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Smart Stress Related Risk Assessment of Pregnant Woman Using Internet of Medical Things

Meenal Kamlakar[1], Dipti Patil[2], Lalit Patil[3]

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Abstract: Pregnancy monitoring is a trending topic of research in the field of Internet of Medical Things. Life of today's pregnant women is quite stressful and good quality sleep can help reduce stress.Stress monitoring of pregnant women can help gynecologists assess its negative impact and thus identify major risks to the health of the mother and her unborn child. A sensor based smart wearable device can aid in monitoring stress.This paper proposes a simple design of a stress monitoring wearable for pregnant women.

Keywords: *IoT, ML, AI, Healthcare analytics, Pregnancy monitoring*

1. Introduction

Each pregnancy is unique and hence the method and frequency of monitoring the pregnancy should be different for every case. It is necessary for the health provider to identify and mitigate the risks associated with pregnancies. Continuous monitoring aid in making necessary provisions for prenatal care. Monitoring pregnancy should include supervision of the medical parameters of the mother and her fetus along with checks to aid management of the lifestyle to be followed by the carrying mother to ensure the optimal well-being of both.

One should not neglect Emotional Health Monitoring during pregnancy as it has become the need of the hour. Smart wearable devices can be used to do this. Monitoring Emotional well-being can be done by analyzing speech patterns, heart rate variability, or sleep quality[1]. ML algorithms can be further used to do the analysis of data collected by smart wearables[2]. Stress, anxiety, or depression can have adverse effects on the mother as well as her unborn baby like, preterm birth, low birth weight, and gestational hypertension.It can also affect the baby's neurodevelopment. Research says that stress hormones of the mother can travel through the placenta and affect the baby's neurodevelopment too.This can result in cognitive dysfunctionality and behavioral issues that can be seen in the child much after the time of birth[3][4].

1Department of Computer Engineering, MKSSS's Cummins College of Engineering for Women Pune, Savitribai Phule Pune University, Pune
1Department of Computer Engineering, Smt. Kashibai Navale College of Engg., Pune. Savitribai Phule Pune University, Pune
2Department of Information Technology, MKSSS's Cummins College of Engineering for Women Pune, Savitribai Phule Pune University, Pune
3Department of Information Technology, Smt. Kashibai Navale College of Engg., Pune. Savitribai Phule Pune University, Pune
** Corresponding author: Meenal Amod Kamlakar, meenal.kamlakar@cumminscollege.in*

Sleep is one major player in affecting the emotional health of any individual. Good quality sleep and proper duration of sleep regulates mood, stress , cognitive functioning and energy level in humans[5][6][7].

Hence it can be said that deprivation of good quality sleep can play a negative role in pregnancy and can cause complications.It is necessary to provide support and guidance to promote healthy sleep during pregnancy so as to minimize the adverse effects of insufficient quality sleep. Use of smart wearable monitoring systems can easily aid in doing this.

In this paper we will discuss the effectiveness of measuring sleep quality using the most sufficient parameters. A design of a compact ,efficient and cheaper smart wearable system to monitor stress levels of pregnant women through sleep monitoring using machine learning algorithms is also presented.

2.Side Effects of Stress on Pregnancy

It has been observed that low quality sleep during pregnancy has been linked with severe physiological effects on both the mother and the developing baby.[8][9]There are multiple risks which occur due to hormone imbalance.There is a risk of developing gestational diabetes due to disturbed glucose metabolism and insulin sensitivity which requires good quality sleep to be normalized.[10]Also there is the risk of having a preterm birth due to the imbalance of hormones which sleep can balance.[11]Risk of having high blood pressure [12] and high probability of cesarean delivery have also been noted in patients showing symptoms of stress as a result of inadequate quality sleep[13]. Low quality sleep can also trigger Mental health issues like depression , anxiety during pregnancy and cognitive issues[14]. Moreover the immune system also gets compromised due to the lack of good quality sleep making the mother susceptible to diseases[15]. A good night's sleep helps the body rejuvenate and maintain the required energy levels[16]. Studies show that poor sleep quality of the mother hampers the fetal growth and its development due to insufficient oxygen which is adequately supplied during sleep[17].The above discussion clearly proves that there is a need to monitor sleep during pregnancy as there is a strong bidirectional correlation between stress and sleep.Stress disrupts sleep patterns.Cortisol ,the stress hormone gets released when a person is stressed[38][6].Inadequate and poor sleep increases stress.Sufficient and good quality sleep regulates stress levels[18]. Stress also affects the baby's neurodevelopment[54][57].

