Self-imperative Care of Pregnancy using IoT Solutions

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Abstract

Typically, routine prenatal care includes several in-person visits with healthcare professionals by pregnant women, where fetal and maternal assessments are performed. This paper proposes an architectural framework for prenatal care using non-invasive, simple, and low-cost internet of things (IoT) monitoring system. The aim is to design an IoT-based architecture that serves as a fundamental system for self-imperative care in regular pregnancy check-ups in the comfort of the home that offers routine prenatal screening tests. The system provides easy access to care regardless of the location and internet availability. We implemented preliminary architecture with simulated sensor data for blood pressure monitoring.

Keywords

care; consultation; internet of things; monitoring; prenatal; pregnant; virtual

1 INTRODUCTION

Maternal health is women's health condition during pregnancy, childbirth, and the postpartum period. Nearly 295,000 women died of pregnancy-related causes in 2017; 84% occurred in developing countries due to the lack of care and awareness [1]. The major causes of maternal mortality and morbidity are infection, hemorrhage, high blood pressure, and obstructed labor [2]. Moreover, hypertension is common in women during pregnancy, leading to multiple deaths worldwide. Chronic hypertension is another disorder, known as preeclampsia (that in severe cases may cause eclampsia), that occurs in approximately 3% to 5% of pregnant women in the developed world, causing severe injury or death [3]. Preeclampsia, in particular, has been found to lead to maternal and fetal mortality, intrauterine growth restriction, and preterm birth [4]. Prenatal care provided to pregnant women has reduced the rate of stillbirth, maternal mortality, and neonatal death [5-10]. Moreover, prenatal care includes several visits to HCPs by pregnant women for fetal and maternal assessment. A minimum of eight prenatal visits to HCPs is recommended by the World Health Organization (WHO) [11] for a healthy pregnant woman, and more visits for those having risks and complications [11]. Typically, physical examinations such as fetal heart rate monitoring, blood pressure monitoring, weight checks, fundal height measurements, and urine tests are performed during each routine prenatal visit, including nutrition and exercise planning [12]. Further, based on the stage of the pregnancy, some visits include additional physical examinations such as blood tests and ultrasound imaging to diagnose the risks that may affect the mother and the fetus (such as gestational diabetes and hypertensive disorders) [12]. As the increase in gestational age increases the risk of obstetric complications, the visits to HCPs are more frequent in higher gestational age [13].

Since early detection of pregnancy complications with regular checkups and monitoring can lead to a healthier birth, the development of information technology that is readily accessible and is able to provide up-to-date health status during the pregnancy is vital. Moreover, the advancements in technology have transformed healthcare delivery. Notably, the IoT exploited various sensing and communication infrastructures that offer data collection, transmission to the remote servers, and analysis and providing feedback, which is well-accepted in the healthcare sector [14]. Increased digitalization in the health care sector and the COVID-19 pandemic have underlined the need to implement accessible care for pregnant women, regarded as a sensible population [15].

Meanwhile, several techniques based on IoT have been developed to remotely monitor pregnant women's medical conditions to address these concerns. A secure IoT-based pregnancy monitoring system is proposed in [16], where three sensors - temperature sensor, memes sensor, and heartbeat sensor - were used to monitor pregnant women's health status. The system operates with a Wi-Fi module interface. The method in [17] remotely monitors the health of pregnant women and provides data visualization for their health care provider. The use of the internet allowed the visualization of sensor data by the healthcare professionals and permitted remote consultation with the pregnant women. A smartphone application is used in [18] that monitors and transmits heart rate sensor data, eating habits, and activity levels of pregnant women. In addition, it provides a medium to communicate remotely with healthcare professionals regarding pregnancy and health status. The approach in [19] presents a mobile monitoring system to identify hypertension using wearable sensors on a pregnant woman's body. It monitors changes in blood pressure and classifies the severity of hypertension using Naïve Bayes, which helps in the decision-making of health care providers. Wireless Body Area Networks (WBANs) for pregnant women, based on the 802.15.4e TSCH standard, are presented in [20], which provides real-time remote monitoring of pregnant women centered on the biosensors' values. The monitoring of pregnant women’s stress level, sleep, and physical activities during pregnancy based on IoT is shown in [21]. IoT-based system in [22] consists of different sensors such as sensors for non-invasive anemia and glucose rate detection, sudden fall detection, heart rate, and body temperature. The system is focused on the extensive health monitoring of pregnant women using Wi-Fi and GSM viable for telemonitoring. The system used in [23], monitors the uterine contraction to determine the possible risk of preterm delivery. The uterine contraction is detected using a wireless body sensor network, which triggers an alert message via a smartphone for values outside normal thresholds. A novel wearable system for fetal movement monitoring is presented in [24], aiming to save hospital resources by implementing monitoring at home. The movement data acquired using four accelerometers are processed and classified with a fuzzy classifier that is categorized into six different movement by which the fetal movement is inspected. However, the classifier was trained with data collected and labeled by pregnant women themselves, which was considered imprecise and highly subjective, degrading its performance.

