

Sensing, Artificial intelligence, and Edge networking towards Rural
Health monitoring (SAFE-RH)



D2.2

**Maternal, Fetus and Infant Health
Monitoring Pilot**

SAFE-RH Project no. 619483-EPP-1-2020-1-UK-EPPKA2-CBHE-JP



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1. Maternal Fetus, and Infant Monitoring Pilot

Maternal, fetus and infant health is indispensable for a healthy society. The major issues that cause maternal health problems and even deaths include ectopic pregnancy [1], miscarriage [2], high blood pressure that leads to preeclampsia [3] [4], and failure in progress of labor that might lead to Caesarean section (C-section) [5]. In addition, iron deficiency is another vital factor of prenatal and postnatal health complications that can be caused due to antepartum or post-partum haemorrhage [6], retained placenta [7], vaginal infection during delivery [8] [9], and many other similar problems. Currently, sensing technology has improved patient pregnancy care, infant healthcare, patient communication, and real-time monitoring of several diseases using sensors, wearable gadgets and devices [10]. The relevant literature reports the use of a variety of solutions, such as in ectopic pregnancy that can be detected early through scans and blood tests by using high resolution and portable ultrasound [11] and complete blood count (CBC) blood test machines [12]. In the case of a miscarriage scans, timely dilation and curettage (D&C) and haemoglobin (HB) level monitoring can help to minimize the relevant complications. Similarly, for blood pressure (BP) [13] monitoring, a variety of digital devices have been designed. Cardiotocography (CTG)/tracing of fetal heart [14] and anomaly scans can reduce fetal deaths and stillbirths and can help in the early detection of congenital abnormalities, pregnancy care [15], hypertension monitoring [16], diabetes [17] mother and fetal care [18], detection of postpartum depression [19], and similar pregnancy complications. Consequently, wearable sensor advances can improve patient–supplier connections for successful pregnancy wellbeing. In addition, for infant healthcare, technology-enabled, well-equipped and intelligent incubators and nasogastric (NG) tubes for nasogastric feed premature infants can improve in time response [20].

Maternal, fetus, and infant health monitoring is important for ensuring the well-being of mother and fetus throughout pregnancy, and infant after birth. This monitoring involves regular check-ups, which include ultrasound scans, blood tests, and physical examinations to assess the maternal health and development of the fetus. These examinations help detect potential risks early, such as gestational diabetes, preeclampsia, and fetus growth restrictions, allowing for timely interventions. Moreover, monitoring maternal health includes tracking vital signs, weight gain, glucose level, and nutritional status, are crucial for maintaining a healthy pregnancy and preparing for a safe delivery. Similarly, for the fetus wellbeing, it is important to monitor heart rate, movement, and position, whereas, in case of infant, body temperature, oxygen saturation level, pulse rate, environment temperature and humidity.

1.1 Rationale

At the beginning of 2020, Pakistan's population was approximately 216 million, with more than 50% inhabiting in rural areas. Besides other basic needs, medical facilities in these areas are deficient [21]. Most of the health budget is allocated to urban areas, leaving rural areas neglected. The availability of doctors in rural areas is scarce, leading to high maternal and infant mortality rates due to the lack of timely medical advice and assistance. To reduce mortality rates and improve healthcare quality, it is essential to provide medical facilities in rural areas. Remote monitoring and consultation for maternal patients can significantly reduce health risks in these regions.

1.2 Objectives

The primary goal is to ensure the well-being of both mothers and fetus using remote sensing and ICT-enabled solutions. The main objectives of the pilot are as follows:

1. To develop remote sensing system using medical sensors that can monitor the maternal and fetus health during pregnancy and communicating with doctor and caretakers using smart alerts.
2. To develop a Basic Health Unit (BHU) scenario that can monitor the maternal health who visit in person in some medical facility in remote rural areas, where her vitals can be recorded and remote consultation with gynaecologist is possible.
3. To provide health indicators/stats to maternal using custom built mobile application that is replica of Management Information System
4. To provide swift communication using user friendly mobile application among all stakeholders including patients, doctors, paramedical staff and care takers in case of both the BHU and remote sensing scenarios.

2. Nomenclature of the Pilot

This section briefly presents the modules of the pilots, and the uses cases adopted to realize the pilot.

2.1 Maternal Module

The maternal module purely deals with the monitoring of the mother during pregnancy considering important vital sign and health related parameters crucial for the well-being of the pregnant women.

2.2 Fetus Module

The second module of the pilot deals with the monitoring of fetus health considering important vital signs, and health related parameters crucial for the well-being of the fetus.

2.3 Infant Module

The third module of the pilot deals with the monitoring of infant health considering important vital signs, and health related parameters crucial for the well-being of the infant.

2.4 Use Cases

Two use cases including facility scenario and remoting health monitoring to realize the pilot are considered and explained in the following sub-sections.

2.4.1 Facility Scenario

In rural areas where consultants and expert doctors are not available, there are designated health units with trained health workers in the form of rural health centres, basic health units or facilities. This scenario deals with maternal health monitoring within Basic Health Units (BHUs) in which expectant mothers visit physically and receive essential care by the health worker. At BHUs, health workers employ medical gadgets and procedures to assess maternal and fetus health.

2.4.2 Remote Monitoring

In this scenario, maternal health, fetus and infant monitoring extends through remote sensing technology. This scenario deals with remote monitoring of maternal, fetus and infant health using wearable sensors. These wearable sensors transmit real-time data to a central monitoring system, enabling healthcare providers to remotely monitor maternal, fetus, and infant health status.

3. Realization of Pilot

This section details all components of the pilots and their implementation, including the proposed architecture, developed software applications, designed hardware components, and trained prediction models.

3.1 Pilot Architecture

The proposed architecture describes the complete SAFE-RH project data flow and important components as shown in Figure 1. This section explains architecture purely from maternal, fetus and infant monitoring perspective. Firstly, maternal vital signs (temperature, heart rate, blood sugar, blood Pressure, oxygen saturation level, and weight) as shown in Figure 2 and fetus parameters (heart rate, movement and position) as shown in Figure 3 and infant related parameters (body temperature, oxygen saturation level, pulse rate, environment temperature, and humidity) as shown in Figure 4 are collected by classified sensors and transmitted wirelessly to the MIS via fog node using a Wi-Fi connection. This fog node, located either at home or in a healthcare facility like a Basic Health Unit (BHU), acts as the initial processing node.

