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A novel fog-computing-assisted architecture of E-healthcare system for pregnant women

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Abstract

Recently, there is a tremendous rise and adoption of smart wearable devices in smart healthcare applications. Moreover, the advancement in sensors and communication technology empowers to detect and analyse physiological data of an individual from the wearable device. At present, the smart wearable device based on internet of things is assisting the pregnancy woman to continuously monitor their health status for avoiding the severity. The physiological data analysis of wearable device is processed with the assistance of fog computing due to limited computational and energy capability in the wearable device. Additionally, fog computing overcomes the excess latency that is created by cloud computing during physiological data analysis. In this article, a smart health monitoring IoT and fog-assisted framework are proposed for obtaining and processing the temperature, blood pressure, ECG, and pulse oximeter parameters of the pregnant woman. Based on real time series data, the rule-based algorithm logged in the wearable device with fog computing to analyse the critical health conditions of pregnant women. The proposed wearable device is validated and tested on 80 pregnant women in real time, and wearable device is delivering the 98.75% accuracy in providing health recommendations.

Keywords Cognitive decision-making · Healthcare system · Intelligent health monitoring · IoT-based smart healthcare system · Pregnancy healthcare · Real-time pregnancy healthcare · Smart healthcare system

Abbreviations

IoT	Internet of things
E-Healthcare	Electronic healthcare
ECG	Electrocardiogram
FAAL	Fog ambient assisted living

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Extended author information available on the last page of the article

BAN	Body area network
PSoV	Probabilistic state of vulnerability
EMG	Electromyography
RF	Radio frequency
SSL	Secure socket layer
DoV	Degree of vulnerability
BBN	Bayesian belief network
ID	Identification
ANN	Artificial neural network
WiFi	Wireless fidelity
GSM	Global system for mobile communications
PPM	Parts per million
MAE	Mean absolute error
RMSE	Root-mean-squared error
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
FTDI	Future technology devices international
MCU	Microcontroller unit
PCB	Printed circuit board
MQTT	MQ telemetry transport

1 Introduction

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. In fact, Lewis [1] states that out of 600,000 women, haemorrhage is a leading cause of death of 38.09% of women, 23.80% died due to the indirect cause, the death reason of 19.04% of women are undetermined, 9.52% died due to sepsis, and 9.52% died due to preeclamptic shock. So, this reveals there is an urgent need for a system to detect changes that occur in the woman's body so that various risks associated with these changes can be stopped or their effects can be reduced to save a life. Smart devices could improve pregnancy outcomes with the least available resources [2].

E-Healthcare (electronic Healthcare) system becomes more popular in both academia and industry [3]. E-Healthcare system connects the patients and the doctors in a real-time environment by using the facility of the Internet and proves advantageous for patients even in the case of emergency [4, 5]. These smart devices track health conditions and offer real-time healthcare solutions to patients. The existing studies have mainly focussed towards the implementation of real-time health conditions including heart, lungs and maternal issues [6].

There are several researchers [7–9] that works in the designing of smart healthcare system for pregnant women to identify the risk factors during pregnancy [10]. As per the previous studies, we found the research gap that none of the system work in remotely capturing maternal data and offers health recommendations. Based on the existing studies, following gaps are identified:

- The current pregnancy healthcare system is based on the manual recording of health parameters which may leads to error while data entry that does not provide accurate predictions in most of the cases.
- Also, the present systems are not able to capture real-time healthcare data remotely without doctors or healthcare professional's intervention.
- Moreover, existing systems do not implement fog computing aspects which are not capable to recommend any suggestion to the pregnant women in the absence of network connectivity. Implementation of fog computing allows the processing of data near to the sensing devices, which helps to take immediate decisions in real-time environment. Moreover, the implementation of fog computing reduces the latency issues that were there with the cloud computing, like processing done only at the cloud end, and in the absence of network connectivity or network slows down, it was not possible to transfer data to cloud servers, and it was not feasible to take necessary decisions on time.
- The facial authentication is not implemented in the present systems rather than passwords are implemented in few which offer the low level of security; also, there is bombardment of the data as the cloud server of the non-pregnant women.

As per the research gaps found in the previous study, the proposed study is based on subsidiary objectives which mainly include:

- Proposed a model for designing and developing a customized sensing with fog node based on nRF technology to capture and process healthcare data of pregnant woman.
- To evaluate the health parameters by rule-based algorithm to analyse the critical health conditions.
- To provide the recommendations to the patient as per the results obtained after evaluation.
- To create a real-time experimental setup, where we receive the sensor data from the customized node and transfer to the doctors using cloud server.

The presented study is organized into different sections. Section 2 discusses the contribution of several researches in healthcare system. Section 3 covers the description related to the layered architecture of the proposed system. Section 4 discusses about the implementation details of the proposed system along with the result obtained. Section 5 finally expressed the conclusion of the study.

2 Review of related work

The current section overviews the contribution of various researchers in the field of IoT and how these systems help to design efficient healthcare systems. It allows the patient to be monitored remotely and offer medicinal services in a real-time environment [11, 12]. Tekeste et al. [13, 14] discussed the several applications of IoT in the healthcare industry. The authors discussed mainly ECG, glucose, and oxygen concentration sensors which are involved in IoT-based E-healthcare systems. Moreover, the authors also discussed several challenges including security, energy consumption, communication network, and data storage in continuous monitoring of IoT-based healthcare systems. Tuli et al. [15, 16] designed home-based IoT-based healthcare system. In this work, the authors implemented an ensemble-based deep learning approach in edge devices to automate the process of heart disease monitoring. The system delivers the health data of the heart patient on demand.

