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**DEVELOPMENT OF AN INTEGARTED WEARABLE DEVICE FOR REMOTE MONITORING OF PREGNANT WOMEN IN GHANA**

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DEVELOPMENT OF INTEGRATED WEARABLE DEVICE FOR REMOTE MONITORING OF PREGNANT WOMEN IN GHANA

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# DECLARATION OF ORIGINALITY

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# ABSTRACT

Pregnancy-related complications pose a huge threat to the lives of mothers and infants, particularly in developing nations. While many of these tragic outcomes could be prevented through timely identification of potential health issues, several barriers persist. In most developing countries, expectant mothers often face multiple challenges that discourage them from seeking proper medical care during pregnancy. These obstacles include the considerable distance they must travel to reach healthcare facilities, insufficient understanding of pregnancy-related health risks, long hours to journey to an antennal clinic and financial constraints. As a result, many pregnant women remain reluctant to make their health a priority during this crucial period of their lives.

Pregnancy-related complications are a significant public health concern, especially in developing countries, where over 40% of pregnancies face serious health risks, according to the World Health Organization (WHO) [2]  .In Ghana, 12% of female deaths (ages 15-49) over the past five years have been attributed to pregnancy complications, with 62% of these deaths resulting from delayed or inadequate medical intervention.[2] Medical experts indicate that more than half of these fatalities could have been avoided through early detection. Timely monitoring of vital parameters during pregnancy can enable the early identification and diagnosis of such complications.

Despite the widespread adoption of smart wearable devices in healthcare over recent times, these alarming statistics highlight the need for further advancements in monitoring and intervention.

To address this, our proposed system uses a wearable device to collect physiological data, which is then processed using fog computing. Fog computing is employed to overcome the computational and energy limitations of wearable devices, as well as the latency issues typically associated with cloud computing in real-time data processing. The proposed IoT-based health monitoring system integrates fog-assisted computing to monitor key physiological parameters such as body temperature, blood pressure, blood glucose levels, oxygen saturation, and heart rate of pregnant women. At the fog node, the system predicts potential pregnancy complications like preeclampsia, anemia, and gestational diabetes. The biomarker values and predictions are then sent to the cloud for further analysis, with access granted based on user authentication roles via a mobile application.

This system aims to reduce the time required to diagnose medical conditions in pregnant women, enabling quicker intervention. Additionally, the patient only needs to visit a healthcare provider in case of an emergency, ensuring a more efficient and timely healthcare process.

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"Coming together is a beginning, staying together is progress, and working together is success."

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# CHAPTER 1 - INTRODUCTION

## Introduction

This chapter begins by providing an overview of the remote monitoring of pregnant women, highlighting its significance and the critical role it plays in ensuring maternal health. It discusses the potential consequences of inadequate monitoring during pregnancy and underscores the benefits of leveraging technology for remote monitoring. The chapter clearly defines the problem, establishing the need for a comprehensive solution. Additionally, it outlines the objectives of the project, detailing its scope and emphasizing its relevance and potential impact on society.

## 1.1 Background

Pregnancy is the most crucial period for a woman, where she needs extra care and has to take precautions for her health as well as the infant’s health. Moreover, the careless attitude of the woman towards her health leads to the occurrence of issues like preeclampsia, eclampsia, which may become the reason for miscarriage or even leads to maternal death. Remote Monitoring of Pregnant Women refers to the use of technology to continuously track and assess the health status and well-being of expectant mothers regardless distance. Remote Patient Monitoring can facilitate effective intervention and early treatment paradigms to prevent the occurrence of pregnancy complications. Potential dangers of not monitoring can lead to critical challenges such as preeclampsia, anemia, low birth weight and developmental delays and ultimately lead to death.

Using technology in maternal care enables medical professionals to make informed decisions rather than solely depending on values captured during antenatal visits.

## 1.2 Problem statement

Pregnancy complications represent a significant public health concern, particularly in developing countries, where the World Health Organization (WHO) reports that over 40% of pregnancies face substantial health risks. In Ghana, this issue is starkly highlighted by data indicating that 12% of female deaths among women aged 15-49 in the past five years are attributable to pregnancy-related complications. Alarmingly, 62% of these deaths are linked to delayed or inadequate medical intervention. [2]

Several barriers, including distance, high transportation costs, and time constraints, hinder many pregnant women from accessing regular antenatal care. These obstacles exacerbate maternal risks by delaying the detection and management of pregnancy complications such as preeclampsia and anemia. The infrequent visits to healthcare facilities result in late diagnoses, which significantly lower the chances of survival for both the mother and the baby.

Addressing these challenges requires a focused approach to improve access to timely and regular antenatal care, ultimately reducing the risks associated with pregnancy complications. This thesis aims to explore and develop solutions to bridge the gap in healthcare accessibility and improve maternal health outcomes.

## 1.3 Project objectives

The objectives of this project revolve around the creation of a wearable device bolstered by the integration of machine learning techniques to address the critical issues associated with monitoring pregnant women. The objectives of this work are in three folds:

* To develop an integrated system consisting of a wearable device and a mobile application to continuously monitor, detect and trigger alerts in event of abnormality.
* To train a machine learning model for risk prediction of pregnancy complications like preeclampsia and anemia long before standard detection window.
* To develop a user-friendly interface system to acquire and visualize information for processing by the system.

## 1.4 Significance of project to society

The significance of this project extends beyond the technical innovation it brings; it addresses a critical public health issue by improving maternal health care. The outcome of this project has the potential to significantly reduce maternal health risks, improve healthcare accessibility, and contribute to the overall well-being of mothers and their babies. Below is an exploration of how this project can positively impact society.

