Framework to Monitor Pregnant Women with a High Risk of Premature Labour Using Sensor Networks

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***Abstract*— Premature birth is the leading cause of death in children under 5 years. Furthermore, surviving children can have a lifetime of disability such as hearing and vision loss or learning difficulties. Research suggests that monitoring uterine contractions can help in evaluating the health and progress of pregnancy, and also determine if the pregnant woman is in labour, and consequently mitigate the effects of premature labour. In this paper, we propose a safe, simple and low-cost system to monitor pregnant women who are at high risk of premature labour. Our system consists of a wireless body sensor network to non-invasively monitor the uterine contractions and trigger a warning via a smartphone if the readings are outside the normal thresholds. We have designed a proof-of-concept prototype and tested it for reliability, performance and power consumption.**

Keywords*— *Wireless body sensor networks, WBSN, pregnant women, premature labour, electrohysterography, EHG.

I. Introduction

Each year, nearly 15 million babies worldwide are born prematurely [1][2]. According to [1][3][4], prematurity is when a baby is born before completing 37 weeks in pregnancy. Premature birth is a serious health issue for new-born babies [5][6]. It is the top cause of death for children under five years [4] with an estimate of 1 million deaths each year worldwide [7], and children who survive a premature birth usually suffer from lifelong disabilities such as hearing and vision loss or learning difficulties [1][5].

Worldwide, 50% of babies born prematurely under 32 weeks in low-income countries die because of the lack of proper healthcare; in high-income countries almost all of them survive. Furthermore, the number of premature births is not decreasing. For example, in the United States and Europe, the number of premature births have increased since 1981 from 9% to 12.7% [9]. Even though premature birth is a worldwide issue, 60% of these premature births happens in developing countries [1].

A. Causes of Premature Births

Premature birth happens for many reasons; however, the cause is often unidentified [1][2]. One of the common reasons is a previous medical history of the woman or her family having premature labour [4]. Moreover, premature birth is a serious issue in healthcare systems [3]. The cost of premature labour affects both healthcare providers and families with an estimate of 26 to 50 billion dollars per year in the United States [5][6][9].

B. Solutions of Premature Births

Based on the issue of premature birth we mentioned before, the researchers suggest that with a practical and cost-effective care, over three-quarters of the babies born prematurely can be saved. According to [10], uterine contractions are an important measurement in monitoring pregnant woman. It can help in evaluating the health and progress of pregnancy [10][11] and determining if the pregnant woman is in labour, and thus evaluate if there is a risk of premature labour [3][10][12]. Researchers also suggest that premature birth rates can be lowered by improving the care of pregnant women before, during, and after pregnancy [1][13]. Because of that, there is a crucial need for an automated approach to continuously monitoring pregnant woman with a high risk of premature labour [8][10]. Such an approach can help in reducing the consequences of premature labour [14]. Moreover, pregnant women with a high risk of premature labour visit the hospital more often to monitor their uterine contractions [13]. These visits may take days or even weeks, which takes the pregnant woman out of the comfort of her home [8]. For these reasons, any proposed approach to monitoring uterine contractions should be continuous, home-comfortable [8], cost-effective [5], and reliable.

C. Wireless Body Sensor Networks

Wireless body sensor networks (WBSNS) are an emerging wireless technology. WBSNS have many applications in healthcare, sport, entertainment, and industry [15] [16]. WBSNS can continuously monitor patients which will help in detecting and lowering patient's health risks [15][17] and improving patient's life [18].

The architecture of a WBSN (shown in Fig. 1) consists of body sensors that collect and send vital signs from the patient's

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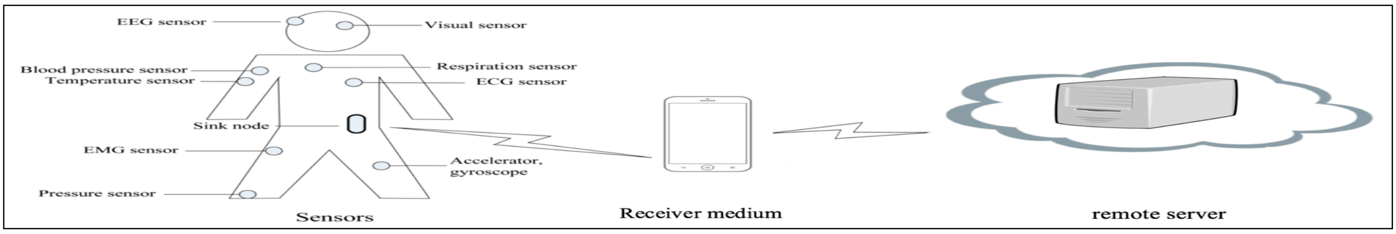

Fig. 1 WBSN architecture

body, a receiver medium to collect and analyze patient's vital signs, and a remote server for data analysis and storage.

Finally, a WBSN has many advantages such as safety, low cost, mobility, wireless communication [15][17], and the ability to communicate with smartphones [19].