Beri et al. [17] presented a work related to the IoT-based healthcare system used to analyse and capture health parameters of the pregnant woman. The authors discussed the various studies in the current field and the different issues that occur to the woman during pregnancy. Moreover, the authors also state that a careless attitude towards pregnancy leads to maternal mortality or infant death. Mutlag et al. [18, 19] discussed the usage of fog computing in healthcare systems. The authors discussed that the utilization of fog computing in the healthcare industry improves the efficiency of the system which reduces latency and response time. Vora et al. [20, 21] described that utilization of fog computing in healthcare systems improves the performance by the faster response and reduces needs latency. The authors proposed a fog ambient assisted living (FAAL) framework, which is the combination of body area network (BAN) with fog computing to improve efficiency. Table 1 compares the proposed system features with the existing system and differentiates how the proposed system is better as compared to the existing systems.

3 Proposed system

This section presents the E-healthcare system architecture that is proposed for the monitoring health status and generating the alerts of the pregnant woman with fog computing. The proposed architecture is shown in Fig. 1. In this, we have designed and developed a customized system for monitoring the health status of pregnant women to ensure maternal good health. The proposed system monitors the mother's health continuously and alerts her to take necessary precautions at every step. This system also provides the health information of the mother to her family and doctors through wireless communication and cloud server. The proposed system provides reminder about the different activities that needs to be done by pregnant women to ensure better health conditions. The system also

Table 1 Comparative analysis of the existing studies with the proposed study

Studies	Temperature	Blood pressure	Heartbeat	Pedometer	ECG	Air quality	Humidity	Gyroscope and accelerometer
Gubi et al. [11]	✓	×	✓	×	✓	×	×	✓
Wang et al. [22]	✓	×	✓	×	×	✓	×	×
Sadek et al. [23],	×	×	×	×	×	×	×	×
Liu et al. [24],	×	×	×	×	✓	×	×	×
Dali and Baral [25]	×	×	×	×		×	×	×
Sakr and El- Gammal [26]	×	×	×	×	✓	×	×	×
Marin et al. [27]	×	×	✓	×	✓	×	×	×
Moreira et al. [28]	×	×	✓	×	×	×	×	×
Quasim et al. [29]	×	×		×	×	×	×	×
Mugoye et al. [30]	×	✓	✓	×	✓	×	×	×
Proposed system	✓	✓	✓		✓	✓	✓	✓

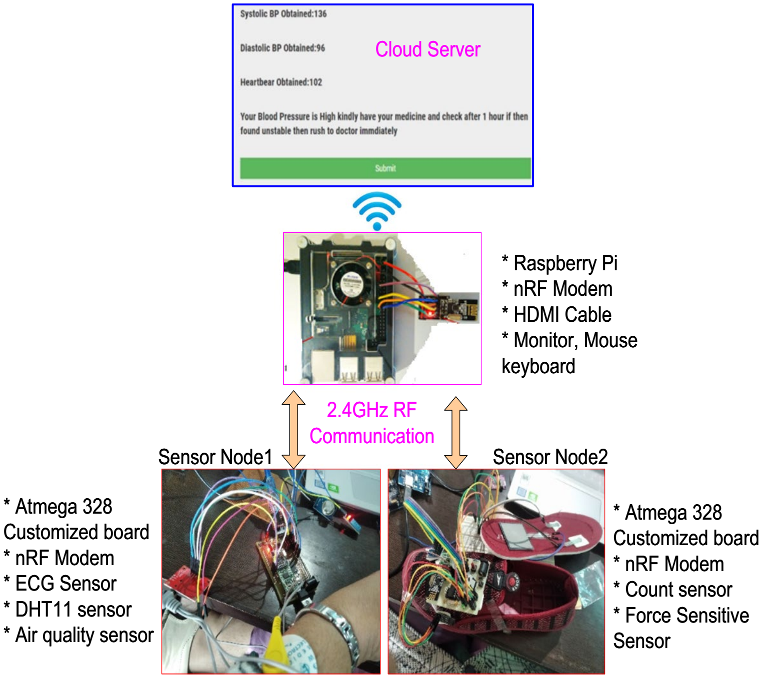


Fig. 1 Layered architecture of the proposed model

assists the doctor to obtain a more analytical view of the health of the patient by her regular activities. Every layer in the system has its predefined tasks and offers services to the other layer. The sensing layer captures data related to health parameters in a real-time environment. Then, the captured data are sent to fog nodes for further pre-processing; the communication between the sensing layer and for a node is performed using the nRF module; the fog node takes the average of collected data after every interval of 5 min, and then if it found the health parameter values more or less than the threshold, then it immediately sends the data to cloud servers and generates alert messages; at the cloud server, the classification algorithm is applied for further data analysis and feature extraction process. For result mining and accuracy prediction, PSoV (probabilistic state of vulnerability) is used to train the model.

3.1 Sensing layer

This layer includes embedded with sensors like temperature, blood pressure, ECG, pulse oximeter placed on customized board to capture the health parameters of the pregnant woman in a real-time environment. The sensing node shown in Fig. 2a integrating ATmega 2560 microcontroller as a processing element, while the sensing node in Fig. 2b using ATmega 328P. These sensing nodes are responsible to capture different health parameters using sensors such

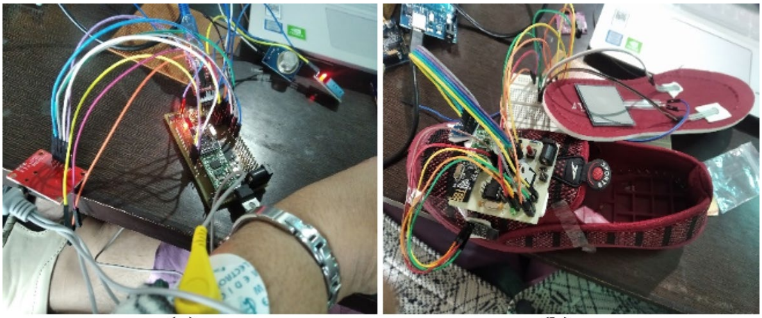

(a) (b)

Fig. 2 **a** Customized sensing node for wrist **b** Customized sensing node for feet

as temperature sensor, blood pressure sensor, heartbeat, pedometer, ECG, Air quality, and humidity as well gyroscope and accelerometer are attached to the microcontroller.