* Early detection of pregnancy complications, hence reducing maternal mortality: Early detection of pregnancy complications is a critical factor in reducing maternal mortality, especially in resource-constrained settings. Complications such as preeclampsia, gestational diabetes, anemia, and infections can develop rapidly during pregnancy, posing severe risks to both the mother and the fetus. Timely identification and management of these conditions are essential to prevent progression to life-threatening stages. Early detection allows healthcare providers to intervene promptly, offering appropriate treatments or referrals to higher-level care facilities. Moreover, early detection contributes to better birth outcomes by facilitating proper planning and preparedness for potential complications. This includes scheduling timely cesarean sections for high-risk pregnancies, monitoring fetal growth and well-being, and implementing necessary lifestyle adjustments.
* Equip pregnant women with tools to monitor and manage their health: Empowering pregnant women with self-monitoring tools and educational resources is crucial in improving maternal health outcomes and reducing pregnancy-related complications. By providing access to biomarker values such as blood pressure, blood glucose level and oxygen saturation, women can actively track vital health on a regular basis. This proactive approach allows pregnant women adjust their lifestyles as often as possible hence reducing the risk of severe outcomes such as preeclampsia, gestational diabetes, and fetal distress. Knowing that potential issues are being monitored and managed can alleviate anxiety for pregnant women and their families, promoting a more positive pregnancy experience.
* Continuous data collection and visualization empower doctors to make informed, data-driven decisions rather than relying solely on periodic observations: Continuous data collection and visualization empower doctors to make informed, data-driven decisions by providing real-time insights into a patient’s health, rather than relying solely on periodic clinical observations. This approach allows for the continuous monitoring of vital health metrics, such as blood pressure, heart rate, and fetal movements, enabling the early detection of potential complications. Data visualization tools present this information in easily interpretable formats, such as graphs and trend lines, allowing doctors to identify patterns and anomalies quickly. By integrating this continuous data into the healthcare system, doctors can make proactive, personalized care decisions, improving maternal and neonatal health outcomes and reducing the risk of severe complications.
* Ease of pressure on antenatal clinics due to reduced visitations: The ease of pressure on antenatal clinics due to reduced visitations is a crucial benefit of implementing remote health monitoring solutions for pregnant women. By enabling women to track key health indicators like blood pressure, glucose levels, and fetal movements from home, the frequency of in-person visits can be reduced, alleviating the strain on clinics. This helps decrease crowding in healthcare facilities, allowing healthcare professionals to focus more on high-risk pregnancies that require immediate attention. With fewer routine check-ups to perform, healthcare workers can better allocate their time and resources, which also reduces clinician burnout. Additionally, remote monitoring increases accessibility for pregnant women in rural or underserved areas, where traveling to clinics can be difficult. This not only eases the pressure on urban healthcare facilities but also ensures more women receive continuous care. Overall, reducing in-person visits improves the efficiency of healthcare systems, enabling them to prioritize urgent cases while providing better care for all patients. Reduced visitations also imply lower transportation costs to antenatal clinics.

## 1.5 Organization of Thesis

## This thesis is structured into five chapters, which are outlined as follows:

Chapter 1 provides an overview of the project and its objectives. It includes context, problem statement, Project objectives, and significance of the Project.

Chapter 2 provides literature and relevant existing approach to the project.

# CHAPTER 2 – LITERATURE REVIEW

## 2.1 Introduction

This chapter provides an overview of existing solutions and technologies related to the remote monitoring of pregnant women. It explores the current methodologies and innovations aimed at improving maternal health outcomes through the use of wearable devices, machine learning, fog and cloud computing. By reviewing existing systems and research, this chapter identifies the strengths, challenges, and gaps in current approaches to remote monitoring and early detection of pregnancy complications. The goal is to highlight how these solutions align with or differ from our approach proposed in this thesis, setting the stage for a deeper understanding of the advancements in maternal health care and the potential impact of this project.

**2.2 Survey of existing solutions**

**2.2.1 A Comprehensive Framework for Wearable Module for Prenatal Health Monitoring and Risk Detection [1]**

The project aims to address the high maternal mo0rtality rate in Bangladesh due to the lack of prenatal health monitoring systems. It proposes a cost-effective, non-invasive wearable device connected to smartphones for continuous health monitoring. The device, worn around the waist, includes sensors placed on the fingers or underarms, monitoring vital signs such as body temperature, oxygen saturation, heart rate, blood pressure, and blood glucose. It also tracks fetal movement and detects falls. Data is stored in a database, and doctors can access it via a portal for historical analysis. An SMS (Short Message Service) alert feature notifies the user and doctor of any anomalies.

The system uses an ESP-32 microcontroller for data collection and transmission to a cloud server over Wi-Fi. Threshold values are set in the microcontroller hence if values are over and above the set values, an alert via SMS is sent to the pregnant woman and the medical officer. Blood glucose levels are measured using an NIR 940nm LED and photodetector, where light absorption varies with glucose levels. A black box is used to minimize interference from external light. Blood pressure is monitored using a device with an EEPROM that communicates via the I2C protocol. For temperature readings, the DS18b20 sensor is used, while the MAX30100 sensor measures oxygen saturation and heart rate. Fetal movement is detected with an ADXL335 acceleration sensor, and fall detection uses the MPU6050 sensor. The system flags fetal movement based on changes in acceleration data from both sensors.