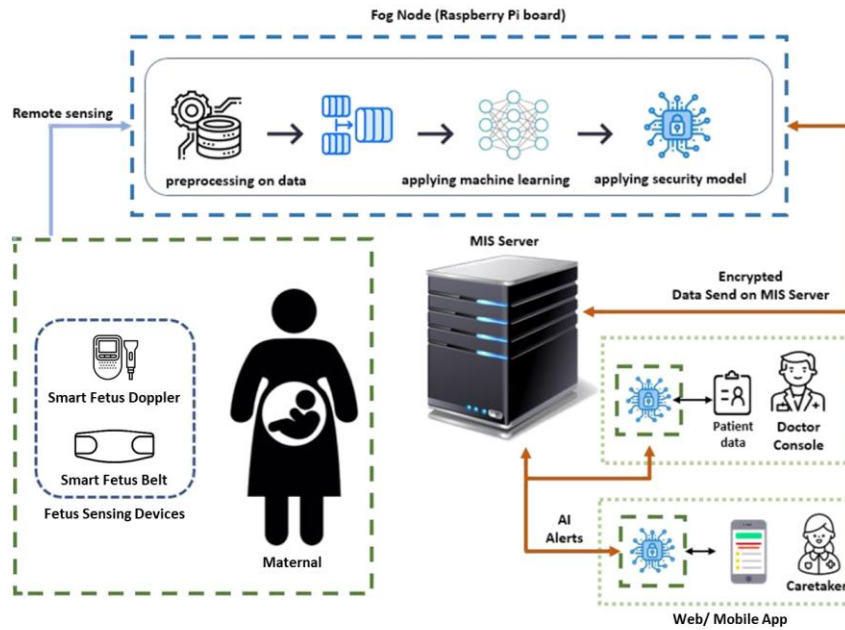


Figure 3: Remote Fetus Health Monitoring

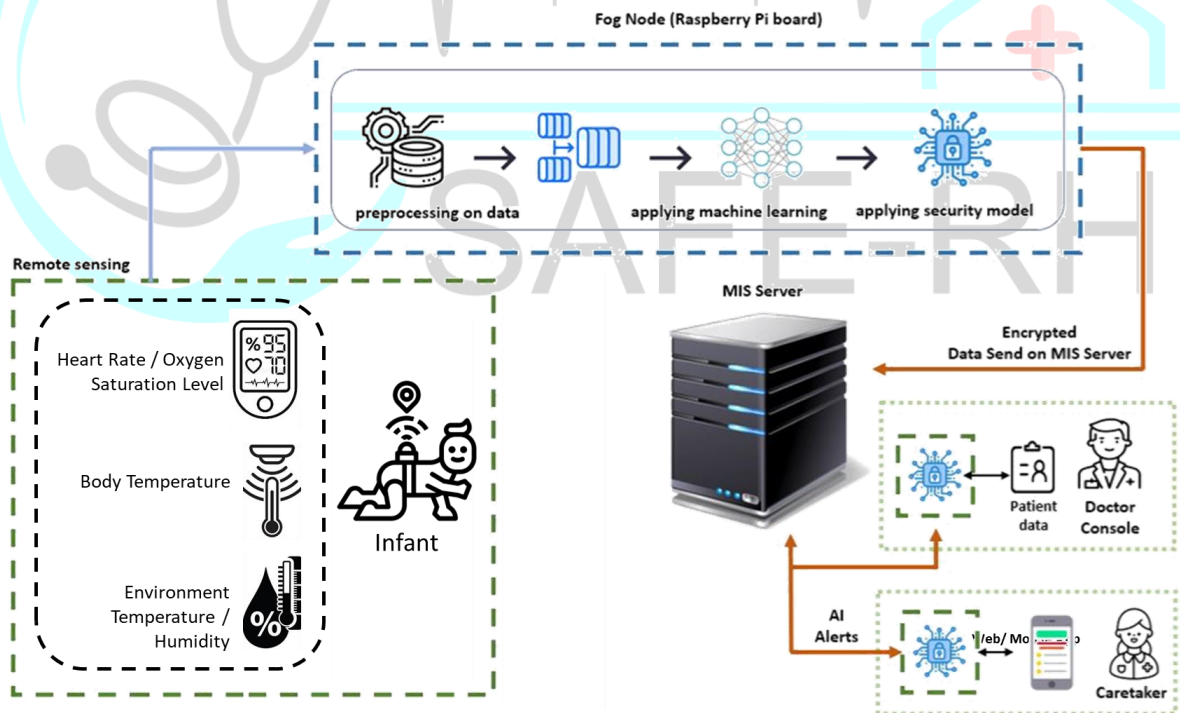


Figure 4: Remote Infant Health Monitoring

Furthermore, the health data is securely stored in cloud storage, ensuring accessibility and reliability. Periodically, the MIS server updates and trains the AI models using the accumulated data from the cloud storage. This continuous learning process enhances the accuracy and effectiveness of the AI models, ensuring that the latest advancements in healthcare monitoring are applied across all edge

nodes. In summary, the MIS architecture seamlessly integrates sensor data collection, processing, privacy measures, alert generation, cloud storage, and AI model training. By leveraging these components, it facilitates proactive healthcare monitoring and intervention, ultimately improving maternal and infant health outcomes.

3.2 Software Applications

This section describes software applications including management information system and mobile application developed to implement the pilot.

3.2.1. Management Information System

The Management Information System (MIS) is an online platform utilized in telemedicine, serving as a centralized hub for medical data management and communication. It comprises various consoles tailored for distinct user groups, including doctors, patients, and paramedics where they can register and sign in as shown in Figure 5 and Figure 6. These consoles provide specialized interfaces catering to the unique needs and roles of each user category within the telemedicine domain.

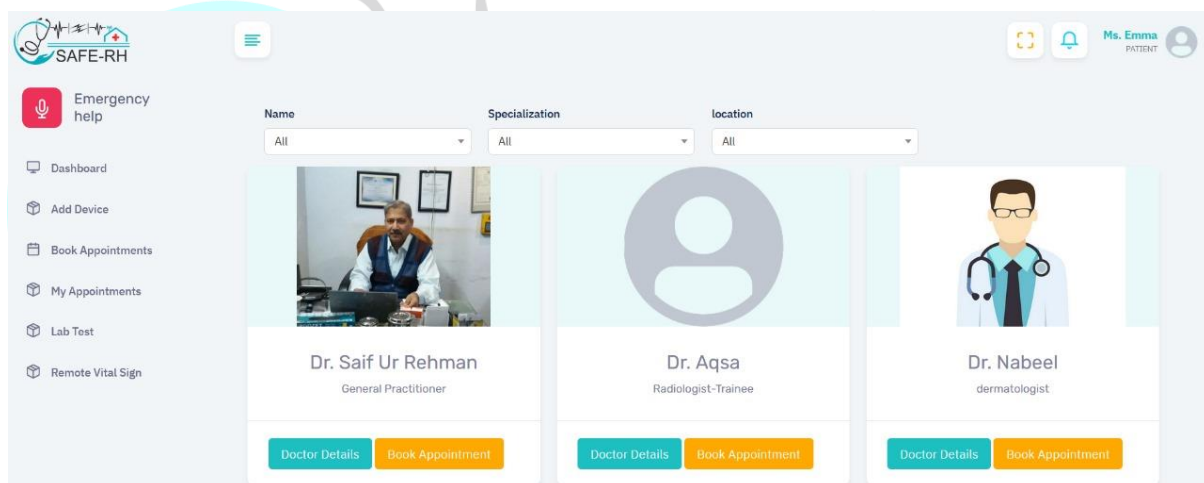


Figure 5: Patient Console on MIS

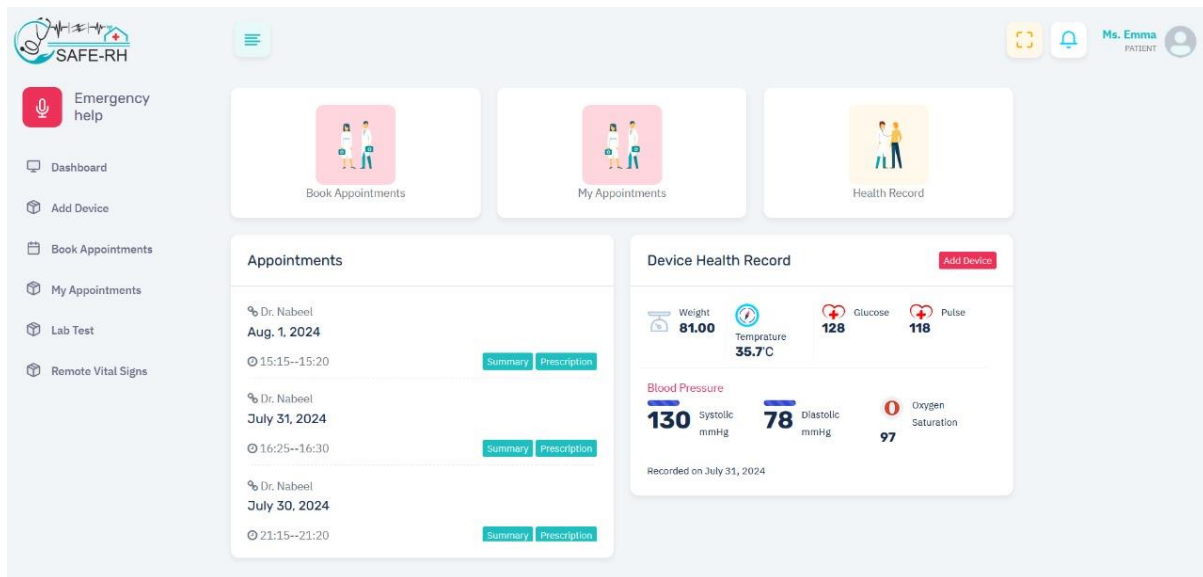


Figure 6: Patient Console for Booking Appointment with Doctor

3.2.2. Mobile App

Mobile application is a replica of the MIS which offers handheld access to all the stakeholders for medical data management and communication. It consists of various consoles tailored for distinct user groups, including doctors, patients, and paramedics where they can register and sign in. The major functionalities offered to each stakeholder are discussed in the following sub-sections.