Moreover, remote maternal monitoring has shown a comprehensive outcome and reflected numerous aspects of pregnancy care. However, conventional maternal monitoring systems are either too specific [19, 23, 24] or too general [16, 22]. They are especially focused on particular risk groups such as hypertension, preterm etc [19, 23, 24]. In addition, some are focused only on monitoring physical activities, behaviors, and habits [18, 21]. Typically, the internet is exploited for data transmission and communication, which may not be relevant for the pregnant population without internet access [16-24]. Thus, to address the health system and the limitations highlighted above, and considering the need underlined by the COVID-19 pandemic, we propose an architectural framework for home-based self-imperative care of pregnant women that facilitates IoT solutions regardless of location and internet access. The proposed system consists of two robust IoT solutions: internet-based and non-internet based. Either solution uses the IoT-based smart sensor network to monitor several physiological signals of pregnant women commonly done in routine prenatal visits and screening tests. The primary focus is to perform a general physical assessment (such as fetal heart rate monitoring, blood pressure monitoring, urine tests, and weight check), thereby reducing the frequency of in-person visits and providing easy access to care in the comfort of the home.

2 PROPOSED METHOD

The schematic diagram of the proposed framework is shown in Figure.1. The proposed system has two major adaptive aspects regardless of the location or internet access: internet based IoT solution and non-internet IoT solution. Internet-based IoT is operated by employing an IoT gateway, while a long-range wide area networks (LoRaWAN) gateway is used for the non-internet IoT solution. These two approaches complement each other. To reduce the connectivity downtime, an IoT gateway could be used when there is internet connectivity while if there is no internet connectivity LoRaWAN could be utilized. Moreover, the overall architecture consists of four layers: sensor data acquisition, middleware gateway, data storage, and application layer. The sensor data acquisition layer consists of the sensor devices that acquire fetal heart tone, blood pressure, and weight values. Similarly, a middleware gateway is chosen based on internet availability; the LoRaWAN gateway is employed where there is no internet access at the endpoint; however, the IoT gateway is utilized in internet-accessible areas. The layer allows the transmission of data acquired from the sensor devices to a central database where the data are stored. The software solution to retrieve data from sensor devices and transmit it to the central database is included in this layer. The acquired sensor data are packaged and sent to the central database using the message queuing telemetry transport (MQTT) protocol. The transmitted data are then stored in the central database, which is later analyzed and displayed on both pregnant woman and healthcare professionals’ end. Finally, the application layer consists of the end-user application for pregnant women and healthcare professionals that allows visualization of the sensor data acquired from the first layer.