# 2.2.2 Explainable Early Prediction of Gestational Diabetes Biomarkers by Combining Medical Background and Wearable Devices: A Pilot Study With a Cohort Group in South Africa [5]

In this article, continuous glucose readings were collected using the Freestyle Libre sensor. This is placed on the upper arm and uses subcutaneous, wired enzyme glucose sensing technology to detect glucose levels in interstitial fluid. The Photoplethysmography (PPG) sensor measures Blood Volume Pulse (BVP), from which heart rate variability can be derived. The Electrodermal activity (EDA) sensor measures the constantly fluctuating changes in certain electrical properties of the skin. The Infrared Thermopile collects peripheral skin temperature, and a 3-axis Accelerometer captures motion-based activity. Empatica E4 wearable sensors were used to record physical activities such as sleeping, sitting, eating, walking, climbing stairs, and talking on the mobile phone. Health background data were collected using a survey. Hence the dataset for prediction of gestational diabetes includes information from three sources: background health information, CGM (Glucose Continuous Monitoring) and Empatica E4 data.

Feature extraction, Feature aggregation and feature selection processes were utilized to summarize the extracted data and choose the most effective features for the regression models. Decision Tree and Random Forest Regressors models were used to estimate biomarker values. The regression models are for the early prediction of biomarker values associated with the presence of GDM (Gestational Diabetes Mellitus). This prediction is done 13 to 16 weeks prior to the standard GDM screening test which is the Oral Glucose Tolerance Test (OGTT).

**2.2.3 Monitoring of Expecting Mothers Using Multiple Sensor Approach: "Preg Care" [6]**

This paper introduces an innovative solution aimed at reducing the maternal mortality rate in Bangladesh through advanced health monitoring technology. The system employs a Near-Infrared (NIR) LED-Photodetector system (940nm) to continuously monitor blood glucose levels non-invasively. For detecting sudden falls, the ADXL-345 accelerometer is utilized. The Max30100 sensor simultaneously measures the oxygen saturation (percentage of hemoglobin) and pulse rate, providing critical insights into cardiovascular health.

The MLX90614 sensor is used for accurate body temperature measurements. Blood pressure readings are manually entered into a mobile app, which then sends this data to the cloud for secure storage and further analysis. An Arduino microcontroller processes all collected data before transmitting it to the cloud.

The system incorporates a Python-based image processing algorithm to analyze images of the pregnant woman's eye pallor. This analysis, conducted in the cloud, predicts the presence or absence of anemia, an important health indicator during pregnancy. The mobile app serves as the user interface, allowing both the pregnant woman and healthcare providers to access processed physiological data and predictions from the cloud.

In emergencies, the system automatically sends SMS alerts to the pregnant woman's relatives, prompting immediate action to prevent further health complications. This comprehensive approach ensures continuous monitoring, timely detection of potential health issues, and quick intervention to improve maternal health outcomes.

**2.2.4** **Wearable Technology Model to Control and Monitor Hypertension during Pregnancy [3]**

In this paper, a wearable technology model designed to monitor and manage hypertension during pregnancy is proposed. The wearable device continuously tracks the pregnant woman's blood pressure, heart rate, and step count, with data collection occurring every 30 minutes. This device connects to a mobile application via Bluetooth, allowing for immediate data transfer to the user's smartphone. Upon successful transfer, the wearable's memory is cleared, ready to collect new data.

Users manually input additional variables such as weight, age, and gestational age into the mobile application. In cases where the smartphone is not connected to the wearable device, the data is temporarily stored on the wearable and later transferred to the phone when a connection is re-established. All data collected is then uploaded to the cloud for secure storage.

The mobile application uses specific parameters to identify potential hypertension risks: blood pressure readings exceeding 140/90 mmHg, a Body Mass Index (BMI) of 30 or more, and weight relative to the patient's height. These parameters help in early detection and management of hypertension in pregnant women.

The application provides the user with real-time health monitoring through statistical displays. Additionally, it offers features for tracking prescribed medications, scheduled appointments, and ongoing treatments. In the event of a high blood pressure incident, the system promptly alerts both the patient and healthcare providers. This alert includes the patient’s current location, displayed via Google Maps, ensuring timely medical intervention.

# 2.2.5 Remote Monitoring System for the Detection of Prenatal Risk in a Pregnant Woman [7]

The article presents a system designed for continuous monitoring of vital parameters, including maternal body temperature, blood glucose levels, maternal heart rate, and the frequency of uterine contractions per minute, using a smartwatch worn on the wrist. Additionally, the system allows for manual input of key data such as maternal age, gestational age, weight, height, and blood pressure by the pregnant woman.

The collected data is securely stored on a cloud-based database and analyzed using a Support Vector Machine (SVM) machine learning algorithm. This algorithm compares the data with historical records to predict potential risks, such as preterm labor or stillbirth.

The system also features a mobile application that enables doctors, hospitals, patients, and a designated family member to register and access its functionalities. In the event of a pregnancy-related complication, the system sends both an SMS (Short Message Service) and an email alert to the registered doctor and the emergency contact of the family member.

The mobile app provides a visual representation of the pregnant woman's health status, accessible to both the patient and the family member. Doctors can also monitor the health status of all their patients through a consolidated chart within the app.

This system is highly effective in enabling doctors to make quicker, informed decisions during emergencies, thereby saving valuable time. It also significantly reduces pregnancy risks such as preterm labor, stillbirth, or miscarriage by facilitating timely interventions.

# 2.2.6A System for Remote Monitoring of Pregnant Women's Health State and Pregnancy Complications Prediction [8]

The article describes a system comprising portable medical devices, including a biochemical analyzer, blood clotting analyzer, heart monitor with an automatic tonometer, spirometer, pulse oximeter, and blood glucose meter, are used to monitor the biomedical parameters of pregnant women. Additionally, a questionnaire is employed to gather supplementary information, such as bad habits, allergic reactions, family medical history, and obstetric and gynecological details. This comprehensive data supports the accurate diagnosis of pregnancy complications, such as preeclampsia, anemia, thrombosis, and gestational diabetes mellitus.