3.2.2.1. Patient Console

Mobile App offers various functionalities at patient console as shown in Figure 7 where the registered patients can:

1. Schedule appointments with doctors by selecting preferred dates and time slots.
2. Access and view their vitals automatically transmitted from medical devices, such as blood pressure monitor, glucometer, and pulse oximeter, view Fetus tracking as shown in Figure 8
3. Book appointments for remote consultations with doctors to discuss health concerns.
4. Communicate with doctors through chat and video calls.

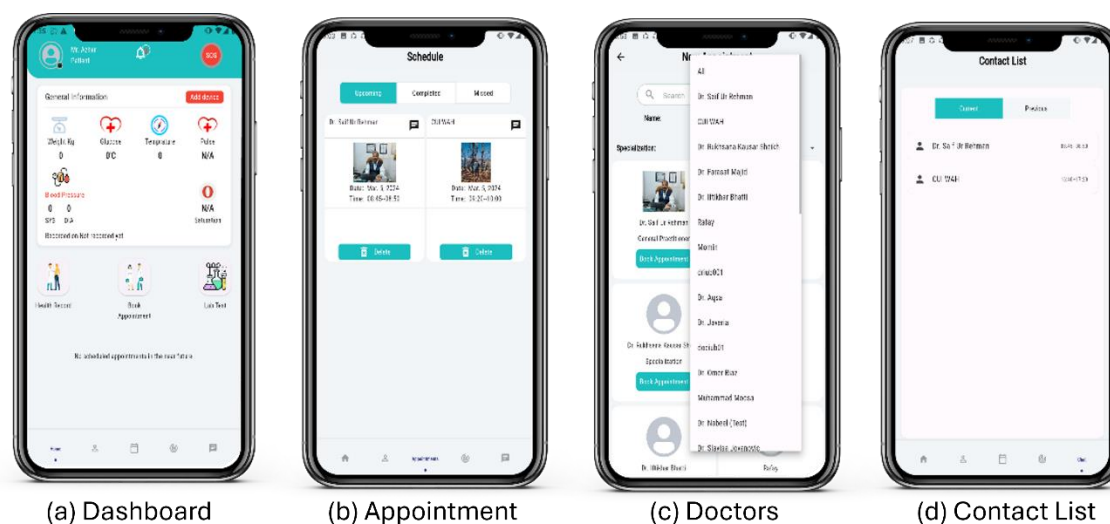


Figure 7: View of Patient Console

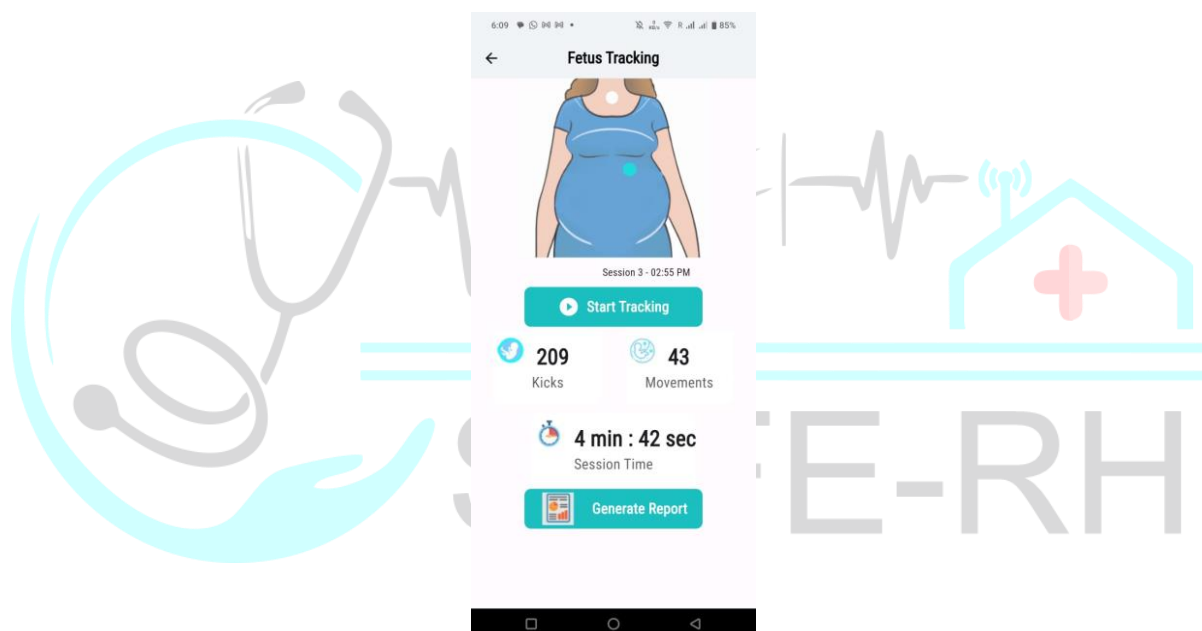


Figure 8: Fetus Tracking on Patient Console

3.2.2.2. Doctor Console

The doctor console offers following major functionalities to the registered doctors as shown in Figure 9.

1. View and manage their appointments, including settings of time slot availability and rescheduling.
2. Conduct remote consultations of patients through secure video calls and help via chat.
3. Prescribe medications, lab investigations and treatments to the patients using dedicated console.
4. Access the list and data of the registered patients, and search and retrieve patient information efficiently.

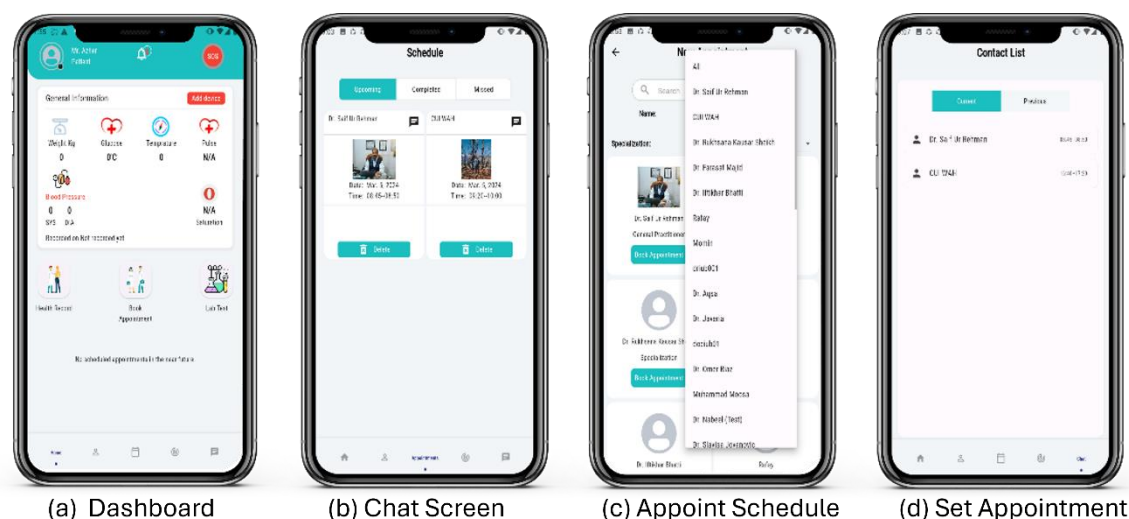


Figure 9: View of Doctor Console

3.2.2.3. Paramedic Console

Like doctor's console, the paramedic console of the Mobile App for the medical health workers offers following functionalities as shown in Figure 10.

1. Manage assigned patients efficiently.
2. Access a list of assigned patients and enabling paramedics to view patient information such as medical history, ongoing treatments, and medications.