3.Methods to Monitor Sleep

Polysomnography is the clinical and standard method to monitor sleep.The patient who needs sleep monitoring needs to be admitted to clinic and monitored overnight.Patients brain waves, eye movements,heart rate ,respiration and many other parameters are recorded and analyzed by a professional to determine the stages and the quality of sleep of the patient[19].Other methods can be used to monitor sleep at home. Wearable devices are used to record parameters which are used to analyze and comprehend sleep quality[20].Parameters like light exposure and sleep awake patterns are used in actigraphy[21].Actigraphy is less accurate than Polysomnography[22].Other wearable devices like smart watches use sensors like the accelerometer, heart rate sensor, Blood oxygen sensor ,to record and determine sleep quality[23].Some specialized devices make use of sensors to measure breathing, heart rate, and movement without which can be placed in close proximity to the person being monitored while sleeping[24].Table 1 below highlights the methods, suitability and dependability of these methods.

Table 1. Analysis of various stress detection techniques

References	Method	Suitability	Technique used	correctness	usability
[25]	Polysomnography:a diagnostic test	People who are troubled with sleep disorders like insomnia, restless legs syndrome, sleep apnea etc usually take this test.	Electroencephalography (EEG) to monitor brain wave activity, Electromyography (EMG) to monitor muscle tone, electrooculography (EOG) to monitor eye movements, and additional sensors to measure breathing rate, heart rate, oxygen levels, and other relevant variables.	Best and most comprehensive test for diagnosing sleep disorders accurately.	Conducted in a sleep laboratory or a specialized clinic with monitoring equipment. Home-based polysomnography affordable systems are also available.
[26]	Actigraphy	Actigraphy is mostly suitable for individuals having insomnia, circadian rhythm disorders, or sleep disturbances associated with certain medical conditions.	Wearable devices having accelerometers are used. Use of light sensors for assessing circadian rhythm disorders are used.	A practical and non-intrusive method used over an extended period.	lightweight, user friendly device that can be worn continuously for long-term monitoring. It can be used for home-based monitoring and field research.
[27] [28]	Smart watches	It can be used for people having small concerns about	Various sensors are used to collect data and algorithms are	Advancements in technology have led to	Smartwatches can be worn throughout the day and night,

		sleep. As compared to polysomnography or actigraphy the results of the sleep analysis are less accurate and less comprehensive.	used to analyze it to estimate sleep parameters like accelerometer and a heart rate monitor to track heart rate variability. Sensors, such as SpO2 (blood oxygen saturation) , Sensors for ambient light , Sensors to gather more data related to sleep quality and environmental factors.	improved accuracy in sleep tracking algorithms, making smartwatches more reliable in estimating sleep duration and providing basic sleep insights.	allowing for continuous tracking of sleep patterns. Sleep summaries which interpret their sleep metrics can be displayed in a user-friendly style and also integration with other health-tracking features help in analysis through graphs.
[29]	Smart beds	Smart beds offer a more comprehensive and integrated approach to monitor sleep. Focus here is to improve the sleep environment. Continuous monitoring and analysis of sleep parameters, help to infer sleep quality, disturbances, and potential improvements.	Various sensors and technologies such as pressure sensors are embedded within the mattress.Data from these sensors are analyzed using algorithms.Moveme nt and body positioning during sleep can be monitored.. Use of cardiography (BCG) sensors that measure the minute vibrations caused by the body's mechanical activity, such as heartbeat and respiration can be done. Insights into Sleep stages, sleep efficiency, and other sleep metrics can be obtained.	It is not as comprehensive as medical-grade devices like polysomnograph y.	It is easy to use daily .Softwares such as mobile applications or online platforms that display sleep data, trends, along with personalized recommendations for improving sleep need to be integrated for viewing Sleep metrics, sleep reports by the user to make necessary adjustments to their sleep environment or routines. Additional features such as adjustable firmness, temperature control, and smart lighting, to enhance overall sleep experience and comfort are provided.
[30]	Wearables	Wearables for individuals who are interested in tracking their overall health and wellness, including sleep habits are available. They are suitable for both general sleep	Wearables use sensors, such as accelerometers and heart rate monitors, to collect data during sleep. The accelerometer and the heart rate sensor is used to monitor	The reliability of the sensors and efficiency of the algorithms determine the accuracy for gaining the insights into sleep patterns.	Wearables are portable, and user friendly for sleep monitoring. Software is used for visual representations of sleep data, sleep summaries.

		tracking and for monitoring sleep for specific sleep concerns, such as insomnia or sleep apnea.	physiological changes. Insights on sleep duration, sleep stages, and sleep quality can be obtained here.		Additional features such as step tracking, heart rate monitoring, and stress management, can be provided for overall health monitoring.

4.Method to Find Out Stress

Stress can be detected mostly either through reporting done by the stressed or using behavioral indicators noted by external entities, but what interests us is the detection of stress through physiological measurements.Physiological parameters like the Respiration flow, Blood oxygen levels, temperature, Heart Rate Variability , Blood Pressure , Cortisol Levels, Galvanic Skin Response and Electroencephalography can be used to measure stress.[31]Table 2 briefs about these parameters.