2.1 Sensor Data Acquisition

The proposed architecture focuses on the self-imperative care of pregnant women for routine prenatal monitoring in the comfort of the home. Typically, the regular prenatal visits include blood pressure measurements, fetal heart tone assessments, weight checks, fundal height measurements, and urine tests; thus, their corresponding sensor devices are utilized for routine checkups to determine the potential risks and complications. The non-invasive blood pressure sensor device is used to measure pregnant women's blood pressure that detects the risk associated with hypertension and preeclampsia. The systolic and diastolic values of the blood pressure are measured by utilizing the oscillometric method, which can also measure pulse rate. Similarly, the most used Doppler device for fetal heart rate monitoring is used to assess the heart rate, rhythm, and regularity of the fetal heart tones. The pregnant woman's weight and fundal height are then self-measured, noted, and updated in the application where the healthcare professional is able to review the data. Along with blood pressure measurement, urinalysis for protein, which is specially done to diagnose preeclampsia, is performed, an examination commonly part of each prenatal screening test [25]. For this, commercially available urinalysis reagent strips that gives a rapid result are used in the proposed architecture [25]. Such results are examined with visual inspection or automated readers, and further testing is undertaken physically during in-person visits if it gives a positive outcome.

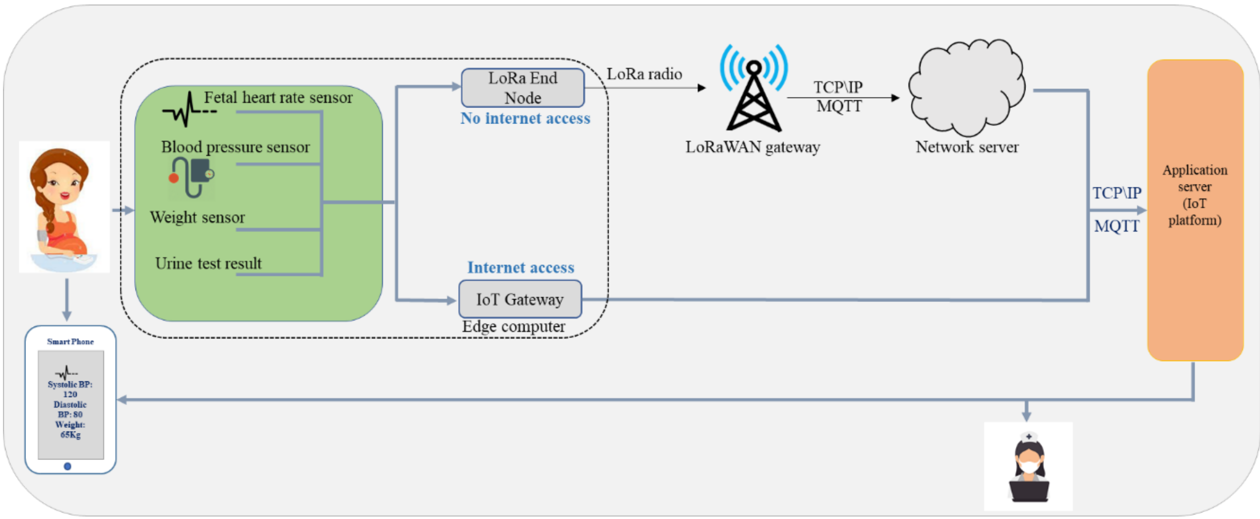

Figure 1. Schematic diagram of the proposed architecture.

2.2 Middleware Gateway

Middleware gateway layer comprises IoT gateways. The gateway on the internet-based approach consists of an edge computer wherein an IoT gateway software is installed. The IoT gateway software is responsible for converting the sensor data into a MQTT format and forwarding it to the remote server. In contrast, in non-internet-based approach, the LoRaWAN gateway receives sensor data employing LoRa radio and forwards it to the network server [26]. The gateway on the internet-based solution is limited to connecting a single pregnant woman to the application server. In contrast, star topology is followed in LoRaWAN (multiple pregnant women can be connected to a single gateway). In addition, the long-range property of LoRa radio helps connect the end nodes (pregnant women) that are deployed in remote areas (inaccessible areas that do not have internet service and are several kilometers from the gateway).

2.3 Data Storage

This layer is a remote database server that stores sensor data. The database server is accessible from the application server for further data analysis.

