoring systems require the gathered sensor and wearables data to be uploaded to a remote site such as a hospital server for further clinical analysis. With the advent of cloud-computing, many wearable sensor systems can now be easily upgraded without the need for user installation of software in their monitoring devices, (Jubi and Abhijeet, 2015) which makes it easier and cheaper to maintain the health monitoring system networks. Custodio et al (2012) updates on architectures and communications &technologies for wearable healthcare systems from a very practical perspective. Custodio et al (2012) proposed LOBIN system which is a healthcare IT platform to both monitor several physiological parameters (ECG, HR, angle of inclination, activity index and body temperature) and track the location of a group of patients within hospital facilities. The system shows and stores the data associated with the patients in real time. The device used to measure the physiological data is wearable, non-invasive, comfortable, and washable. The location algorithm is used in the system to accurately determine the hospital room where a given patient is located. Furthermore, the system supports the architecture of alarms by setting different triggers tailored to each patient and the transmission of certain parameters when the Management System explicitly requests them (on-demand) or after any alarm occurs. Developments in the internet of things (IoT) – the network of physical devices, vehicles, buildings and other items embedded with electronics, software, sensors and network connectivity, enabling healthcare providers to collect and exchange data – are allowing healthcare to be administered more remotely (Haghi et al 2017).These developments have changed the scenario of how diseases are diagnosed. The internet of things has numerous applications in healthcare, from remote monitoring to smart wearable sensors and medical device integration.(Metcalf et al 2016). It has the potential to not only keep patients safe and healthy, but to improve how physicians deliver care as well. Internet-connected devices have been introduced to patients in various forms (Metcalf et al 2016). Whether data comes from fetal monitors, electrocardiograms, temperature monitors or blood glucose levels, tracking health information is vital for some patients (Hamida et al 2015). Many of these measures require follow-up interaction with a healthcare professional. This creates an opening for smarter devices to deliver more valuable data, lessening the need for direct patient-physician interaction. In the future, 74 percent of the smart phone users surveyed believe they will be using wearables to exchange information with other devices and physical things around them. It's a shift that has been pointed to in Ericsson Consumer Lab's annual trend report, in which it is indicated that 85 percent of smart phone users think intelligent wearable electronic assistants will be commonplace within 5 years and see that smart phones don't have to be the only information device in the IoT era, in which devices and physical objects will be connected via the cloud. Wearable technology is transforming the entire digital health landscape and enabling patients to analyse meaningful data and make informed decisions in relation to personal healthcare. Wearables are now creating a culture of patient empowerment whereby healthcare professionals can incorporate new technologies into their diagnoses. New wearable devices can be deployed to improve the level of engagement between patients and healthcare providers. Increasingly nowadays healthcare providers are seeking to leverage the power of mobile technology and specifically wearables to find new solutions to traditional healthcare issues.

3. Proposed Conceptual Framework



This section describes the proposed architecture of the integrated system that monitors the vital parameters and emergency alerts remotely. In the first stage the expecting mothers suspected of high risk pregnancy (HRP) during antenatal checks will be fitted with a device containing sensors for monitoring vital parameters like uterus muscle contraction, Foetal heart beat, mother pulse, BP etc. These data once pre-processed for normalisation and removal of noise through signal filtering process will be transmitted to a mobile equipped with a receiver. These signals will be analysed through a decision support system running in the mobile that will raise an alert based on the anomalies detected in the signals. The alert

together with the signals will be further analysed at the server in the data centre for confirmation. If the alert required immediate attention all the stake holders, the health worker, corresponding doctor, health centre , care giver etc will be informed and all steps required for providing immediate care and or transfer to hospital (in case of emergency like ambulance) will be initiated and further follow-up of the patient's health status will be carried out. If the alert does not require immediate referral to hospital or provider, an alert message will be sent to the patient. Simultaneously the health worker linked/ providing antenatal services to the mother will be alerted and asked to check on the patient. The status will be further updated based on this. If the alert was a false alarm the patient will still be sent a health message as a preventive measure. In low setting resources the signals from the sensors can be collected in the mobile offline and transmitted to server on periodic intervals. In this case the algorithm detects a medical alert in the mobile application it will send an automatic alert message to health worker indicating an immediate action to be taken. This will help in proactively identifying problems due to HRP and reducing deaths due to HRP.