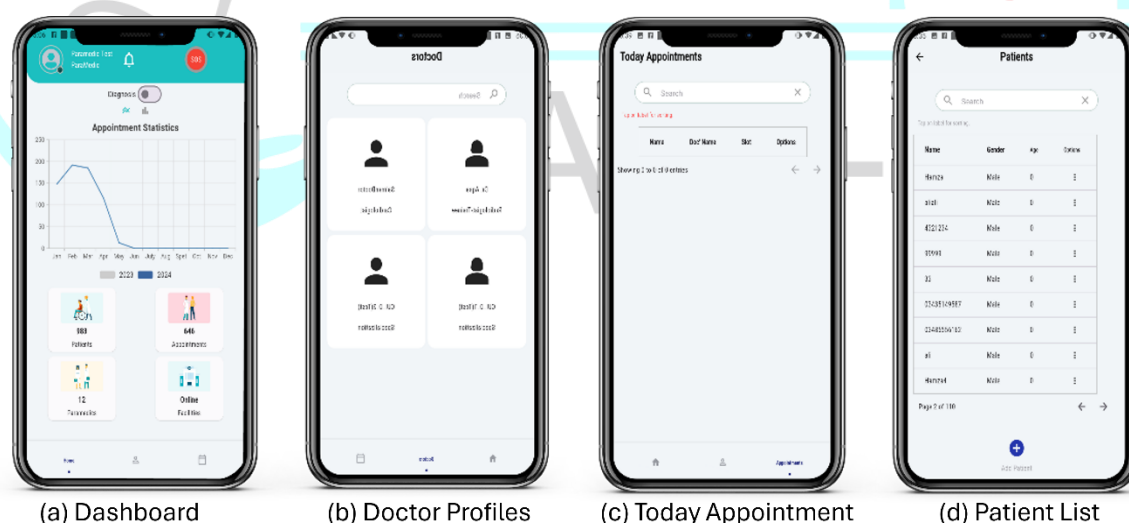


Figure 10: View of Patient Console

3.2.2.4. Caretaker Console

Mobile App also provides a console to the caretaker of the patients as shown in Figure 11 and it offers following functionalities:

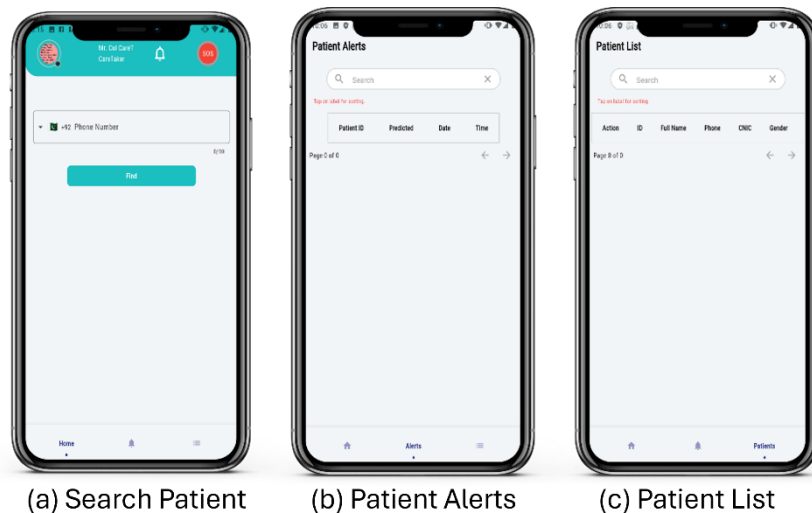


Figure 11: View of Caretaker Console

1. Add patients under their care and access a comprehensive list of all patients they oversee.
2. Create patient profiles using this console by recording the information relevant to a specific patient such as demographics, medical conditions, and contact details.
3. Creating patients' ensuring that caretakers have all necessary information readily available for effective patient care.

3.3. Implementation of Use-Cases

This section covers the operational flow, technical implementation details including the hardware and software systems designed for the aforementioned both scenarios.

3.3.1. Facility Scenario

A facility or Basic Health Unit (BHU) scenario is where an individual physically arrives at the clinic or facility for medical assistance as shown in Figure 12. Upon arrival, a paramedic welcomes the patients and registers them on the Management Information System (MIS), if not registered earlier. The paramedic then proceeds to take the patient's vital signs using different devices as described in the following subsections as well as other necessary notes such as medical history and symptoms. These details are promptly uploaded in the MIS for the record-keeping and for onward examination by the doctor. A patient has a option for online consultation with a doctor by video calls / chat and get examined. Also, a patient may consult physically with a doctor if available in BHU. In this way a facility scenario provides flexibility and accessibility in healthcare delivery. This streamlined process ensures efficient management of patients' data and facilitates seamless interaction between patients and healthcare providers at the BHU. The important medical gadgets considered for the facility or BHU scenario are discussed in the following sub-sections.

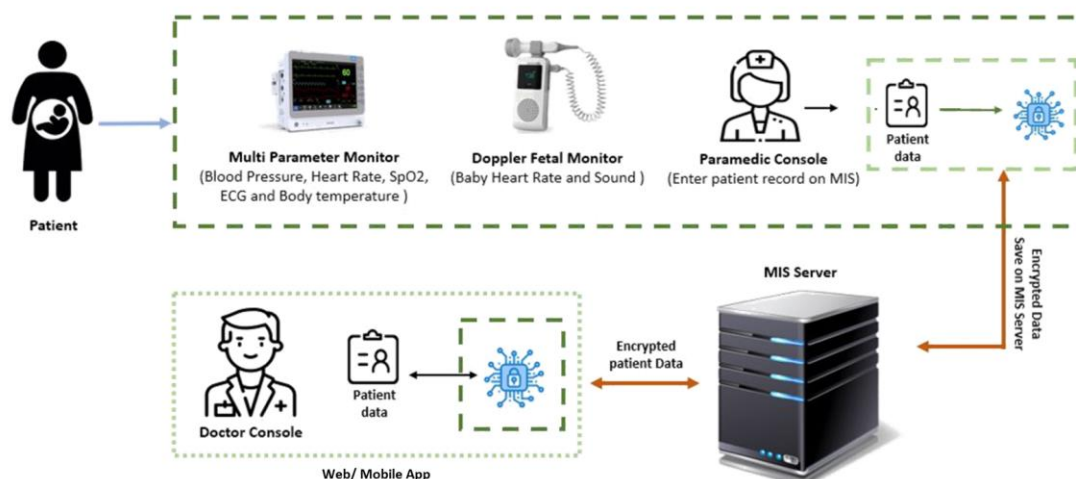


Figure 12: The Facility/ Basic Health Unit (BHU) Scenario

3.3.1.1. Doppler

One of the medical gadgets of maternal health monitoring at a BHU is a doppler to monitor the fetus heart rate. This non-invasive gadget allows healthcare providers to assess the baby's heartbeat, providing valuable insights into fetus well-being. The doppler gadget is shown in Figure 13. This gadget monitors fetus heart rate crucial for reducing the pregnancy risks in BHU settings.



Figure 13: Fetus Doppler for Heart Rate Monitoring

3.3.1.2. Multi-Parameters Monitor

The other gadget considered for the scenarios is multi-parameter monitor as shown in Figure 14. The gadget is equipped with six essential parameters for comprehensive maternal health assessment including ECG (Electrocardiogram), PR (Pulse Rate), Resp. (Respiration Rate), NIBP (Non-Invasive Blood Pressure), SpO2 (Oxygen Saturation), and TEMP (Temperature). These parameters provide healthcare providers with critical insights into the cardiovascular, respiratory, and overall physiological status of pregnant women. By monitoring these vital signs, deviations from normal ranges can be promptly identified, enabling early detection and management of potential health issues. Thus, these collected

parameters provide a holistic view of the maternal well-being, and ensuring timely interventions and improved outcomes for expectant mothers in a BHU.

Figure 14: Multiparameter Monitor



for Vital Signs

3.3.1.3. Infant Body Patch

Similarly for infant health developed as shown in Figure oxygen saturation level, and to these vitals, it also measures environment temperature and humidity as presented in Table 1. These parameters provide healthcare providers with critical insights into infant health. By monitoring these vital signs, deviations from normal ranges can be promptly identified, enabling early detection and management of potential health issues. Thus, these collected parameters provide a holistic view of the infant well-being and ensuring timely interventions and improved outcomes for infant health in a facility scenario.