2.4 Application Layer

This layer is an IoT platform that provides feedback on potential risk factors or notification of risks to health care professionals and pregnant women based on the analysis of the monitored data. For example, an email or SMS can be sent to a concerned party as an alarm or alert using the IoT platform (e.g., Thingsboard [27]). Thingsboard is an open-source IoT platform. In addition, the end-user application that shows the result on the user's end (pregnant women and healthcare professonals) is also included in this layer. The end-user application provides a summary of their health status to the pregnant women and assistance to healthcare professionals to examine this status remotely.

3 RESULTS

To illustrate preliminary results, we realized the internet-based approach using simulated sensor data, as shown in the Figure 2.

A program was written to simulate Photoplethysmography (PPG) signals using different heart rates. PPG is a simple optical technique used to detect volumetric blood changes in peripheral circulation. As the latest research suggests that the PPG signal can be utilized to estimate blood pressure [28], we simulated PPG signals to realize blood pressure. The simulation software was installed on an edge computer (Raspberry Pi 3) that published MQTT packets (simulated PPG signals) every 10 seconds. Moreover, an IoT gateway software from the Thingsboard was installed on the same device, which subscribed to the simulated PPG signal and forwarded them to the Thingsboard cloud. A dashboard was created in the Thingsboard cloud to illustrate the simulated PPG signals as time series telemetry.

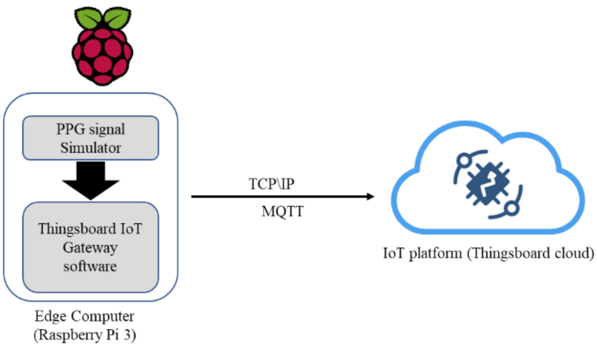

Figure 2. Architecture for the internet-based approach using simulated sensor data.

The result of the simulated PPG signal is shown in Figure 3. As shown in Figure 3., orange and green color lines depict the PPG signals using heart rates of 100 and 70, respectively. Based on the signal value, an alert message (email or SMS) can be sent from the Thingsboard cloud to the pregnant woman and healthcare professionals when the PPG signal is outside the threshold range.

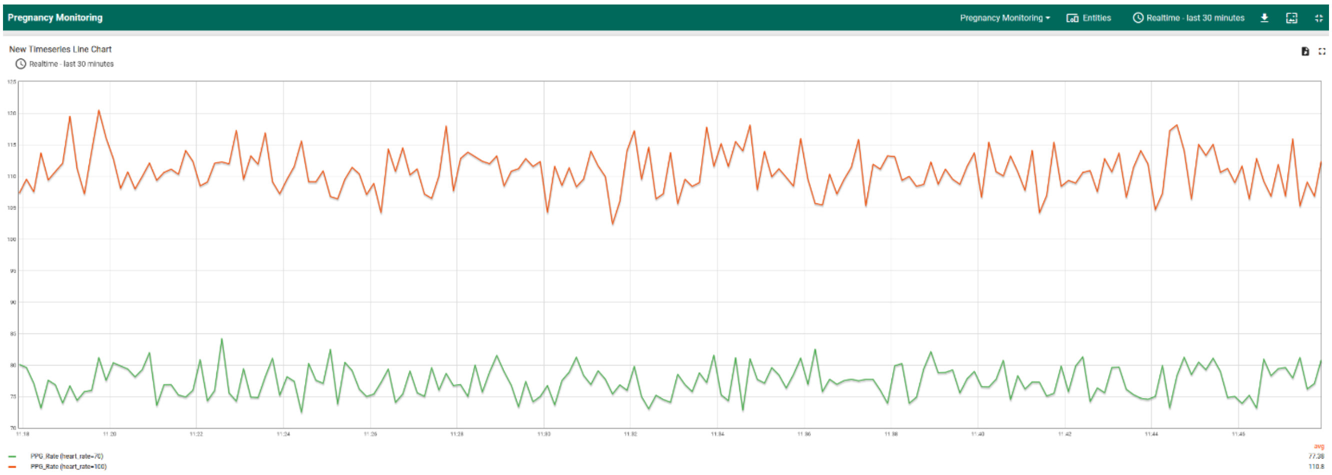

Figure 3. Simulation result of internet-based architecture for PPG signal.