4. Discussion

The proposed framework for maternal health care above is very realistic and feasible in its setup today because most currently available noninvasive hemodynamic technologies and remote monitoring devices are cheap, and their simplicity is similar to using a mobile phone or tablet computer as the recent advancement of medical devices, intelligent sensors, Internet of Things (IoT), efficient telecommunication and information based smart decision support system (DSS) has paved a paradigm shift in maternal health care (Kashem et al 2012). The factor need to be taken in to consideration to promote the use of above integrated remote monitoring system will be if there is understanding among all stakeholders that this is not only to provide the alert in emergency situation, it can also be used simultaneously for day to day monitoring of hemodynamics parameters. This can be realized only when the data collected from integrated system through the proper use of data mining and predictive analytical tools. There is a substantial movement in this direction in the healthcare industry as these tools can enable healthcare organizations to predict trends in the patient conditions and their behaviors, which is accomplished by data analysis from different perspectives (Milovic and Boris 2012). Wearable devices & sensors such as accelerometers & gyroscopes, wireless communication networks & data capture technology are used for processing and decision support for fetal monitoring (Majumder, Mondal and Jamal Deen2017). Some of the sensors measure uterine activity & fetal heart rate. For example PURE trace- a non-invasive innovative device that uses Electrohysterography (EHG), to measure the specific electrical activity of the uterine muscle, (Sasson et al 2017) was recently introduced by Nemo Healthcare Inc. When muscle cell contract, small changes occur in the electrical potential across the cell walls. During cell walls, electrical activity of the uterine muscle can be measured on the maternal abdomen. Graphium electrode patch is applied to the abdomen & records this electrical activity non- invasively. Sensor amplifies and converts these signals to a measurement method for uterine activity. In addition, the wearable sensors for monitoring systems are usually equipped with a variety of electronic and MEMS (ciuti et al 2015) sensors, actuators, wireless communication modules and signal processing units. The measurements obtained by the sensors connected in a wireless Body Sensor Network (WBSN) (Thanh and Younghan 2016) are transmitted to a nearby processing node using a suitable communication protocol, preferably a low-power and short-range wireless medium, for example, Bluetooth Zig Bee (custodio et al 2012), Near Field Communications (NFC) (Hamida et al 2015). Offering remote monitoring of obstetric parameters to a high-risk group, associated with offering routine antenatal care by midwifes to the low-risk group, allows timely identification of most cases of abnormal pregnancies without increasing ambulatory or in-hospital interventions. The authors strongly believe that time has come now for health organizations to facilitate research on a structured and an organized medical implementation of today's simple technological innovations, which worldwide may offer accessible and individualized prenatal care to all pregnant women, without the need for increasing costs for public health care through reduction of interventions or hospitalizations for presumed or missed diagnoses.

5. Conclusion

Recent advances in wearable sensor technologies offer new opportunities to accurately monitor the high risk pregnancy cases as the demand for wearable and remote patient monitoring systems is increasing in India. Research by IDC Insights states that increase in healthcare awareness, portable and convenient usage of wearables, and entry of large smart phone manufacturers are expected to drive growth in the wearable technology in India. While innovation is rapid in this area, there is a need to develop applications very quickly. Finally, the need for continuous and longitudinal monitoring requires the development of truly wearable and nonintrusive technology solutions that will increase compliance. The framework has provided a basis for more detailed study on the benefits and disadvantages of wearable sensors in monitoring high risk pregnancies, of special relevance for pregnant mothers, clinicians, policymakers and industry practitioners with healthcare system where the Indian government envisions transforming the nation and creating opportunities for all citizens by harnessing digital technologies and to empower every citizen with access to digital services, knowledge, and information. We consider that this paper makes a clear and intertwined contribution. This kind of literature review on use of wearable sensors for remote monitoring of high risk pregnancies is innovative because it has never been done before. Today's advances in digital and remote health monitoring are becoming more sophisticated, easy to use, and turn a pregnant woman's health data into actionable and meaningful information for caregivers and researchers. All pregnancies can benefit from continuity of care, continuous monitoring, data collection, and access by physicians.

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