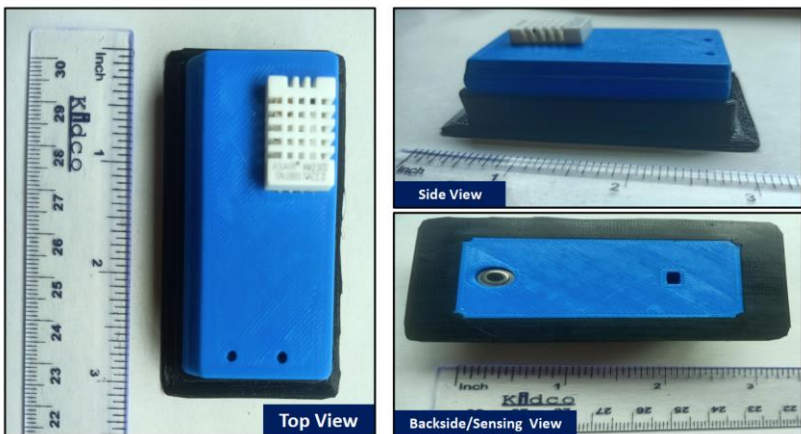


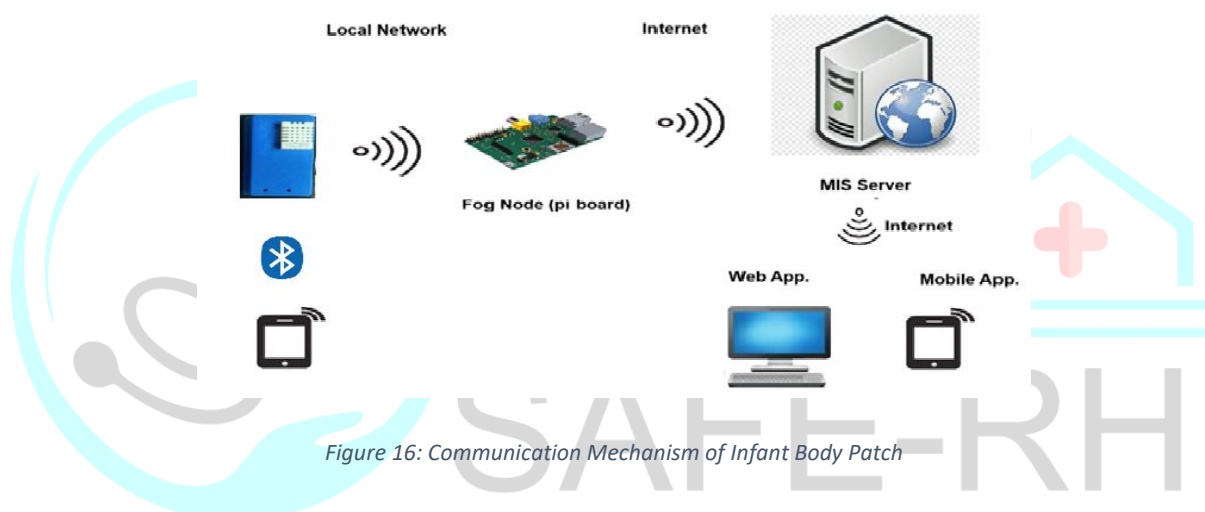
Figure 15: Infant body Patch for Vital Signs

Table 1: Sensors used for Infant body Patch

Item	Component	Figure	Description
Controller	ESP32 Wroom		Controller for sensors data processing and wireless data transmission.
Heart Rate / Oxygen Saturation level	MAX30100		MAX30100 is a highly integrated pulse oximeter and heart-rate sensor module, which is capable of providing accurate and reliable measurements of blood oxygen saturation (SpO2) and heart rate
Body Temperature	MLX90614		MLX90614 is a non-contact infrared temperature sensor that can accurately measure object temperatures without touching them..

Environment Temperature / Humidity	DHT22		DHT22 is used to measure precise environment temperature and humidity readings.
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Error! Reference source not found. The infant body patch can communicate with MIS server or Fog Node using WIFI while its WIFI configuration (SSID and Password) and destination address can be set through mobile application via Bluetooth. The patch continuously monitoring stats using sensors without disruption. The central hub serves as the intermediary device that collects real-time data from the patch placed on the body of infant. It then securely transmits this data to the MIS via Fog node, ensuring timely access for healthcare providers to monitor and analyse maternal health parameters remotely. The communication mechanism of infant body patch is shown in Figure 16.



3.3.2. Remote Monitoring

The second scenario of remote health monitoring of maternal, fetus and infant is implemented using remote sensing technology. It consists of medical grade wearable sensors which transmit real-time data to a MIS server, enabling healthcare providers to remotely monitor maternal, fetus, and infant health. The wearable sensing technologies used for maternal, fetus, and infant health monitoring are discussed in the following sub-sections.

3.3.2.1. Maternal Remote Monitoring

For maternal remote health monitoring a set of sensors for blood pressure, glucose level, temperature, weight, heart rate, and oxygen saturation levels are used as described in Table 2. These sensors are strategically placed on the body to seek real time data of maternal. The wearable nature of these sensors allows for seamless integration into the daily routine of expectant mothers, enabling continuous monitoring without disruption. Facilitating seamless communication between the

wearable sensors and the MIS is a hub component. This central hub serves as the intermediary device that collects real-time data from the wearable sensors worn by expectant women. It then securely transmits this data to the MIS via fog node, ensuring timely access for healthcare providers to monitor and analyse maternal health parameters remotely.

Table 2: Sensing Gadgets and Parameters Measured

Devices	Parameters Measured	Figures
Oximeter	Oxygen Saturation, Heart Rate	
Sphygmomanometer	Systolic Blood Pressure, Diastolic Blood Pressure	
Glucometer	Blood Sugar Level	
Weight Machine	Weight	

The real time readings received from these sensing gadgets are fed into MIS and displayed on both web client of MIS and Mobile App as shown in the Figure 17.



Figure 17: Sensing Devices Readings Display on MIS and Mobile App

3.3.2.2. Fetus Remote Monitoring

To monitor the wellbeing of fetus, the fetus movement monitoring belt and the fetus heart rate monitoring doppler are designed and discussed in this section.

A. Fetus Movement Remote Monitoring Belt

A belt that monitors the fetus movement remotely is designed and developed as shown in Figure 18. It is a non-invasive wearable sensing belt placed on tummy of expectant woman that detects kicks and movements of fetus, and send the real time data to MIS server that can be viewed by healthcare providers.

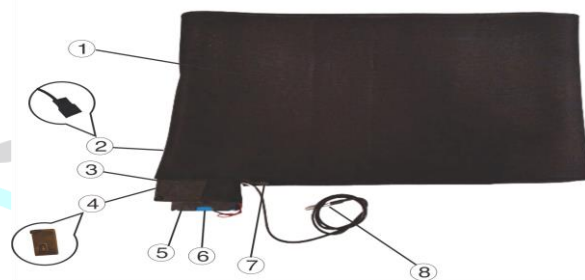


Figure 18: Fetus Movement Remote Monitoring Belt

The belt consists of three different sensors, the first for measuring pressure force, the second for measuring temperature, and the third for measuring the maternal movement as described in Table 3. The sensing part of belt is a grid of thin Film Pressure Sensor (FSR), less than 0.4mm thick. It is designed to detect pressures up to 10kg, and it responds accurately to pressures as low as 150g. It boasts response and recovery times under 1ms and 15ms respectively, staying resilient against electromagnetic induction (EMI) and electrostatic discharge (ESD). It functions seamlessly across temperatures from -20°C to 60°C, offering stability. Overall belt size is 50x65mm with a 45x45mm sensitive area, it integrates flexibly into the belt design. Additionally, a temperature sensor monitors ambient temperature shifts, enhancing usability. Gyroscope detects the movement of the patient that is used to avoid the interference in the data due to movement of patient herself.