4 CONCLUSION

We propose an IOT-based architectural framework for self-imperative care and monitoring of pregnant women in the comfort of the home. The proposed system provides easy access to care regardless of the location and the internet availability based on two different IoT solutions: internet-based and non-internet based. The IoT solution is based on a smart sensor network that performs physical assessments of pregnant women that are commonly carried out during routine prenatal visits and screening tests. In-home monitoring, analogous to the regular checkup in the proposed system, reduces the frequency of in-person visits to the hospital, requiring in-person visits only for further diagnosis and physical examination that require the HCP's supervision. Moreover, the system helps in the early detection of risks, which enables adequate care and on time treatment for pregnant women. Besides, the proposed architecture prototype could reduce the gap between expectant mothers and medical specialists/resources and has a potential use in various e-Health home care applications. Also, the implementation of the proposed research work would help society move towards healthier lives and well-being among pregnant women and reduce their mortality rate. In future work, we will consider the real-time implementation of the complete architecture of the proposed framework using a real sensor, including evaluation and analysis of its performance and results. In addition, performance-wise comparison between two approaches will be performed.

REFERENCES

[1] "Maternal mortality." https://www.who.int/news-room/fact-sheets/detail/maternal-mortality (accessed April 8, 2022, 2022).

[2] "WHO | Maternal and reproductive health." [Online]. Available: https://www.who.int/data/gho/data/themes/maternal-and-reproductive-health.

[3] L. Benschop, J. J. Duvekot, J. Versmissen, V. van Broekhoven, E. A. Steegers, and J. E. Roeters van Lennep, "Blood pressure profile 1 year after severe preeclampsia," *Hypertension*, vol. 71, no. 3, pp. 491-498, 2018.

[4] F. M. Musyoka, M. M. Thiga, and G. M. Muketha, "A 24-hour ambulatory blood pressure monitoring system for preeclampsia management in antenatal care," *Informatics in Medicine Unlocked*, vol. 16, p. 100199, 2019.

[5] N. Regassa, "Antenatal and postnatal care service utilization in southern Ethiopia: a population-based study," (in English), *Afr Health Sci*, vol. 11, no. 3, pp. 390-397, 2011. [Online]. Available: <Go to ISI>://WOS:000306171400015.

[6] X. J, K. KD, M. SL, and T.-V. B, "Deaths: final data for 2007," 2010.

[7] S. Partridge, J. Balayla, C. A. Holcroft, and H. A. Abenhaim, "Inadequate Prenatal Care Utilization and Risks of Infant Mortality and Poor Birth Outcome: A Retrospective Analysis of 28,729,765 U.S. Deliveries over 8 Years," (in English), *American Journal of Perinatology*, vol. 29, no. 10, pp. 787-793, Nov 2012, doi: 10.1055/s-0032-1316439.

[8] J. A. Ozimek and S. J. Kilpatrick, "Maternal Mortality in the Twenty-First Century," (in English), *Obstetrics and Gynecology Clinics of North America*, vol. 45, no. 2, pp. 175-+, Jun 2018, doi: 10.1016/j.ogc.2018.01.004.

[9] C. J. Berg, W. M. Callaghan, C. Syverson, and Z. Henderson, "Pregnancy-Related Mortality in the United States, 1998 to 2005," (in English), *Obstetrics and Gynecology*, vol. 116, no. 6, pp. 1302-1309, Dec 2010, doi: 10.1097/AOG.0b013e3181fdfb11.

[10] M. Mrisho *et al.*, "The use of antenatal and postnatal care: perspectives and experiences of women and health care providers in rural southern Tanzania," (in English), *Bmc Pregnancy and Childbirth*, vol. 9, 2009, doi: Artn 1010.1186/1471-2393-9-10.