The captured data from these devices is transmitted to the pregnant woman’s smartphone via Bluetooth and subsequently sent to the medical institution’s server. From there, the results are forwarded to the medical officer responsible for managing the patient’s care. Decision Tree machine learning model is employed, with threshold values defined for each parameter. If any device readings exceed these thresholds, an alert is automatically sent to the medical officer for prompt intervention.

# 2.2.7 A Remote Blood Pressure Data Collection and Monitoring System for Expectant Mothers [16]

This article presents a smartwatch model, GE-W74, was utilized to measure blood pressure and transmit the data to a mobile application via Bluetooth connectivity. Additionally, a Photoplethysmography (PPG) heart rate sensor and an Electrocardiogram (ECG) sensor were employed. The recordings from these sensors were analyzed by medical officers to manually predict the onset of pre-eclampsia, rather than solely relying on blood pressure values recorded during antenatal visits.

The mobile application displayed the collected readings to the pregnant woman and her caregivers. It offered customization options, allowing the expectant mother to set her preferred data collection intervals, determining when data should be sent from the smartwatch to the app. Furthermore, the app included a feature to adjust skin color settings, ensuring the PPG sensors functioned effectively across different skin tones.

A separate mobile application was developed for use by Community Health Volunteers (CHVs), Community Health Extension Workers (CHEWs), and the next of kin. This app was designed to enable these external stakeholders to monitor and intervene when persistent high or low blood pressure readings were detected, providing timely support to the expectant mother.

# 2.2.8 A Remote Healthcare Monitoring Framework for Diabetes Prediction Using Machine Learning[15]

This work outlines an automated smart health monitoring system for diabetes prediction using supervised machine learning algorithms, including K-Nearest Neighbor, Logistic Regression, Gaussian Naïve Bayes, and Support Vector Machines. Data is collected from various healthcare and consumer devices. Among these algorithms, the Support Vector Machine demonstrated the highest accuracy. The PIMA Indian Diabetes Dataset is used for model training and evaluation.

The system incorporates threshold values in the models to detect abnormalities in blood glucose and blood pressure levels, notifying medical professionals via a web application and mobile app in such events. The healthcare devices employed include a Samsung Note 8 smartphone, a Huawei GT 2 smartwatch, an iHealth blood pressure monitor, an iHealth glucometer, and an iHealth pulse oximeter.

The web application provides optional user inputs for parameters such as skinfold thickness, the number of pregnancies, and pre-existing medical conditions. While the primary objective is to predict the likelihood of diabetes, additional risk factors like low activity levels, weight gain, heart rate, sleep patterns, activity types, and durations are also monitored. This holistic approach enables doctors to make informed decisions based on the user’s overall health status.

Captured data from the devices is transmitted to a mobile app via Google Fit APIs. The mobile app forwards this data to a cloud database, where it is stored and analyzed for diabetes prediction. The results are subsequently sent to a dashboard accessible exclusively by medical professionals.

# 2.2.9 Virtual Midwife for Pregnant Women and Alert System [9]

This paper proposes a system consisting of a compact device designed to monitor vital health parameters and send alerts to medical officers and pregnant women when predefined thresholds are exceeded. The system records body temperature, heart rate, and oxygen levels using a temperature sensor, a heart rate sensor, and a pulse oximeter, respectively. The data captured by these sensors is transmitted to a Node Microcontroller Unit (MCU) for processing. Once processed, the data is sent to the cloud for storage and access. If any vital parameters surpass the threshold values programmed into the microcontroller, an alert is sent to the corresponding medical officer, prompting them to contact the pregnant woman.

The data is accessible through two separate mobile applications; one for medical officers and the other for pregnant women. The app for pregnant women allows them to choose their preferred midwife, nurse, or doctor to provide care throughout their pregnancy. Besides notifying them of captured values from the sensors, the app also sends regular reminders to stay hydrated and offers dietary suggestions for a healthier lifestyle. The app for medical professionals is primarily used to view the recorded values from the IoT, alerts if anomaly in event of anomaly in vitals and communicate directly with the pregnant woman.

# 2.2.10 Maternal HealthCare Using IoT-Based Integrated Medical Device: Bangladesh Perspective [10]

This article introduces a remote monitoring system comprising a wearable device equipped with various sensors, an ESP32 module, a cloud platform, and a mobile application. The wearable device collects data from pregnant women, including blood pressure, body temperature, oxygen saturation levels, and heart rate. This data is initially stored in the ESP32 module until a connection with the cloud platform is established.

Once a communication link is active, the data is transmitted to the cloud, where it is analyzed by a machine learning algorithm. The algorithm identifies critical risk conditions and promptly sends notifications to healthcare professionals, enabling them to take necessary preventive measures to mitigate potential pregnancy complications. The processed data is then visualized in the mobile application as graphs, allowing healthcare providers to identify risk levels effectively.

# 2.2.11 IOT Based Wearable Health Monitoring System for Pregnant Ladies Using CC3200 [11]

This paper presents a healthcare solution that combines a compact wearable device with a web application. The wearable device measures critical parameters such as body temperature, pulse rate, and blood pressure of pregnant women. These analog signals are transmitted to a CC3200 microcontroller, which features an in-built ADC (Analog-to-Digital Converter) and Wi-Fi module. The microcontroller converts the analog signals into digital data and uploads them to the cloud.

From the cloud, the processed data is forwarded to the doctor's computer via an assigned IP address. If the captured values deviate slightly from the preset normal range, an alert, accompanied by an alarm sound, is sent to the doctor. The doctor can then review the data and send a prescription back to the patient's IP address.

In cases where the values exceed the critical threshold, the doctor will arrange for an ambulance and notify the patient's relatives with an alarm message. This ensures timely intervention in emergency situations.