D. *Uterine electrohysterography*

Using the WBSN sensor, we can record the electrohysterography (EHG) of the uterus to monitor uterine contractions. The measurement unit of EHG is millivolt (mV). EHG is one of several techniques, such as tocodynamometer and intrauterine pressure (IUP), that can monitor uterine contractions [10]. Other than EHG, these techniques have their limitations [10]. One of the significant advantages of EHG is the non-invasive measurement, i.e., the sensor can be easily attached to the pregnant abdomen [11][12], that measures electrophysiological signals of uterine muscles [10]. EHG is also more accurate than the other techniques in measuring uterine contraction signals [10][12][13]. Besides, studies have shown that EHG can detect the occurrence of normal and premature labour up to 27 weeks of pregnancy [13]. By using WBSNs to collect EHG signals and analyzing them with a smartphone, we can detect if the pregnant woman is in labour and then alert her if so.

In this paper, we propose a safe, simple and low-cost system to monitor pregnant women who are at high risk of premature labour. Our system consists of a wireless body sensor network to non-invasively monitor the uterine contractions and trigger a warning via a smartphone if the readings are outside the normal thresholds. We have designed a proof-of-concept prototype and tested it for reliability, performance and power consumption.

The rest of the paper is organized as follows. Section II presents the literature review of some of the previously proposed approaches. Section III describes the design and implementation of the proposed system. Section IV presents the results of experiments performed on a proof-of-concept prototype to determine the efficacy of the proposed system. Section V discusses the results. Section VI concludes the paper and outlines future work.

II. LITERATURE REVIEW

Several studies have been proposed for monitoring pregnant women. In one of the first studies [20], the authors focused on sensors' signal processing and filtering techniques. In the second proposal [21], the authors proposed a fetal heart monitor using a portable stethoscope. Their system was an extension of the system proposed in [20]. The authors of the third study [22] proposed a healthcare system using a Bayesian model to support decision making for their system. In the three proposals, the authors have focused on the technical side of the system such as filtering and classifying signals from sensors to improve the quality of the data received from these sensors.

The fourth study proposed by [8] focus on designing a telemonitoring system called Nemo Healthcare. The authors designed a system that monitors the signals of fetal heart rate, maternal heart rate, uterine contraction and fetal electrocardiogram. The system sends the signals wirelessly to a server. The doctor then can monitor and diagnose the pregnant woman's health status. We can notice that their system requires a server and a physician to monitor the results. Although it is a well-designed system, it can be expensive and requires the physician to contribute his/her time to monitor the results.

The fifth study by [23] proposed a system to monitor the cardiotocograph signals of the pregnant woman. The system collects data from the sensor they designed and sends an alarm to a smartphone. The smartphone then sends the alarm to the server system called ObGyn, where the physician can monitor the results at any time. Similar to the previous system designed by [8], this design can be expensive to implement, and the physician must contribute his/her time to monitor the results.

III. PROPOSED SYSTEM

Based on the advantages of WBSNS and EHG, we propose a system to monitor pregnant women with a high risk of premature labour. The system consists of a sensor and a smartphone. The sensor will be implemented on the pregnant woman abdomen as a non-invasive method to continuously measure EHG signals of the uterus and send them to the smartphone. The smartphone will then analyze the received data, and if the readings are out of the normal threshold, the smartphone will trigger a warning. The system will be fully portable and hence will not restrict the pregnant woman from moving around freely. That means the pregnant woman can be monitored while she is in the comfort of her home and does not have to visit the hospital unless it is necessary. Moreover, the system will not be expensive to deploy, which means it is an affordable system for developing countries as well as developed countries. Finally, there is no need for the physician to contribute his/her valuable time to analyze the results.

A. *System implementation*

We designed and implemented a proof-of-concept application using Android operating system. The application was deployed on Asus Nexus 7 tablet. To test the application, we used a uterine contraction signals dataset of pregnant women in labour from the PhysioNet databases [24]. The database we used was the Icelandic 16-electrode Electrohysterogram (EHG) Database [25]. The dataset we used from this database was the ice001_l_1of1 dataset. The dataset has a list of 99467 uterine contraction readings in mV of a pregnant woman in labour. Because each patient has a different threshold for contractions detection [10], we can modify the application based on the patient's preferences. These preferences will be determined by the obstetricians. Based on [10] research outcome, the threshold is selected based on the false positive rate. Therefore, we chose a threshold of 5.7 mV to detect if there is a contraction or not in the dataset. The chosen threshold's false positive rate is 3.79%. The application will be continuously analyzing the dataset input for any uterine contraction equal or above the threshold. Each monitoring session will last for 30 minutes [26]. In each session, the application will count uterine contractions for a period of 10 minutes. At the end of the 30-minutes session, the application will calculate the average of the contractions count of the three 10-minutes periods. If the average is above 5, a warning will be triggered to notify the pregnant woman. Fig. 2 shows the software flowchart, where Contr is contractions count, CC used to determine if the session reached the 30-minutes mark, R is the retrieved reading, and Ts and Te are the start and end time used to determine each 10-minute period.