The major goal of this layer is to capture real-time health data of the pregnant woman for 9 months. The customized board captures the health data continuously and creates an RF communication channel to the fog node. The microcontroller obtains the data from every sensor in a purely synchronized way and assigns a timestamp to every sensor for data collection. The captured data are then sent to the fog node in a secured way by encrypting captured data using quantum hash functions. Moreover, the data authenticity is performed at the fog layer where the user is authenticated by the iris and face recognition system.

The different components used in both sensing node is elaborated as follows.

3.1.1 Customized sensing node of wrist

The customized sensing node of the wrist comprises of ATmega 250 microcontroller, nRF module, blood pressure sensor, ECG sensor (AD8232), pulse oximetry sensor (Max30100), atmospheric temperature sensor (DHT11), and atmospheric pollution sensor (MQ135). The sensors empower the customizing sensing node of wrist to monitor the temperature, blood pressure, pulse rate, and arterial blood oxygenation.

Moreover, the temperature, humidity, and air quality of the environment are also monitored with the customized sensor node of wrist. The ATmega 2560 microcontroller is integrated in the customized node for generating signals and obtaining data generated by the sensors. nRf module enables to communicate the sensor data over the wireless communication. Moreover, the customized sensor node is powered with external power supply through the power jack. The appropriate voltage to the sensors and other components is achieved with different voltage converter integrated on the node. Table 2 presents the description and features of the various components that are embedded in customized sensing node. The final customized sensor node of wrist after integrating all the components on the board is shown in Fig. 2a.

Table 2 Customized sensing node of wrist

Sensor	Operating voltage	Data capacity	Response time	Number of pins	Speed	Include memory	Cost
ATmega 2560	4.5–5.5 V	8bits	–	100	0–16 MHz	Yes	9.47$
Blood pressure sensor	5 V	8bits	3 min	3	9600 Baud Rate	Yes	41.19$
ECG sensor (AD8232)	3.3 V	Analog Signals	–	6	2.5 Hz	No	19.95$
Pulse oximetry sensor (Max30100)	1.8–5.5 V	14bits	–	7	100 kHz	No	2.73$
Atmospheric temperature sensor (DHT11)	3.3–5 V	8bits	15 s	4	0.5 Hz	No	2.71$
Atmospheric pollution sensor (MQ135)	2.5–5 V	12bits	–	4	50 Hz	No	5.89$
nRf module	1.9–3.6 V	1 or 2 Mbps	–	20	2.4 GHz	Yes	2.62$

3.1.2 Customized sensing node of shoe

The customized sensing node of the shoes comprises of ATmega 328P microcontroller, accelerometer, and nRF module. Accelerometer sensor is employed for measuring amount of pressure falling on foot. The nRF module enables to communicate the sensor data over the wireless communication. Moreover, the customized sensor node is powered with external power supply through the power jack. The appropriate voltage to the sensors and other components is achieved with different voltage converter integrated on the node. Table 3 presents the description and features of the various components that are embedded in customized sensing node of shoe. The final customized sensor node of shoes after integrating all the components on the board is shown in Fig. 2b.

3.2 Fog layer

At the fog layer, initially, the authentication of the user is performed with iris and face of individual through recognition authentication server. This server is installed at the fog server which calls the stored information about the woman, from cloud storage, and then applies the logic to compare the credentials before the start of any pre-processing data. The fog node is created with Raspberry Pi. Cloud server sends the user credentials in encrypted form, which the fog server first decrypts, and then compares the provided credentials with the stored ones. If the credentials found matched, it further starts its task of pre-processing of data, but if it is found to be unauthenticated, then it triggers an error message and immediately discards the collected data. The pre-processing task of this layer involves the feature extraction from the collected dataset. It categorizes the collected data into two branches, viz. normal or critical. These two branches will be divided on the basis of existing threshold values as shown in Table 4. Every sensor data is considered according to these branches. This function of branch decides the required task to be performed by the fog node, and it is as follows: If the parameter values are found to be normal, then the fog servers directly send data to the cloud server wirelessly using SSL protocol for further health analysis. Also, some recommendations are issued to the patient like the quantity of glass of water or medicine and so forth to better health conditions; if the health parameters are found under the critical situation, then an immediate alert message generates to the doctor's end and the women's

Table 3 Customized sensing node (b) components

Sensor	Operating voltage	Data capacity	Response time	Number of pins	Speed	Include memory	Cost
ATmega 328	1.8–5.5 V	8bits	–	32	20 Hz	Yes	3.63$
Accelerometer (ADXL345)	2.5 V	13bits	–	8	3200 Hz	No	15.15$
nRf module	1.9–3.6 V	1 or 2 Mbps	–	20	2.4 GHz	Yes	2.62$

Table 4 Categorization of health conditions according to threshold values

Parameter	Threshold normal condition		Threshold critical condition	Issue/disease associated with critical condition	Threshold severe condition	Threshold severe condition
Systolic blood pressure	140–159 mm Hg	Mild hypertension	160 mm Hg	High blood pressure	180 mm Hg	Preeclampsia
Diastolic blood pressure	90–109 mm Hg		110 mm Hg		110 mm Hg	
Pulse rate	60–100 PPM	Normal health condition	121–141PPM	High heart rate	142–162PPM	Serious cardiac issue
Air quality index	0–100	Satisfactory air pollution	100–300	Poor Air quality may cause pneumonia or asthma issue to infant and woman	301–500	Severe air quality may cause lung disease to infant or pregnant lady

recommendation app. This helps a woman to get immediate medical health in the case of severe health conditions.