# 2.2.12 Fuzzy Intelligent System for Patients with Preeclampsia in Wearable Devices [12]

This article discusses a wearable device designed as a watch that measures blood pressure and transmits the data to a mobile application via Bluetooth. The mobile app integrates an AI model trained to predict the likelihood of preeclampsia. The model uses a dataset collected from a hospital in Colombia, comprising information about patients with potential preeclampsia diagnoses.

The dataset includes attributes such as age, body mass index (BMI), pregnancy trimester, blood pressure readings, family medical history, and other relevant factors. Once the watch records a blood pressure reading, this value is combined with other attributes on a row from the dataset. A Decision Tree machine learning model then processes this data to predict whether a pregnant woman is at risk of developing preeclampsia.

# 2.2.13 A novel fog‑computing‑assisted architecture of E‑healthcare system for pregnant women [13]

The proposed framework introduces a smart health monitoring system utilizing IoT and fog-assisted technologies to track the health of pregnant women over a nine-month period. The system integrates various sensors to capture critical health data, including temperature, blood pressure, ECG(Electrocardiogram), and pulse oximeter readings, as well as environmental factors like temperature, humidity, and air quality. These sensors are connected to a customized wrist node, which uses an ATmega 2560 microcontroller to process data from the wrist sensors, while an ATmega 328P microcontroller manages and processes data from the sensors embedded in the foot node. The foot node includes an accelerometer, pedometer, and gyroscope to monitor physical activity and stability, with data transmitted wirelessly using an nRF(Nordic Radio Frequency) module.

Captured data is timestamped and encrypted using quantum hash functions to ensure secure transmission to the fog node. At the fog node, the data undergoes initial processing, and user authentication is performed using iris and face recognition systems. The fog node analyzes the data using a Bayesian Belief Network (BBN) model. Once processed, the data is sent to the cloud for storage. Health recommendations, such as reminders to drink water or take medication, are delivered from the cloud server to the pregnant woman's mobile app dashboard. In cases where critical health conditions are detected, immediate alerts are sent to medical professionals and the patient's app via GSM (Global System for Mobile Communications), ensuring timely medical intervention. The cloud layer manages data storage and provides remote access for doctors and attendants, delivering a comprehensive health monitoring solution that combines real-time data collection with secure and efficient processing, enhancing health management for pregnant women.

# 2.2.14 SAARTHI: Real-Time Monitoring of Patients by Wearable Device [14]

This paper proposes a system that integrates an IoT-based wristband device to monitor and capture real-time data, including acceleration, atmospheric temperature, humidity, heartbeat, and the individual’s location. Clinical data such as blood sugar levels, cholesterol levels, and chest pain type are provided by healthcare facilities. Both the real-time data from the wristband and the clinical data from the hospital are transmitted to the cloud.

A machine learning model analyzes this data to predict the potential presence or absence of heart disease. The predictions are reviewed and verified by a medical expert before being made accessible through a web and mobile application, where patients and their family members can view the results.

Additionally, the system includes an alert manager that continuously compares incoming data with pre-configured critical thresholds stored in the wristband device. If any critical condition is detected, the system sends an alert via SMS to a healthcare provider or a family member, ensuring timely intervention.

# 2.2.15 Design of an IoT Based Monitoring System for Expectant Rural Women in Developing Countries[17]

This article proposes a system consisting of a pulse sensor, temperature sensor, and GPS (Global Positioning System) to collect data, with an Arduino microcontroller processing the captured information. The processed data is then sent by the microcontroller to a GSM (Global System for Mobile Communications) module, which transmits the data to the cloud for storage. From the cloud, the data is emailed to healthcare providers if predefined conditions are met. Moreover, if the expectant mother’s body temperature exceeds the threshold of 39 degrees Celsius, an automatic email alert is sent to notify the healthcare provider of the condition. The system uses the MAX30205 sensor for body temperature measurement, the MAX30100 sensor for pulse detection, and the BN-220 GPS sensor for real-time location tracking. The selected microcontroller is the ATmega328, and the SIM900A GSM module is used for data transmission. Additionally, an LCD is incorporated for display purposes.

# 2.2.16 Smart Pregnancy Health Monitoring System Using IOT [18]

This paper proposes a healthcare system that monitors three vital signs of a pregnant woman and a fetal vital sign, transmitting the collected data to the cloud via an Arduino Uno. The system allows access to all recorded data through a smart device. The SEN-11574 heart rate sensor measures the mother’s heart rate, the LM35 sensor captures body temperature, the ADXL335 sensor tracks fetal movements, and a blood pressure sensor monitors the mother’s blood pressure. All data is first sent to the Arduino Uno, then uploaded to the cloud, and finally made accessible on a smart device.

# 2.2.17 Low Cost, Non-Invasive, and Continuous Vital Signs Monitoring Device For Pregnant Women In Low Resource Settings (Lvital Device) [19]

This article presents a system designed for monitoring the vital signs of pregnant women. The system includes a blood pressure sensor attached to the wrist, a heart rate sensor placed on the finger, and a temperature sensor positioned under the armpit. A DS18B20 digital temperature sensor is used to measure body temperature, while a SEN 11574 pulse sensor continuously monitors the pulse rate. The blood pressure is measured using a Sunrom sensor.

The system is powered by a solar cell, which provides energy to the Arduino microcontroller. The microcontroller device is preprogrammed with normal ranges for these vital signs. An LCD screen, GSM module, buzzer, and three LEDs (green, red, and blue) are connected to the microcontroller to facilitate user interaction.

The LCD displays messages to inform the user about system activities, such as notifying them when an SMS has been sent.The GSM module sends SMS alerts when the measured values fall outside the preset normal ranges. If a vital sign deviates from its normal range, the buzzer automatically triggers an alarm. After a minute, the GSM module sends a text message to a pre-set caregiver’s phone number and displays a message on the LCD indicating a message was successfully sent.