Table 3: Sensors used for Fetus Belt

Sensor Type	Usage/Description	Figure
Thin Film Pressure Sensor (FSR)	Ultra-thin design for pressure detection, range up to 10kg, rapid response	
Temperature sensor	Measures ambient temperature variations	

Gyroscope sensor	Detects the movement	
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Since the belt operates wirelessly, it needs to be connected to Wi-Fi and configured to send its data to the fog node. The manual of the fetus movement remote monitoring belt is provided in Annexure A of deliverable Cross-Pilot.

B. *Fetus Heart Remote Monitoring Doppler*

For monitoring the heart rate of fetus, usually a handheld fetus doppler device is used as shown in Figure 19. To detect and send the fetus heart rate remotely to MIS server, a handheld fetus doppler device is customized. This data can be accessed remotely through a mobile and web application, and it enables healthcare providers to monitor the fetus heart rate from a distance, facilitating timely interventions and ensuring comprehensive care throughout the pregnancy.

The fetus doppler device operates at 2.5MHz that consists of ultrasound transducer, microcontroller unit, amplifier (EL7222), and bandpass filter (OPA2356). The fetus heart rate data from its microcontroller is decoded and sent to ESP32 that facilitates seamless data transmission to MIS server.



Figure 19: Customized Doppler for Fetus Heart Rate Remote Monitoring

For wireless data transmission to the fog node, the fetus doppler device needs to be connected to Wi-Fi and configured properly to send its data. The manual of the fetus heart rate remote monitoring device is provided in Annexure B.

C. *Communication of Fetus Remote Monitoring Devices*

A good communication link is required to monitor the fetus movement remote monitoring belt and fetus heart rate remote monitoring doppler. The data communication of these devices is shown in Figure 20. Patients are at remote end from where the data is acquired using both devices which is transmitted to fog node i.e. raspberry pi using local network. Fog node further transmit the data to MIS server from where it can be viewed by healthcare providers using web and mobile applications.

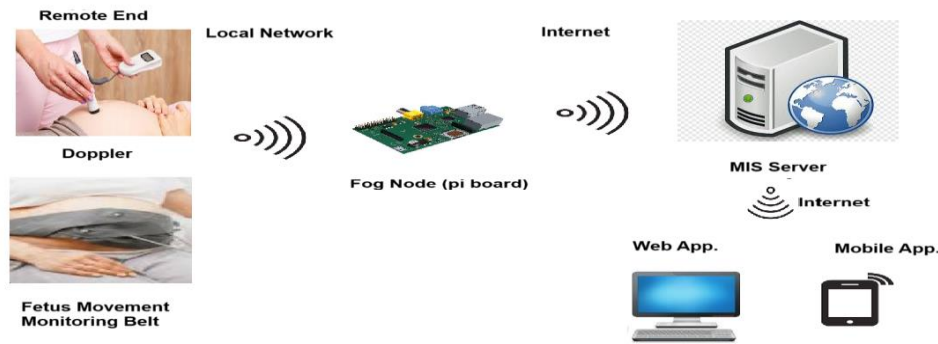


Figure 20: Data Transmission from Doppler and Belt

3.3.2.3. Infant Remote Monitoring

The infant body patch can also be used for remote health monitoring scenario of infant as discussed in section 3.3.1.3.

3.4. Prediction Models

In the remote patient monitoring system artificially intelligent alters are generated to intimate the caretakers and healthcare providers to predict the health conditions. This predictive capability enables healthcare providers to identify potential health risks early and intervene proactively, thereby improving maternal wellbeing and reducing the likelihood of complications during pregnancy. Different prediction models proposed for the remote maternal and fetus monitoring are discussed in the following sub-sections.

3.4.1. Gestational Diabetes Mellitus

Gestational Diabetes Mellitus (GDM) is a health condition that occurs during pregnancy when blood sugar increase than normal limit [22], if handled carefully it usually return to normal after childbirth [23]. This situation causes significant health problems as it can affect both the mother and the developing fetus. From the fetus perspective, GDM has the negative effects on macrosomia that results in a big size of the newborn baby, neonatal hypoglycaemias which is low blood sugar in newly born baby and respiratory distress syndrome which may result to long term complications [24]. In addition, this condition also leads to the higher rates of stillbirths and the congenital anomalies as well. These risks show the importance of early detection and management of the situations like these. GDM occurs mainly due to increased insulin resistance in pregnant women and is mainly caused by the hormonal changes of pregnancy [25].

A machine learning model is developed that combines various machine and deep learning techniques to enhance predictive performance. The methodology approach integrates a comprehensive strategy for GDM prediction. The initial steps involves exploratory analysis and data pre-processing. The combined pre-processing strategies contribute to a comprehensive dataset for

the training of the random forest model for effective GDM prediction. The model undergoes several steps to enhance its predictive capabilities, as illustrated in Figure 21.

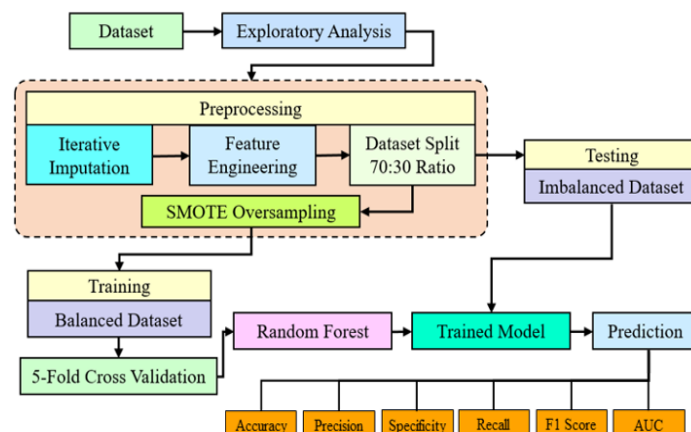


Figure 21: Methodology for Developing the GDM Model

The dataset used for GDM prediction is sourced from Kaggle¹. The dataset was collected in 2021 from Anbu Hospital and Nalam Clinic in Kumbakonam city of Tamil Nadu in India. The dataset comprises 3525 instances and a single binary target variable. The dataset features include demographic information, clinical indicators, prenatal health factors, blood pressure measurements, and glucose results. Further details regarding the dataset are summarized in Table 4.

Table 4: Characteristics Summary of the GDM Dataset

Sr. No.	Feature Name	Data Type	Min	Max
1	Age	Integer	20	45
2	Body Mass Index (BMI)	Integer	13	45
3	Previous Miscarriage (0 or 1)	Binary	0	1
4	Mean Diastolic Blood Pressure (mmHg)	Integer	60	124
5	Mean Systolic Blood Pressure (mmHg)	Integer	90	185
6	Glucose Level (mg/dL)	Integer	80	403
7	Class Label (GDM/Non GDM) (0 or 1)	Binary	0	1

The details about the training and testing sets are presented in Table 5. Among various classification models, the random forest model shows good performance on both the training and testing sets. The results indicate its robustness and generalizability.

Table 5: Summary of the Training and Testing Dataset

Training Set			Testing Set		
Total Instances	Non-GDM Labelled Instances	GDM Labelled Instances	Total Instances	Non-GDM Labelled Instances	GDM Labelled Instances

¹ <https://www.kaggle.com/datasets/sumathisanthosh/gestational-diabetes-mellitus-gdm-data-set>

2,980	1,490	1,490	1,058	663	395
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The detailed performance results are depicted in Figure 22. As summarized in Table 5, the model achieves an accuracy of 97.75% on the training set, with precision at 96.72%, specificity at 96.64%, recall at 98.86%, an F1 score of 97.78%, and an AUC of 99.86%. These metrics highlight the model's ability to effectively learn from the training data needed for accurate GDM prediction.