3.2.1 Data categorization

This layer is responsible to categorize data into different classes which are based on the probability technique, i.e. degree of vulnerability (DoV). The DoV is calculated for a particular parameter p_i which is unfavourable to the health conditions of mother. It allows finding a probabilistic estimation of the harmful effect of specific parameters on health. This estimation allows health professionals to set threshold values of health parameters for a woman in various stages of pregnancy. This study also estimated the DoV by applying Bayesian belief network (BBN) model. This technique was found to be useful for classifying parameters based on predefined threshold values. DoV and BBN allow determining the classes of the collected dataset inefficient manner. Moreover, the system takes the average value of the health parameters after 5 min; so, DoV is calculated by the fog node after the interval of p_τ.

3.2.2 Mathematical modelling

The current section discussed the mathematical modelling of the BBN network to predict health categories. Let $P\left({}^{p_n}/_{c}\right)$ and $P\left({}^{p_c}/_{c}\right)$ represent the "Normal" and "Critical" probability of health conditions under the attributes $c > \theta$(predefined threshold) at the given period T and W considered as the weight associate for predefined attribute c. The BBN model based on weighted probability $P_w\left(c > {}^{\theta}/_{p_n}\right)$ is given as follows:

$$P_w\left({}^{c}/_{p_n}\right) = w(c) \times P\left({}^{c}/_{p_n}\right)$$

Accordingly, $P(p_n/c)$ can be inferred from the following formula:

$$P_w\left({}^{p_n}/_{c}\right) = P_w\left({}^{c}/_{p_n}\right) \times P\left(p_n\right)P(c)$$

More specifically,

$$P_w\left({}^{p_n}/_{c}\right) = w(c) \times P\left({}^{c}/_{p_n}\right) \times P\left(p_n\right)P(c)$$

where

$$P(c) = P_w\left({}^{c}/_{p_n}\right) \times P\left(p_n\right) + P\left({}^{c}/_{p_c}\right) \times P\left(p_c\right)$$

More Specifically,

$$P(c) = w(c) \times P\left({}^{c}/_{p_n}\right) \times P\left(p_n\right) + P\left({}^{c}/_{p_c}\right) \times P\left(p_c\right)$$

As per the above calculations, DoV can be calculated as:

$$DoV = \frac{1}{k}\sum_{c} P_w\left({}^{p_n}\!/_{c}\right)$$

The health condition is taken as critical when DoV is calculated more than the predefined threshold value. Every attribute is to be converted into two categories as mentioned previously. Based on the calculated DoV, the parameter values will be segregated as shown in Fig. 3.

Based on the capture parameters certain, it is valid to say that certain parameters are interlinked and may affect the normality of other related health parameters. As per these parameters, BBN further segregates parameters for deciding on the further

Normal	Body Temperature	Systolic Blood Pressure	Diastolic Blood Pressure	Heartbeat (BPM)	Pedometer	ECG	Air Quality (PPM)	Humidity (%)	Gyroscope & Accelerometer
D1	Low: 97.5	Low: 70	Normal: 70	Normal: 60	400	Graph	290	30	Normal
D2	Normal: 98.4	Normal: 80	Normal: 80	Normal: 85	250	Graph	269	39	Normal
D3	Normal: 98.5	Normal: 85	High: 85	Normal: 85	300	Graph	287	32	Normal
D4	Normal: 98.7	Normal: 96	Normal: 75	Normal: 75	450	Graph	300	33	Normal
D5	High: 99.2	Normal: 115	Normal: 65	Normal: 65	250	Graph	450	45	Normal
D6	High: 100.2	Normal: 120	Normal: 70	Normal: 70	200	Graph	400	32	Normal
D7	High: 101.3	High: 135	High: 90	High: 120	90	Graph	237	54	Normal
D8	High: 100	High: 129	Normal: 80	Normal: 80	149	Graph	325	43	Normal
D9	High: 99.5	Normal: 120	Normal: 73	Normal: 73	133	Graph	261	47	Normal
D10	Normal: 98.3	Normal: 113	Normal: 79	Normal: 69	200	Graph	278	31	Normal

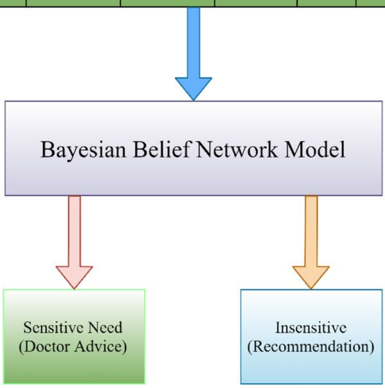


Fig. 3 Segregation of health-related parameters based on DoV

action to be performed. If some abnormalities are found in the dataset, BBN creates classes for prediction, which allows the system to generate an alert message to the doctor and patient's family; otherwise, some recommendations can be offered to the pregnant woman. PSoV further determines the probability of affecting health parameters due to some other health parameter or some environmental conditions. This prediction helps to offer immediate health services at women's doorstep. As in the above case, it may be predicted that a woman may get fever or abnormalities in heart rate or blood pressure level due to the bad PPM concentration. After predictive analysis, the data sent to the cloud server by using the secured method of quantum walks. The present study applies the quantum hash function to encrypt the health parameter so that it can be securely sent to the cloud server.

3.3 Cloud layer and end user layer

The cloud layer includes the cloud server which is responsible to send health messages to the user (doctor, patient's attendants). This layer allows the data to be available for use 24×7. To access the data, one needs to authenticate himself by their provided ID, password, and face recognition. If the user is found to be authenticated, the cloud server shows the data to the user in decrypted form. The user can log in to the system via any smart device such as tablets, smartphones, and laptops. This layer is implemented using a customized application which is designed using open-source Django framework. In this application, rule-based algorithm is applied to compare the collected health parameters with the thresholds and detect the emergencies or offer recommendations as per the data analysis. This application includes four panels including admin, patient, hospital, and doctors. The admin panel in the customized application is responsible to manage the various information and features used in the application; by using patient panel, pregnant woman is getting the healthcare data and also can directly contact with doctor for any kind of opinion; in hospital panel, there is provision to manage all records or patients related to the doctors; the doctor panel allows the communication between doctor and patient. Moreover, by using this panel, the doctor can get the detail and summarized view of the patient's health records by only single click.