For accuracy, the system’s measurements were compared with those from standard medical devices: a sphygmomanometer for blood pressure, a pulse oximeter for pulse rate, and a thermometer for temperature.

# 2.2.18 IOT-Based Monitoring System for Expectant Women [20]

This work aims to remotely monitor vital signs: body temperature, pulse, sweat, and heartbeat as biomarkers to assess the health status of pregnant women. The system uses a DHT11 sensor for temperature, a MAX30100 sensor for pulse and heart rate, and a sweat sensor, all of which are placed on a wearable belt. The sweat sensor monitors hydration levels, crucial for preventing dehydration in expectant mothers.

A boost converter is employed to increase the operating voltage of the sensors. The boost converter is powered by a battery. The collected data is processed by a NodeMCU microcontroller, with threshold values set for each sensor. When these values exceed or drop below the thresholds, an alert is sent to the pregnant woman.

The processed data is then sent to the cloud for storage. In cases of health complications or missed appointments, health officials receive real-time alerts, ensuring timely responses. The system features two websites: one for doctors or healthcare centers and another for the pregnant woman’s relatives or caregivers, providing accessible monitoring and communication.

# 2.2.19 Smart Wearable Obstetric Assistant and Reminder [21]

This paper proposes a device designed to monitor the pulse rate and body temperature of pregnant women, as well as detect falls using an accelerometer. The device also includes a GPS antenna to track the location of the user. In case of an incident, such as a slip or fall, the system uses GSM technology to send alerts via text messages. Additionally, an LCD screen is incorporated to display messages from the doctor, including instructions on medications and their dosages, ensuring the pregnant woman receives timely and accurate guidance.

# 2.2.20 IoT Enabled Prenatal Health Monitoring System for Pregnant Women [22]

This paper presents an innovative solution aimed at reducing high mortality rates in India. The system includes several sensors: an LM35 temperature sensor, a heartbeat rate sensor, a blood pressure sensor, a sweat sensor for measuring sugar levels, a MAX30100 pulse oximeter for oxygen level measurement, a 3-axis accelerometer for detecting fetal kicks, and a weight scale for tracking body weight. Data collected from these sensors is processed by an Arduino microcontroller, which then transmits the processed data to a SIM900A GSM module. This module sends the data to the cloud for storage. The stored data can be accessed via both mobile and web applications, ensuring comprehensive monitoring and easy accessibility.