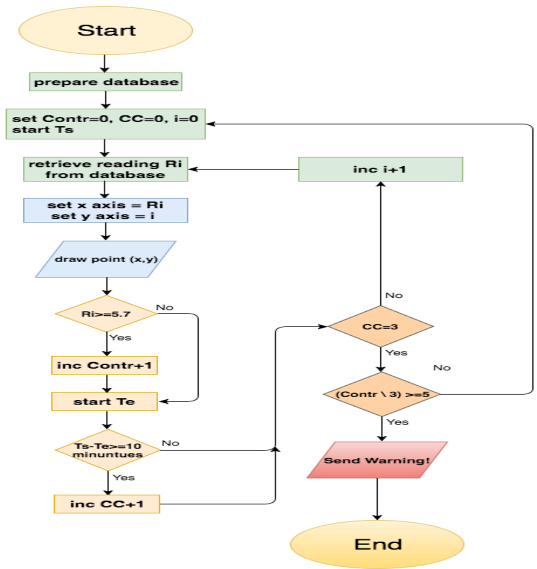

Fig. 2 Software flowchart

IV. Performance Evaluation results

We evaluated the application in terms of threshold false positive rate, CPU and Memory performance, and power consumption. The application was running for 30 minutes during testing and triggered a warning at the end of the 30 minutes.

A. Threshold and false positive rate

We chose the threshold of 5.7 mV based on its false positive rate of 3.79%. As we can notice from Table I, values lower than 5.7 mV will result in high contraction counts, which will always trigger the warning whether there is a labour or not. With 5.8 mV, contractions count is low, which will result in no warning. That contradicts the dataset properties which indicates that the pregnant woman was in labour at the time of recording. Finally, any result above 5.8 mV will result in no contraction counts.

TABLE I. THRESHOLDS' CONTRACTIONS COUNT

Threshold (mV)	Count of Contractions from the Application
6.0	0
5.9	0
5.8	16
5.7	82
5.6	901

B. CPU and Memory performance

The application uses an average of 40% of the CPU power. In terms of memory usage, the application allocates 26.64 MB of memory out of 1.80 GB of the device's memory.

C. Power consumption

The device has a battery capacity of 3448mAh. The application consumes between 103.44mAh (3%) and 137.92mAh (4%) of the battery charge.

Fig. 3 shows the full analysis of the application battery consumption. The screen red bar shows that the screen was on. The Audio bar shows the warning was not triggered until the end of the 30-minutes period. The temperature was 24.4 °C (75.9°F). Finally, the "charging on" green bar shows that the device was not charging during the application's running time.

V. Discussion

As we mentioned before, each pregnant woman can have her own threshold. Our analysis results indicate that 5.7 mV has the optimum false positive rate of 3.79% and that why we chose this value from the dataset to be our threshold.

The application runs smoothly with the 40% average of CPU power consumption. Moreover, the application allocates 26.64 MB out of 1.80 GB of the device's memory. This is about 1.44% of memory usage which is considered low.

Finally, power consumption results show that the application took only 3% to 4% of battery's charge. Considering that the screen was always on and the device temperature was normal, we can conclude that the application consumes battery charge efficiently.

VI. Conclusion

Premature birth is a worldwide issue that often leads to the baby's death or life-long health problems. We aim to reduce the issues of premature births complications by using WBSNS in our system design to monitor the uterine contraction EHG. We designed a proof-of-concept application to test our proposal. We evaluated our proposed system in terms of thresholds false positive rate, CPU and Memory performance, and power consumption.

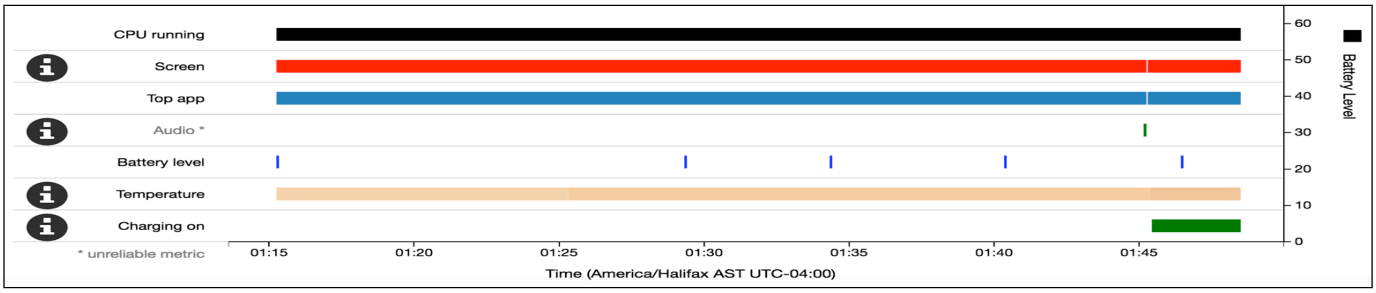

Fig. 3 The full analysis of the application battery consumption

In future work, we will implement the system with a sensor to obtain real-time data from the pregnant women, improve the application performance and resources consumption, and improve its design by getting feedback from obstetricians.

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