4 Real-time implementation

In this section, we present the implementation of the proposed methodology in the real-time scenario. The proposed E-Healthcare system performs the required function in different steps as shown in Fig. 4. The proposed E-healthcare system starts automatically when it gets a touch onto the touch sensor.

The system starts capturing data and then sends the captured data to the fog node via Bluetooth. At the fog node, the pre-processing of data is done, and after the interval of every 5 min, the data is sent to the cloud storage from where any smart device can access data from a remote location. The current system works in several phases in which initially the data is acquired from several sensors worn by the

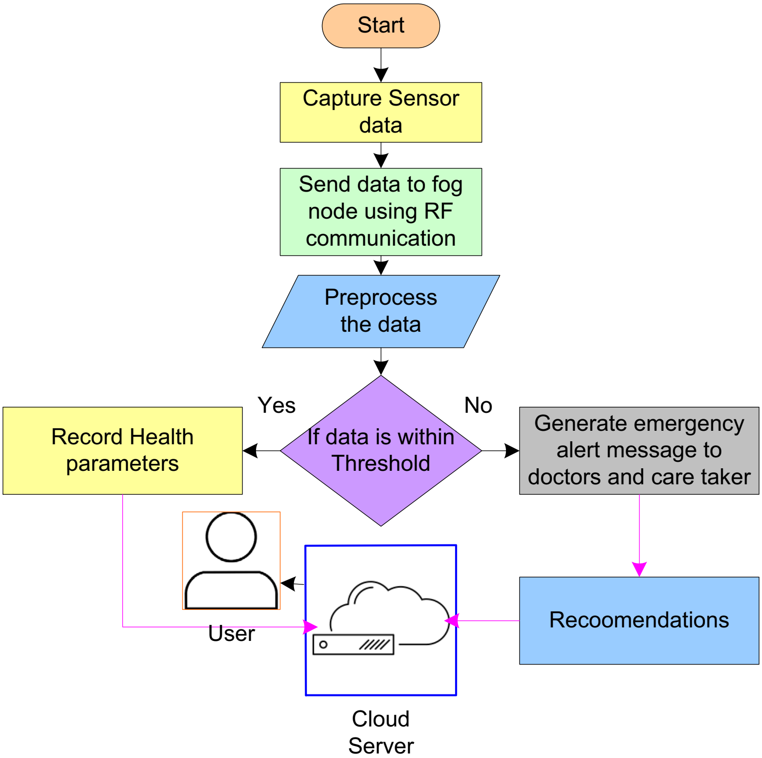


Fig. 4 System flow diagram

woman during her pregnancy for regular check-ups. In the further phase, the data is classified by BBN network, and the prediction analysis is performed using the ANN PSoV technique. Then in the next phase, the required action is performed according to the predicted results. The healthcare data is captured from pregnant women via an E-Healthcare kit using different sensors, i.e. temperature sensors, pulse oximeter sensors, blood pressure, heartbeat, air quality, and humidity. To capture temperature data, LM35 is used in the proposed system. LM35 is a three-pin sensor that takes the input of 5 V and provides the analog output of the sensor.

To detect the pulse rate of pregnant women, the system uses a pulse oximeter sensor. The woman needs to place her finger on the pulse oximeter sensor and the sensor then captures the pulse at a regular time interval. Moreover, women need to wear blood pressure cuff to obtain blood pressure and heartbeat. To detect air quality and humidity, MQ5 sensor is used. These sensors are connected via ATmega 2560 as a processing element. This device is used as it is a portable and handy microcontroller device with good processing capability. The system is then connected with the fog node via the nRF module.

Pedometer, gyroscope, and accelerometer embedded to the shoe to capture several steps and time duration of sitting in a stable position. At this place, ATmega 328 is used as a microcontroller to collect data. The fog node is designed using ATmega 328 and Raspberry Pi which receives data from the sensor and gateway layer via nRF. This fog node is created to process data and is responsible to transfer data to a cloud server so that it can be accessed from any device. The fog node sends data to the cloud server using the Wi-Fi module of Raspberry Pi with the Wi-Fi router connected at home. The cloud server used in this case is Thingspeak. Thingspeak is the cloud storage offered by MATLAB which provides data the results in the form graph, or it may allow the user to download the collected data in the form of an excel sheet.

The doctor may provide suggestions to the patient via the customized app. The customized app is web-based application and is created using Django framework with MySQL as the database to store the information related to different persons associated with the system. The customized app includes different panels like, admin, user, hospital, doctor, and attendee's panel. There is separate login panel created for all types of users associated with the system for maintenance of the security and authenticity of the user.

Admin panel is the core component of the application by which we can create or manage the roles that can be offered to the several individuals associated with the system. The admin is having the rights to maintain overall information regarding the system. The admin panel have rights to create hospitals, users of the system, and provide different views to manage or handle huge users at the same time. Hospital panel is the second panel which is created by the admin. The admin provides the rights to the hospital for performing different tasks. Any outside hospital can put request to the admin to avail proposed device. The hospital can be registered successfully only on the approval of the admin. Once the hospital gets registered with the web application, it can easily add doctors that can be further contacted by the patients directly.