[11] WHO. "ANC Guideline " https://www.who.int/reproductivehealth/news/ANC_guideline-presentation.pptx (accessed.

[12] N. I. o. C. H. a. H. Development. "What is prenatal care and why is it important? ."

https://www.nichd.nih.gov/health/topics/pregnancy/conditioninfo/prenatal-care (accessed September 15, 2020.

[13] B. M. M. Pflugeisen, MEd, C. M. McCarren, RN, S. M. Poore, M. A. Carlile, and R. M. Schroeder, "Virtual Visits: Managing prenatal care with modern technology," *MCN: The American Journal of Maternal/Child Nursing*, pp. 24-30, 2016.

[14] L. Ungurean and A. Brezulianu, "An internet of things framework for remote monitoring of the healthcare parameters," *Advances in Electrical and Computer Engineering*, vol. 17, no. 2, pp. 11-16, 2017.

[15] G. Weigel, "Novel coronavirus “COVID-19”: Special considerations for pregnant women," *Retrieved May*, vol. 10, p. 2020, 2020.

[16] S. Gayathri, T. Bharathi, A. DevleenaJerusha, and A. A. Kumar, "Pregnant Women Health Care Monitoring System Based on IoT," *International Journal of Engineering Technology and Management Science, ijetms. in Issue: 1*, no. 2, 2018.

[17] S. Veena and D. J. Aravindhar, "Remote Monitoring System for the Detection of Prenatal Risk in a Pregnant Woman," *Wireless Personal Communications*, vol. 119, no. 2, pp. 1051-1064, 2021.

[18] G. K. Endo, I. Oluwayomi, V. Alexandra, Y. Athavale, and S. Krishnan, "Technology for continuous long-term monitoring of pregnant women for safe childbirth," in *2017 IEEE Canada International Humanitarian Technology Conference (IHTC)*, 2017: IEEE, pp. 6-10.

[19] M. W. Moreira, J. J. Rodrigues, A. M. Oliveira, and K. Saleem, "Smart mobile system for pregnancy care using body sensors," in *2016 International Conference on Selected Topics in Mobile & Wireless Networking (MoWNeT)*, 2016: IEEE, pp. 1-4.

[20] A. Sene, I. Niang, A. Diop, and A. Gueye, "T4PW: TSCH in WBAN for Real-Time Monitoring of Pregnant Women," in *International Conference on Industrial Networks and Intelligent Systems*, 2021: Springer, pp. 3-15.

[21] F. Sarhaddi *et al.*, "Long-Term IoT-Based Maternal Monitoring: System Design and Evaluation," *Sensors*, vol. 21, no. 7, p. 2281, 2021.

[22] T. G. Troyee, M. K. Raihan, and M. S. Arefin, "Health Monitoring of Expecting Mothers using Multiple Sensor Approach:“Preg Care”," in *2020 2nd International Conference on Advanced Information and Communication Technology (ICAICT)*, 2020: IEEE, pp. 77-82.

[23] H. Allahem and S. Sampalli, "Framework to monitor pregnant women with a high risk of premature labour using sensor networks," in *2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM)*, 2017: IEEE, pp. 1178-1181.

[24] X. Zhao, X. Zeng, L. Koehl, G. Tartare, and J. De Jonckheere, "A wearable system for in-home and long-term assessment of fetal movement," *IRBM*, vol. 41, no. 4, pp. 205-211, 2020.

[25] K. L. Tucker *et al.*, "The feasibility and acceptability of self-testing for proteinuria during pregnancy: a mixed methods approach," *Pregnancy Hypertension*, vol. 12, pp. 161-168, 2018.

[26] A. Farhad, D.-H. Kim, S. Subedi, and J.-Y. Pyun, "Enhanced lorawan adaptive data rate for mobile internet of things devices," *Sensors*, vol. 20, no. 22, p. 6466, 2020.

[27] "Thingsboard IoT platform." https://thingsboard.io/ (accessed 05-04-2022, 2022).

[28] G. Slapničar, M. Luštrek, and M. Marinko, "Continuous blood pressure estimation from PPG signal," *Informatica*, vol. 42, no. 1, 2018.