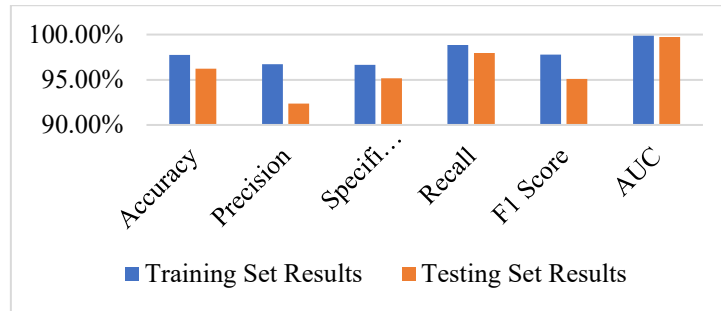


Figure 22: Performance of Model on Training and Testing Dataset

On the testing set, the model has accuracy of 96.22%, precision of 92.36%, specificity of 95.17%, recall of 97.97%, an F1 score of 95.09%, and an AUC of 99.74%. These performance metric results are quite significant especially since the testing set did not have a balanced target class distribution similar to what SMOTE created in the training set. This performance indicates the model's performance is well suited for its application in the real-life situations as described in Table 6. The high AUC implies that the model possesses high confidence in differentiating between the GDM and non-GDM cases.

Table 6: Performance on GDM Model

	Accuracy	Precision	Specificity	Recall	F1 Score	AUC
Training Set Results	97.75%	96.72%	96.64%	98.86%	97.78%	99.86%
Testing Set Results	96.22%	92.36%	95.17%	97.97%	95.09%	99.74%

3.4.2. Preeclampsia

Eclampsia is a major issue in obstetrics that has serious consequences on maternal and fetus health for women and babies. These serious conditions is diagnosed using established criteria like high blood pressure along with visual disturbances [26]. It has been implicated with unfavourable complications comprising of preterm birth, placental separation, and intrauterine fetus death [27]. The potency of these complications is correct and unambiguous and proves the importance of timely diagnosis and treatment preventing their occurrence in the first place.

In the part a rule employed for diagnosing these serious conditions, such as preeclampsia and eclampsia, involves established criteria including high blood pressure readings, accompanied by other

relevant symptoms such as headaches and visual disturbances. Early diagnosis is crucial, as it enables prompt management to mitigate associated risks. The baseline diagnosis is established after 20 weeks of gestation if blood pressure (BP) readings consistently measure 140/90mmHg or above on two separate occasions, indicating hypertension and potential complications warranting medical attention.

3.4.3. Pregnancy Risk Assessment

This model is trained on available dataset at Kaggle² with following attributes and classify maternal health into three distinct classes: low risk, moderate risk, and high risk based on vital signs data acquired from maternal sensing devices. The dataset consists of over 1000 records collected from doctors and health practitioners, encompassing various maternal health parameters was created. The attributes of this dataset used are listed in Table 7.

Table 7: Characteristics Summary of the Pregnancy Risk Dataset

Sr. No.	Feature Name	Data Type
1	Age	Integer
2	Body Temperature	Integer
3	Heart Rate (beats per minute)	Integer
4	Mean Diastolic Blood Pressure (mmHg)	Integer
5	Mean Systolic Blood Pressure (mmHg)	Integer
6	Blood Sugar (mmol/L)	Integer
7	Class Label(low/ Medium/ High Risk)	Categorical

Number of classifiers are applied and among these, random forest algorithm performed well, hence it is used to train on the dataset. Using machine learning algorithms, pregnancy risks can be predicted well in time by analysing factors. This allows for personalized risk assessments and timely interventions. Random Forest exhibited superior performance, achieving an accuracy rate exceeding 90%. Subsequently, the Random Forest model is deployed on fog nodes within the healthcare infrastructure, enabling timely access to predictive capabilities for generating alerts and informed decision-making by healthcare providers

3.4.4 Fetus Health Prediction

Health of the mother and the baby are critically important for well-being of families and communities. Maternal health refers to women's health during pregnancy, baby-birth, and postpartum periods. Congenital Heart Disease (CHD) is a major factor leading to mortality of a fetus and is reported at approximately 0.8-1.2% worldwide [28]. Congenital heart defects can be diagnosed by continuous

² <https://www.kaggle.com/datasets/csafrit2/maternal-health-risk-data>

fetal cardiac observation during pregnancy [29]. Ultrasonography (US) and Cardiotocography (CTG) are Doppler-based imaging techniques to get fetal heart rate statistics. The fetus's safety is at risk upon exposure to a 2 MHz ultrasound wave as well as requiring experienced medical staff to perform tests on the expecting woman [30]. Additionally, these methods entail extensive manual involvement and repeated adjustments of the transducers can cause discomfort for pregnant mothers. An additional disadvantage of these methods is their large design, which renders them inappropriate for use in a hospital setting, and the requirements for skilled handling restrict their uses in remote fetal monitoring.

Diagnosis of stillbirth relies on signs like lack of fetal movement and absence of a heartbeat. Healthcare providers investigate causes and provide support to prevent future occurrences. The rule used for the diagnosis of stillbirth is primarily based on observing signs such as the lack of fetal movement and the absence of a heartbeat. Healthcare providers closely monitor these indicators during prenatal check-ups. A normal baseline heart rate for a fetus typically ranges from 110 to 160 beats per minute. If the baby's heart rate falls below 110 beats per minute for an extended period or remains under 100 beats per minute for more than three minutes, it may indicate fetal distress. In such cases, healthcare providers may investigate potential causes and provide necessary support to prevent adverse outcomes and reduce the risk of stillbirth.

3.5. Data Security

The security of medical data transmission over the internet is a paramount concern. As our reliance on interconnected systems grows, so does the need for robust methods to protect sensitive information from unauthorized access [31]. One effective approach to safeguarding data is through encryption and decryption processes, transforming data into an unreadable format before transmission and then reversing this process at the receiving end to retrieve the original information. Symmetric key encryption and decryption, where a single secret key is used for both processes, stands out as a widely adopted and efficient method. Recognizing the importance of this approach, we have developed our own symmetric key encryption and decryption algorithm, specifically designed for lightweight Internet of Things (IoT) devices [32].

Recognizing the importance of this approach, we have developed our own symmetric key encryption and decryption algorithm, specifically designed for lightweight Internet of Things (IoT) devices.

Our algorithm addresses the constraints of IoT devices, which typically have minimal memory capacity and restricted processing power. It offers robust protection without overburdening these limited resources. Through rigorous testing and comparative analysis, we have demonstrated that our

algorithm exceeds the performance of other state-of-the-art solutions in terms of efficiency and security.



Figure 23: Encryption on Sensing Devices and Decryption on Fog-node

The data encryption process at the source, such as a smartwatch equipped with sensors to measure vital signs like blood oxygen saturation (SpO2), body temperature, and heart rate as shown in Figure 23. As soon as these values are captured, the watch immediately encrypts the data using our symmetric key algorithm. The symmetric key, pre-generated and securely stored within the watch's memory, is crucial for both encryption and subsequent decryption. Once encrypted, the watch transmits this protected information over the internet to our designated edge node, a Raspberry Pi board. Upon receiving the encrypted data, the edge node initiates the decryption process using the same symmetric key, successfully revealing the original vital sign values [33].

The proposed methodology data encryption, key generation, Gen-box generation, and performance evaluation measures that are used for the Research are discussed in this chapter in detail.

3.5.1. Security Framework

The primary goal of this research work is to design an efficient and optimized cryptography algorithm for battery power IoT devices, as shown in Figure 24. The steps followed for the research experimentation are explained below:

1. **Key Generation Process:** A user-input-based strategy is present for the key generation method for IoT devices. Initially we take two arguments from user and then make sub key using random byte selection. Then we generate SHA256 to generate hash of these keys. These hashes are 32 bytes but we need 16 bytes. So, we perform compression to get 16-byte output. In compression we use mod to select 16-byte form original hash. At the end we perform XOR on all hashes to generate single key for symmetric cryptography. This key we will used in data encryption and decryption.