Doctor panel is responsible to get whole profile related to the patient by just one click. By using this customized application, the doctor does not require to ask some hereditary issues or vital health parameters of the pregnant woman as the system collects the information in advance from patient before reaching to doctor. Moreover, the system also provides the facility to doctor to register his/her patients directly if the patient does not approach the doctor through the proposed system. User panel is the backbone of the proposed system where all the health information regarding patient is stored. When user get connected with customized sensing nodes, then also the health-related data is directly stored in the database, and by using this panel, the user can get the health-related recommendations and the condition of the health parameters in an effective way. Moreover, this panel allows user to view the historical data about her health in the case of different pregnancies. By using attendee panel, the patient's attendees can get the health information regarding patient easily from any location. This helps the attendees to know about the condition of the patient.

Besides the customized application, the proposed system helps the patient in other way also. The GSM module is installed and attached to Raspberry Pi to send the health information to the family members of the woman via text messages. Moreover, this module is used to send information to the nearby hospital in the case of any emergency. The doctors from the acquired data can be able to analyse the pulse rate pattern and temperature of the pregnant woman's body. This data is permanently on the cloud server, and the doctor will provide suggestions to the woman via a customized app installed on phone, according to the data obtained.

4.1 Security implementation

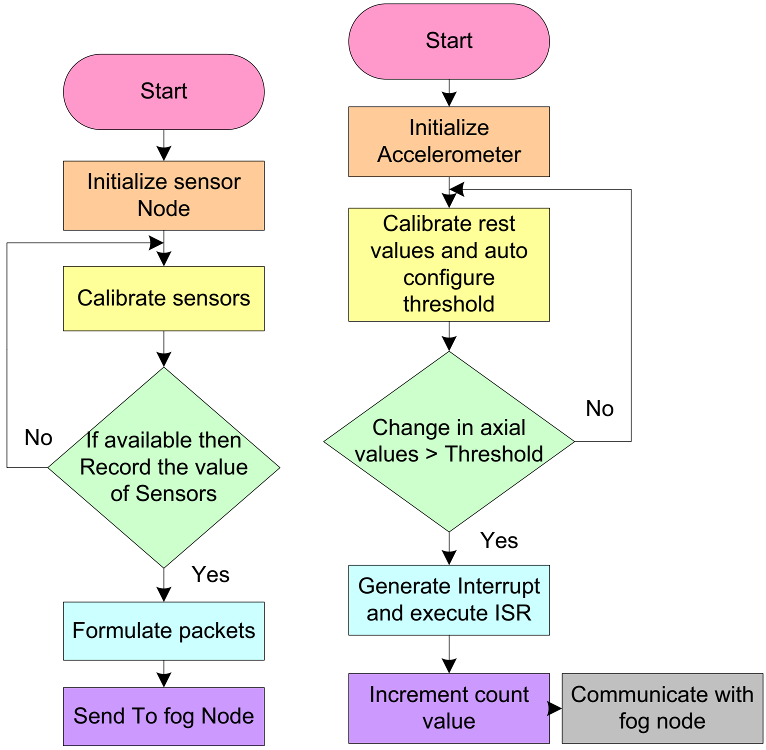
The secured data transmission is the major concern of the proposed system. The data transferred between the sensing nodes is implemented using nRF short range communication. Moreover, MQTT broker server is used at fog server for the face recognition system. It offers a uni-modal biometric mechanism by using multi-biometric methodologies of the iris recognition system. The study works in three phases which include feature extraction by finding fusion between DM and MAM in parallel, feature reduction method for reducing the vector size, and classification technique for finding classifier by ED. This process allows the data authenticity by which only the pregnant woman registered with the system can check health parameter. Furthermore, the passwords are used for data authentication at different levels. Every user needs to prove his authenticity before getting information from the system.

4.2 Algorithms of the proposed system

The proposed algorithm for customized sensing node of wrist, customized sensing node of shoes and fog node is shown algorithms 1, 2 and 3 along with their flowchart representation in Fig. 5.

Algorithm 1:
//This algorithm finds some health parameters SBP, DBP and ECG level of the pregnant woman and also calculates the air quality of the environment around her.

```
Step1    Start
Step2    Initialize BP serial
Step3    If bpserial.available0
             i.   Read SBP, DBP
             ii.  Read Heartbeat
Step4    if(ecg_serial.available())
             i.   Read analog values from sensors.
Step5    if(DHT_serial.available())
             i.   Read temperature and Humidity
Step6    if(Air_Quality.available())
             i.   Read PPM level
Step7    Exit
```



(a) Wrist **(b) Shoe**

Fig. 5 Flowchart of customized sensor node of wrist and shoe

Algorithm 2:

The algorithm captures the direction, takes pressure signals from sensors, and finds the step count. Here variable k implies $0 \leq k \leq n$.

Step1 Start

Step2 Input raw values of the accelerometer.

Step3 x-val:= $\sum_k^n$ x − axis movement

Step4 xavg:=x-val/n;

Step5 y-val:= $\sum_k^n$ y − axis movement

Step6 yavg:=y-val/n

Step7 z-val:= $\sum_k^n$ z − axis movement

Step8 z-avg:=z-val/n

Step9 total_vect$_i$:=

$$\sqrt{(x_{acceleration} - xavg)^2 + (y_{acceleration} - yavg)^2 + (z_{acceleration} - zavg)^2}$$

Step10 total_ave$_i$:= (totvect$_i$+totvect$_{i-1}$)/2

Step11 if totalave$_i$>θ

a. if fsr$_1 \leq$ 100& fsr$_2 \leq$100 & fsr$_3 \leq$100

i. steps++

Step12 Exit

Algorithm 3:

//This algorithm inputs the data from customized node(a) and customized node(n) and process the data.