## 2.3 Summary of existing solutions

Table 2.3. 1 Literature review

|  |  |  |  |
| --- | --- | --- | --- |
| AUTHORS | TITLE | PROJECT DESCRIPTION | LIMITATION |
| Tasnia Tabassum,  Saurav Podder,  Sk Tahmed Salim Rafid | A Comprehensive Framework for Wearable Module for Prenatal Health Monitoring and Risk Detection | The project develops a cost-effective, non-invasive wearable device for continuous prenatal health monitoring, integrating various sensors and an ESP-32 microcontroller to track vital signs, fetal movement, and falls, with data accessible via a cloud server and SMS alerts for anomalies. | No integration of a predictive mechanism to forewarn a risk of complication. |
| Sefki Kolozali,  Sara L. White,  Shane Norris,  Maria Fasli,  Member,  IEEE,  Alastair van Heerden | Explainable Early Prediction of Gestational Diabetes Biomarkers by Combining Medical Background and Wearable Devices: A Pilot Study With a Cohort Group in South Africa | The study uses data from continuous glucose monitoring, Empatica E4 wearable sensors, and health surveys to extract and select features for Decision Tree and Random Forest regression models, enabling early prediction of gestational diabetes biomarkers up to 16 weeks before standard testing. | No alerts were sent in event of emergency for all predictions made |
| Trisihita Ghosh Troyee,  Md.Kaiser Raihan,  Mohammed Shahriar Arefin | Monitoring of Expecting Mothers Using Multiple Sensor Approach: "Preg Care" | The paper presents an advanced health monitoring system using various sensors and a Python-based image processing algorithm for non-invasive glucose monitoring, cardiovascular health assessment, anemia prediction, and emergency SMS alerts, aiming to reduce maternal mortality in Bangladesh by ensuring continuous and timely prenatal health monitoring. | Efficiency of components used was overlooked |
| Betsy Diamar  Balbin Lopez,  Jimmy Alexander Armas Aguirre,  Diego Antonio Reyes Coronado,  Paola A. Gonzalez | Wearable Technology Model to Control and Monitor Hypertension during Pregnancy | The paper proposes a wearable device for continuous hypertension monitoring during pregnancy, connecting to a mobile app via Bluetooth to track vital signs, detect hypertension risks, and send real-time alerts with location details to patients and healthcare providers for timely intervention. | The project is limited to one pregnancy complication. |
| S. Veena,  D. John Aravindhar | Remote Monitoring System for the Detection of Prenatal Risk in a Pregnant Woman | The article proposes a smartwatch-based system for continuous maternal health monitoring, using SVM analysis of vital parameters and manual inputs to predict pregnancy risks, with alerts and a mobile app enabling real-time monitoring and timely medical interventions for doctors, patients, and family members. | The app displays health data on a daily basis, providing detailed insights for each day individually rather than aggregating or showing data continuously over multiple days or months. |
| Inna Korneeva,  Kristina Kramar, Evgeniia Semenova, Zafar Yuldashev | A System for Remote Monitoring of Pregnant Women's Health State and Pregnancy Complications Prediction | This article describes a system using portable medical devices and a Decision Tree machine learning model to monitor pregnant women's health parameters, transmit data via Bluetooth to a smartphone, and alert medical officers of abnormal readings for timely intervention. | Bluetooth technology has a short range, requiring the mobile device to be close to the wearable device for reliable data transfer. |
| Moses Thiga,  Pamela Kimeto,  Mvurya Mgala,  Emmaniel Kweyu,  Steve Wanyee,  Tooroti Mwirigi | A Remote Blood Pressure Data Collection and Monitoring System for Expectant Mothers | This article presents a GE-W74 smartwatch, which monitors blood pressure, heart rate, and ECG, transmitting data to a customizable mobile app for pregnant women and caregivers, with additional support apps for health workers and family to monitor and manage pre-eclampsia risks. | No consideration is made for instances of emergency cases where there is no internet connectivity. |
| Jayroop Ramesh,  Raafat Aburukba,  Assim Sagahyroon | A Remote Healthcare Monitoring Framework for Diabetes Prediction Using Machine Learning | This work outlines an automated smart health monitoring system for diabetes prediction using supervised machine learning algorithms, integrating data from various healthcare devices to notify medical professionals of abnormalities via a web and mobile app. | The scope is limited to diabetes prediction. |
| Roshni Ramprabhu, Shalini Suresh,  Dr. K. Latha,  Venkatesh D | Virtual Midwife for Pregnant Women and Alert System | This paper presents a compact device system that monitors vital health parameters in pregnant women, sending alerts and providing data access via mobile apps for both medical professionals and the women, facilitating health monitoring and communication. | The system does not account for emergency situations where internet connectivity is unavailable. |
| Mohammod Abul Kashem,  Marzia Ahmed, Naderuzzaman Mohammad | Maternal HealthCare Using IoT-Based Integrated Medical Device: Bangladesh Perspective | This article introduces a remote monitoring system for pregnant women, utilizing a wearable device, ESP32 module, cloud platform, and mobile app to collect, analyze, and visualize vital health data, enabling healthcare professionals to identify and respond to potential pregnancy complications. | Increase in network latency and consumption of more bandwidth is problematic for scenarios that demand immediate responses due to sole reliance on cloud computing |
| V.Santhi,  K. Ramya,  APJ.Tarana,  G. Vinitha | IOT Based Wearable Health Monitoring System for Pregnant Ladies Using CC3200 | This paper presents a healthcare solution combining a wearable device and web application to monitor pregnant women's vital signs, transmitting data via a CC3200 microcontroller to the cloud and notifying doctors of abnormalities for timely interventions. | No consideration is made for scenarios of no internet connectivity especially for emergency situations |
| Macarena Espinilla, Javier Medina,  Ángel-Luis García-Fernández,  Sixto Campaña,  Jorge Londoño | Fuzzy Intelligent System for Patients with Preeclampsia in Wearable Devices | This article discusses a wearable watch that measures blood pressure and uses a mobile app with an AI-driven Decision Tree model, trained on a Colombian hospital dataset, to predict the risk of preeclampsia in pregnant women. | The scope of this project is limited to preeclampsia prediction. |
| Rydhm Beri,  Mithilesh K. Dubey,  Anita Gehlot,  Rajesh Singh,  Mohammed Abd‑Elnaby,  Aman Singh | A novel fog‑computing‑assisted architecture of E‑healthcare system for pregnant women | The proposed framework introduces an IoT and fog-assisted smart health monitoring system for pregnant women, integrating various sensors and microcontrollers to securely collect, process, and transmit health and environmental data, providing real-time alerts and health recommendations via a mobile app and cloud storage. | No predictive mechanism on captured data. |
| Mrs. Priya R. L,  Anish Vaidya,  Mohit Thorat,  Vinit Motwani,  Chetas Shinde | SAARTHI: Real-Time Monitoring of Patients by Wearable Device | This paper proposes an IoT-based wristband system that collects real-time health data and clinical information, using a machine learning model to predict heart disease, with alerts sent to healthcare providers or family members for timely intervention. | Data must be transmitted to centralized cloud servers for processing, resulting in increased network latency, even in emergency situations. |
| Namuddu Haliima,  Gerard Rushingabigwi,  Frederic Nzanywayingoma | Design of an IoT Based Monitoring System for Expectant Rural Women in Developing Countries | This article proposes a system using sensors and an Arduino microcontroller to monitor maternal health, transmitting data via a GSM module to the cloud, where alerts are sent via email when preset conditions in the microcontroller are met or exceeded. | No predictive mechanism to forewarn a risk of pregnancy complications |
| Anandakumar M, Bharathiraja K, Muhammed Ijas,  Suhith M,  Mrs.R. Santhoshi | Smart Pregnancy Health Monitoring System Using IOT | This paper presents a healthcare system that uses sensors to monitor four maternal and one fetal vital, transmitting the data via an Arduino Uno to the cloud, where it can be accessed through a smart device. | Emergency scenarios where internet connectivity is unavailable are not accounted for in the system.  No predictive mechanism to forewarn risk of a pregnancy complication |
| Kokeb Dese,  Gelan Ayana,  Gizeaddis Lamesgin Simegn | Low cost, non-invasive, and continuous vital signs monitoring device for pregnant women in low resource settings (Lvital device) | The article describes a solar-powered system using an Arduino microcontroller to monitor pregnant women's vital signs, including blood pressure, heart rate, and temperature, with alerts sent via GSM module and deviations indicated by a buzzer, while an LCD displays system activity messages. | No predictive mechanism to forewarn risk of a pregnancy complication |
| Dr.G.Shanthi M.Tech,  Ann Avelin. R,  Atchaya N,  Dharani P,  Dheeksha.M | IOT-Based Monitoring System for Expectant Women | This work presents a wearable system with sensors for monitoring pregnant women's vital signs, processed by a NodeMCU microcontroller, with alerts for health deviations and real-time data sent to the cloud, accessible via websites for healthcare providers and the pregnant women’s relative or caretaker. | No predictive mechanism to forewarn risk of a pregnancy complication |
| Varsha Ishwar Salunke, Gowthami S,  Jaikanth S,  Mr. Manoranjan Kumar | Smart Wearable Obstetric Assistant and Reminder | This paper presents a device that monitors pulse rate, body temperature, and falls in pregnant women, tracks their location via GPS, and uses GSM to send alerts and display medical instructions on an LCD screen. | No graphical visualization of captured values on a mobile app  No predictive mechanism to forewarn of risk of pregnancy complication |
| Ankit Bansal,  Vijay Anant Athavale, Kushwant Kaur,  Atul Garg | IoT Enabled Prenatal Health Monitoring System for Pregnant Women | This paper presents a system that uses various sensors to monitor vital health metrics, processes the data with an Arduino, transmits it via a GSM module to the cloud, and makes it accessible through mobile and web applications to help reduce mortality rates in India. | No alerts are sent in the event of abnormality in vitals captured.  No predictive mechanism to forewarn risk of pregnancy complication |