2. **Data Encryption Process:** Various processes are involved in the suggested approach for optimizing encryption in battery-powered IoT devices. We perform basic function and steps to generate strong and complex cipher. Initially function take the input from sensor that check it length if they length of data is equal to define threshold otherwise, we add random padding on them using character, number, and special symbol. After padding we scramble this data with our define table and convert this data into Uni2Hex matrix. Gen-box we apply this matrix to add avalanche effect on this matrix. This Gen-box we generate using Particle swarm optimization algorithm of artificial intelligence. At the end we apply secret key on this data and wrap this data on Unicode. This process is highly efficient and optimize for battery powered and resource constrained IoT device.
3. **Gen-Box:** In third step design the cryptography Gen-box using genetic algorithm because genetic algorithm iteratively generates and select the best candidate for Gen-box using fitness evaluation. For fitness evaluation we use cryptography standard parameter like avalanche effect, non-linear attack and linearity effect. At the end we generate highly efficient and secure Gen-box for data encryption in resource constrained IoT device.

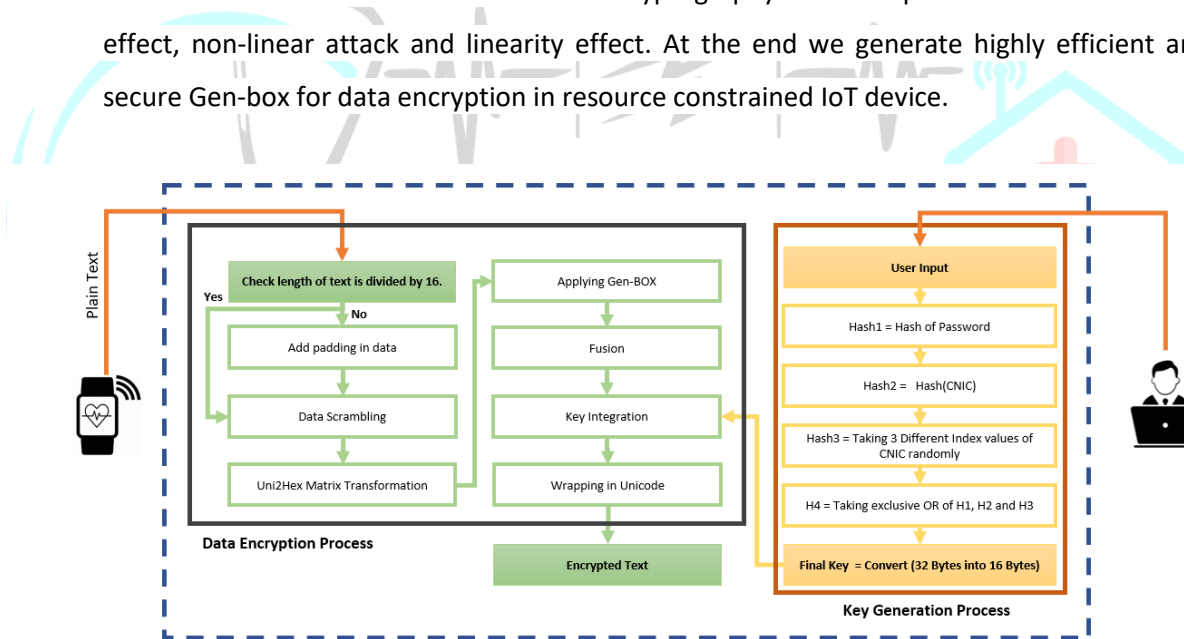


Figure 24: Framework of Methodology

3.5.2 Avalanche Effect and Complexity Level Analysis

In proposed algorithm we also check complexity and avalanche effect. This process will show how many are change if we change one bit and even if we pass same input each then what will be happened. In proposed solution we achieve maximum avalanche effect when we change one bit whole

cipher is changed even we compare same input many times and compare the similarity score as shown in Table 8.

Table 8: Comparison of the Similarity in Cipher Input Value of "109"

Output	Input 1	Input 2	Input 3
å^«r õú&->¿ã Ã	—		
f'«Ô3 ↕#&øÉ>û°Ã	9.09%	—	
1z«4ä~xz&ÄÄ>◀[ÿÃ	17.78%	12.77%	—
☺"«w" dÃ&eÓ>ÛÃ	9.76%	13.95%	9.09%

3.5.3 Cryptanalysis

In proposed symmetric cryptography our mainly focus to provide data integrity and confidentiality using share common key for data encryption and decryption. Symmetric cryptography normally considers secure but still there has some vulnerability some attack. In proposed technique we overcome some attacks like brute force, known plain text, chosen plain text, differential attacks and liner attacks. In brute force attacker try all possible key untill valid key is found. Attacker more feasible if length of key is small and they enough resource for breaking the key. So this kind of attack we need strong encryption process and large key in our proposed algorithm has strong encryption mechanism and large key our key is size 128 bit accroding to standard of symmetric cryptography technique. Same in case of known plaintext scenario if hacker known plaintext then they can deduce encryption key and encryption pattern process. In that scerio if we stonge encryption resis known plaintext attack by ensuring the that knowldge of plain text does provide the knowldge to determine the secert key.

4. Demonstrations and Workshops

The maternal and fetus remote monitoring system was demonstrated in various Rural Health Centers (RHC) of Khutri-Bangla and Khanqah Sharif, Figure 25 shows few of the glimpses. The sessions were arranged to train doctors and paramedical staff on how to effectively utilize these technologies and use the monitoring equipment, interpret the data, and respond to alerts effectively. The interactive sessions included hands-on practice, ensuring that the staff felt confident in using the systems independently. The feedback from the health professionals was positive, highlighting the system's potential to significantly impact rural healthcare delivery. This initiative represents a significant step

forward and ultimately aims to reduce maternal and fetus mortality rates and improve overall health outcomes.



Figure 25: Few Shots of demonstration and Workshop Sessions

5. Deployment of the Pilot in Rural Areas

The deployment of the pilot phase for the maternal and fetus remote monitoring systems was successfully completed at a gynecologist's clinic in Bahawalpur. Comprehensive training for the clinical staff was included in the deployment process to ensure proficiency in using the equipment and interpreting the data. Initially, took five volunteer subjects for training session as shown in Figure 26.



Figure 26: Few Shots while using Fetus Movement Remote Monitoring Belt

However, the deployment process initially faced some challenges such as least cooperation of the paramedical staff, and acceptance of technology by the clinic administration and patient. However, all the challenges were smoothly addressed by the SAFE-RH deployment team in couple of awareness meetings. In which doctors and paramedical staff were informed about how the system is easy to use, 2) only basic level training is solicited and 3) significance of this system to reduce the mortality rate. The paramedical staff was ensured for not putting extra load in their work routine. Consequently,

they all agreed to cooperate and accept to implement the maternal and fetus health monitoring system.

6. Conclusions

The successful completion of the pilot has made numerous positive achievements, aligning with the rationale and objectives set out at the beginning of the document.

The implementation of maternal and fetus remote sensing systems using medical sensors has notably improved the early detection of pregnancy-related complications. The development of a Basic Health Unit (BHU) scenario for monitoring maternal health in remote rural areas has proven to be a vital advancement. Women visiting these facilities can now have their vitals recorded and participate in remote consultations with gynecologists. This has addressed the critical gap in medical services availability in rural areas, thereby reducing maternal and infant mortality rates due to the lack of timely medical advice and assistance.

Moreover, the custom-built mobile application that mirrors the Management Information System (MIS) has empowered mothers by providing them with essential health indicators and statistics. This accessibility to health data promotes proactive health management and informed decision-making during pregnancy. The user-friendly mobile application has also facilitated swift communication among all stakeholders, including patients, doctors, paramedical staff, and caretakers.

In conclusion, the Maternal and Fetus Health Monitoring pilot presents a robust, innovative approach to improving maternal and fetal health outcomes. By leveraging cutting-edge technology, comprehensive security measures, and practical implementation strategies, this project lays the groundwork for a future where advanced health monitoring is accessible to all, ensuring healthier pregnancies and safer deliveries. In this regard, four research articles have been published in reputable journals that support the project's outcomes. The project's positive achievements in early complication detection, enhanced patient engagement, and a scalable framework validate its effectiveness and set a precedent for integrating advanced health monitoring systems into broader healthcare infrastructures, ultimately contributing to the overall well-being of mothers and their fetus.

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Few Infant related references can be included

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