Step1 Start and calculate DoV
Step2 while true
  a. BP:=Health parameter from customized node(a)
  b. for x,y in parameters:
    i. if x==','|| x== '\n' || x== '\r' || y== ',' || y== '\n' || y== '\r' then
      - continue
    ii. else
      - sbp←x
      - dbpi←y
  c. if sbpi<80 then
    i. Category←"Low BP"
  d. elseif 80≤sbpi≤120
    i. category←"Normal"
  e. else
    i. Category←"High BP"
  f. Category → *Recommendation*
Step3 Decode ECG Signals
Step4 Apply filtration process
Step5 Set screen resolution
Step6 Apply ensemble based machine learning approach to predict label for the obtained results.
Step7 Plot the results
Step8 Detect room atmospheric temperature and pollution level
Step9 Temperature & Humidity → Recommendations
Step10 Detect PPM level
Step11 If PPM≤500 then
Step12 Recommendation→ *Fresh Air*
Step13 elseif 500<PPM≤1000
Step14 Recommendation → *Poor Quality*
Step15 else PPM>1000
Step16 Recommendation ≔ *Very Poor Air Quality*
Step17 Set PSoV:= 0.
Step18 Compare calculate DoV with predefined threshold
Step19 If DoV is "Normal" then:
    Encrypt data using Hash function
  Else:
    Generate recommendation and alert messages to doctor's and patient's panel
Step20 Send completed data to cloud with secure transmission in encrypted format.
Step21 Exit

5 Results and discussion

The algorithms discussed in Table 5 provide the way to run customized nodes to capture healthcare data. This section discusses the results obtained by the proposed system. Every sensor starts working only getting in contact with the woman. If someone else wears the sensors attached to the system, at the time of authentication, fog sever directly discards the captured data and displays the error message. It will not perform any classification or prediction based on captured data. The system works only when the user passed the authentication step. After applying BBN, we

Table 5 Comparative analysis of the proposed system with the existing studies

Parameters	Moreira et al. [31]	Abdullah et al. [32]	Omesh et al. [33]	Oti et al. [34]	Proposed system
Domain specific	Depression prediction in Pregnancy	Telemonitoring health of pregnant woman	Health monitoring pregnant woman	Stress monitoring of pregnant woman	Health parameter of pregnant woman
Focussed area	Emotions of pregnant woman	Foetal rate, body temperature	Heart beat	Heart rate vulnerability	High blood pressures impacts
Sensing technology used	Machine learning	IoT	IoT	IoT and edge computing	IoT
Data classification model used	Decision tree	Not applicable	Not applicable	Heart rate	Physiological (blood pressure, heartbeat, pulse rate) Atmospheric pollution
Data extraction	Dataset	Sensors directly	Not applicable	Not applicable	Heterogeneous
Information mining	Analytics	Not applicable	Location-based	Classification	Decision-based mining
Data storage	Not applicable	Cloud	Database	Cloud	Cloud and MySql
Output presentation	No	Yes	Yes	Yes	Yes
Security mechanism	No	No	No	No	Yes

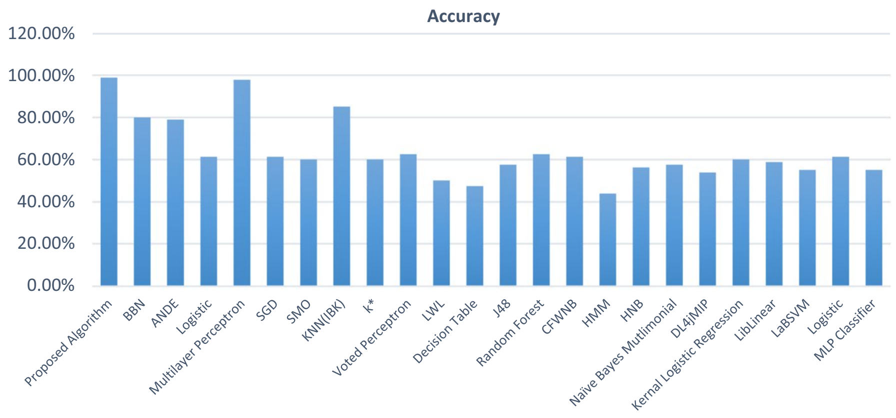


Fig. 6 Accuracy comparison of the proposed methodology with the existing methodologies

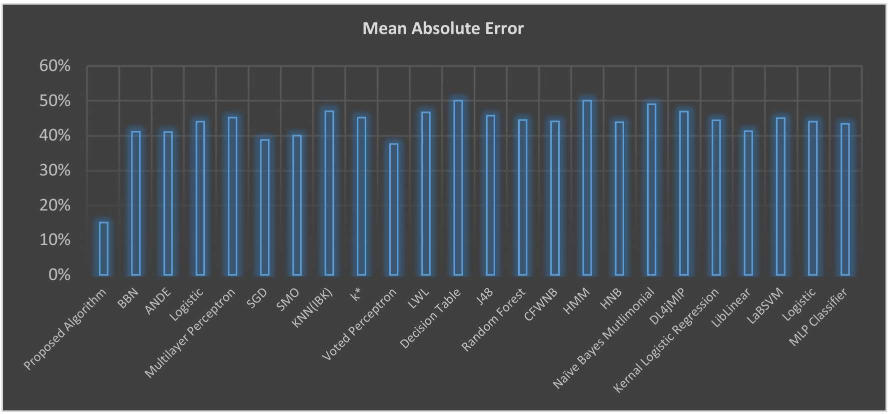


Fig. 7 MAE comparison of the proposed methodology with the existing methodologies

predict the accuracy, mean absolute error (MAE), root-mean-squared error (RMSE) along sensitivity, and specificity. Figures 6, 7, 8, 9 show the predicted results and perform accuracy and error prediction. Figure 6 shows the accuracy obtained by the proposed system, i.e. 98.75% as compared with the other existing algorithms. Moreover, the proposed algorithm is found to be useful as it is having least MAE (Fig. 7) with only 15% and RMSE (Fig. 8) with 20% which is much more in other algorithms. Also, sensitivity and specificity (Fig. 9) found satisfactory with the results obtained from the proposed system are compared with the actual digital thermometer and pulse sensor and found 98.75% accuracy rate. This section discussed the working principle of the proposed system. The proposed model is suitable for heath prediction during pregnancy, and it is safe to use and offer better results by providing a complete solution within a system instead of buying several systems individually. It also reduces the cost factor required for taking care of the pregnant woman by providing healthcare facilities at her doorstep. Moreover, the proposed system may