## 2.4 Proposed solution

Our project involves the integration of a wearable device, a trained machine learning model, and a mobile application to provide continuous monitoring and proactive health management for pregnant women. The wearable device is designed to capture a range of critical physiological data, including body temperature, blood pressure, blood glucose levels, oxygen saturation, and heart rate. This data is continuously collected and transmitted to a fog node, where it undergoes preliminary processing. At this stage, a machine learning model, specifically designed for pregnancy-related health risks, analyzes the data to predict potential complications such as preeclampsia or gestational diabetes. TinyML, a lightweight version of machine learning, is applied to the fog node for efficient, real-time predictions without the need for extensive computational resources.

Once the data is processed and predictions are made, it is sent to the cloud for secure storage. This stored data can be accessed at any time by authorized users through a smart device after successful authentication. The cloud-based storage ensures that healthcare providers can monitor the patient’s health remotely and intervene when necessary, while also providing a centralized data repository for long-term analysis and trend monitoring.

In addition to the real-time data collection and processing, the system is programmed to send personalized health recommendations to the pregnant woman from the cloud. These recommendations are based on the analysis of her health data and aim to improve her overall well-being. For example, the system might suggest dietary adjustments, hydration tips, or physical activity guidelines tailored to her specific needs.

In the event of an emergency or if the system predicts a significant health issue, an immediate alert is sent directly to the mobile app of the pregnant woman. This alert, delivered via GSM (Global System for Mobile Communications), notifies the woman of the potential risks and advises her to visit the antenatal clinic for a more thorough examination. The use of GSM allows the system to send reliable, real-time alerts, even in areas with limited internet connectivity, ensuring that the pregnant woman can receive timely intervention when needed.

Overall, this system aims to enhance maternal healthcare by offering continuous monitoring, early detection of pregnancy complications, and timely interventions. The combination of wearable technology, machine learning, and mobile connectivity empowers pregnant women to take control of their health and receive personalized, data-driven care throughout their pregnancy.

## 2.5 Scope of Project

The scope of this project involves developing an integrated system that combines wearable technology, cloud-based processing, and machine learning to enhance maternal health outcomes. The system focuses on early detection, continuous monitoring, and proactive intervention to reduce the risk of pregnancy complications. By enabling continuous data collection, offering personalized recommendations, and providing timely alerts, the system aims to improve the quality of care for pregnant women. Below is a comprehensive explanation of the project's components and objectives.

* **Wearable Device and Data Collection**  
  The project includes the development of a wrist-worn wearable device that captures real-time physiological data from the pregnant woman. Key vitals such as body temperature, blood pressure, heart rate, blood glucose levels, and oxygen saturation are continuously recorded by the device. Additionally, supplementary data, such as the presence of protein in urine (a potential indicator of preeclampsia), will be manually inputted by the pregnant woman into a mobile app.
* **Machine Learning for Early Prediction at the Fog Node**  
  The preprocessed data is fed into a machine learning model at the fog node, which has been specifically trained to predict pregnancy complications ahead of the typical detection window. The model analyzes the data in real-time, detecting anomalies in vital signs such as blood pressure and blood glucose levels that may indicate conditions like preeclampsia, gestational diabetes, or other complications. By performing this analysis locally at the fog node, the system can generate immediate predictions and alerts, which are then sent to the cloud for storage and further analysis. Alerts are provided to both the pregnant woman and her healthcare provider, ensuring timely intervention if any anomalies are detected.
* **Data Transmission and Cloud Integration**  
  The captured data from the wearable device, along with the manually inputted information, is sent to the cloud for centralized processing and storage. This enables seamless data access, long-term monitoring, and integration with machine learning models for predictive analysis. The cloud infrastructure ensures scalability and secure storage of sensitive health data, providing the backbone for real-time processing and future data-driven health insights.
* **Mobile App for Visualization and Alerts**  
  A mobile app is developed to serve as the interface for both the pregnant woman and her doctor. The app provides a personalized dashboard where the pregnant woman can view her recorded vitals, receive recommendations, and track her health trends over time. The doctor’s dashboard allows healthcare providers to monitor multiple patients, review real-time data, and receive alerts in the event of an anomaly, facilitating quick decision-making and proactive care.
* **Alerts and Notifications**  
  In the event of a detected anomaly, the pregnant woman receives and alert to visit the antenatal care as soon as possible and her doctor receive immediate alerts of predictions made via the mobile app. The use of a reliable alert system is crucial for ensuring that health risks are addressed before they escalate into more serious complications.

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