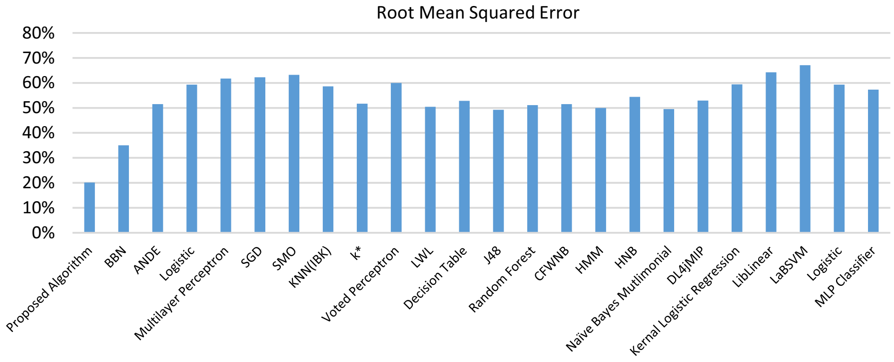


Fig. 8 RMSE comparison of the proposed model with the existing models

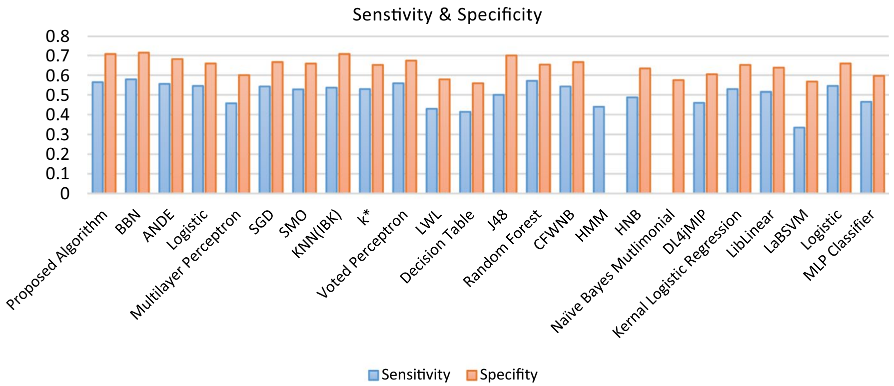


Fig. 9 Sensitivity and specificity comparison of the proposed methodology with the existing methodologies

find to be useful in the case of pandemic as it allows the contactless health monitoring of the pregnant woman. The proposed system also helps to save time of doctor or patient as doctor can remotely analyse the patients and provide suggestions as per the requirement. Furthermore, the patient only requires moving to the doctor in case of any emergency. In this way, the system may become bliss for the pregnant woman as suggested by the doctors.

Thesis

6 Comparative analysis

In this section, the comparison of the proposed pregnancy healthcare system with existing related studies is presented. As stated in the previous sections, health is the crucial parameter as several attributes are associated with it. Moreover, the present study discussed about the different concepts compared to the several state-of-the-art studies which presents the overall efficiency of the system. The comparative analysis is shown in Table 5.

- *Domain-specific* parameter discusses the information regarding healthcare domain on the basis of which the study is carried out. Furthermore, the discussion about the information related to the proposed system in healthcare domain is presented.
- *Focussed area* parameter discusses deep information about the area of healthcare focussed by the existing studies and proposed study. The parameter mainly discussed the influence of the studies in the pregnancy healthcare industry.
- *Sensing technology* parameter presents the collection of healthcare data at the core of the research. It is critical to find out kind of sensing technology that researchers have implemented in studies for delivering effective healthcare services.
- *Data classification model* parameter presents the information about the specific category of data classifier model that has been implemented in different studies for effective vulnerability determination, as it stated in the preceding sections concerning the efficacy of healthcare data categorization before vulnerability assessment.
- D*ata extraction* parameter presents the evaluation of effectiveness of system with feature extraction technique for heterogeneous data. This parameter compares the presented system with comparable research based on the features extraction mechanism.
- The technique of *data mining* is implemented on continuous data extraction from the database for realizing the real-time healthcare assessment. Henceforth, it becomes important parameter for analysing the proposed model on the basis of the underneath data mining technology indulged for data extraction.
- *Data storage* parameter presents data that have been saved in the database for evaluation. In other words, it includes the details on the data storage strategy that researchers have employed to store real-time heterogeneous health-related data.
- *Output presentation* parameter is used to compare the suggested model to existing research in the field based on the output result that are presented to the target user. It will also provide information about the health-on-healthcare user interface for the evaluating the user health.
- *Security mechanism* presents appropriate security measures on the acquired data that contains personal health information. This parameter contains details on the various security approaches used by researchers to protect healthcare data.

7 Conclusion

This study proposed an E-healthcare system for the pregnant woman that monitor regular health variations occurred in their body due to pregnancy. The proposed framework is based on the IoT sensors data collection and the fog devices for capturing the collected data from these sensors. Moreover, the proposed model refines the data at the fog devices and sends refined data to the cloud server for providing better analysis of health variations and disease occurred in the body of the women. In nutshell, the proposed pregnancy E-healthcare system monitors the health variation of pregnant women and can able to become 24×7 health assistance at the doorstep of the mother. The current system offers an accuracy of 98.75% as compared with the other available devices. The system is more portable and offers health prediction within a single system. In future aspects, the system can be extended to work on dual mode, i.e. it can be extended to work with non-pregnant and pregnant individuals by setting threshold values.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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