Table 2. Impact Analysis of various physiological parameters for Stress Detection

References	**Parameter**	**Effectiveness in measuring stress**	**Measurement technique used**	**Metric and values**
[32]	Respiration flow	Respiration flow and breathing pattern changes with stress and can be measurable . Stress may not be the only reason for this change and vice versa. Heart rate, skin conductance, and self-reported measures also need to be monitored for more accurate prediction of stress.	Sensors(measuring air flow) in Certain wearable devices or chest straps (which expand when we breathe in)may detect and measure chest movements during breathing and can be used to predict respiration flow. airflow directly.	Respiration Rate is used to count the number of breaths per minute. Respiration Patterns indicate the rhythm and regularity of breaths.
[33]	Blood oxygen levels	Stress causes respiration, heart rate, and blood flow to change to some extent , which in turn can affect blood oxygen levels. Potential stress-related changes can be indicated by monitoring blood oxygen levels.	Pulse oximetry can be used for measuring blood oxygen levels. It measures the oxygen saturation in arterial blood. Pulse oximeters use light-emitting diodes (LEDs) to shine light through the skin. A photodetector measures the amount of light absorbed by oxygenated and deoxygenated blood for the estimation of blood oxygen levels.	SpO2 is the metric used to represent the percentage of hemoglobin molecules in arterial blood that are saturated with oxygen. Normal resting SpO2 levels typically range from 95% to 100%. Stress causes SpO2 levels to fluctuate.

[34][35]	Temperature	During stress the blood flow, metabolism, and hormone levels in the body changes due to which body temperature also can change. Hence to identify potential stress-related changes, change in body temperature can be monitored.	Thermometers or temperature sensors can be used in . Wearable devices for continuous monitoring of temperature variations throughout the day.	Temperature of the body rises due increased metabolic rate, increased blood flow, and the activation of the body's stress response.Hence dependency on temperature alone for measuring stress levels is not sufficient.
[36]	Heart Rate Variability	Higher levels of stress typically cause high variability in heart rate and lower stress levels cause less variability of heart rate.Thus by monitoring HRV, it is possible to track changes in stress levels or relaxation.	The electrocardiogram (ECG) signal is used to capture the electrical activity of the heart. We have many wearable devices with built-in heart rate monitoring capabilities. The ECG signal is studied to extract the time intervals between consecutive heartbeats, and HRV analysis is performed on these intervals.	Time Domain Measures such as Standard Deviation of NN Intervals (SDNN) and Root Mean Square of Successive Differences (RMSSD) are used to quantify various aspects of the beat-to-beat variability. Frequency Domain Measures such as High-Frequency Power (HF): Represents parasympathetic activity. Low-Frequency Power (LF): Reflects a mixture of sympathetic and parasympathetic activity. LF/HF Ratio: Indicates the balance between sympathetic and parasympathetic activity.
[37]	Blood Pressure	Blood pressure monitoring can be moderately effective in assessing stress levels as it can reflect the impact of stress on the cardiovascular system. During stressful situations, the body's	The measurement technique used to assess blood pressure typically involves the use of a sphygmomanometer, which can be either manual or automated. Manual	The two primary metrics associated with blood pressure are systolic blood pressure (the higher number) and diastolic blood pressure (the lower number). These measurements are

		stress response can cause an increase in heart rate, vasoconstriction, and the release of stress hormones, which can result in elevated blood pressure. By monitoring changes in blood pressure, it is possible to observe deviations from the baseline and identify potential stress-related responses. However, it's important to note that blood pressure alone may not provide a comprehensive assessment of an individual's stress levels. Other factors, such as heart rate variability, self-reported measures, and additional physiological parameters, are often considered in conjunction with blood pressure for a more comprehensive evaluation.	sphygmomanometers involve using an inflatable cuff around the upper arm and a stethoscope to listen for the sounds of Korotkoff (the sounds heard when blood flow starts and stops during cuff deflation). Automated devices use oscillometric technology to measure blood pressure without the need for a stethoscope. There are also wearable devices that can continuously monitor blood pressure throughout the day using non-invasive methods, such as optical sensors.	typically reported in millimeters of mercury (mmHg). Blood pressure values can vary widely depending on factors such as age, sex, health conditions, and individual variations. During stress, blood pressure may increase temporarily. The extent and duration of the blood pressure response can vary among individuals and depend on the intensity and duration of the stressor. Therefore, tracking changes in blood pressure and comparing them to an individual's baseline values are essential for understanding stress-related responses.
[38]	Cortisol Levels	Monitoring cortisol levels reflects the body's stress levels.	Samples of saliva, blood, or urine are used for laboratory analysis to determine the cortisol levels..	Unit of cortisol is micrograms per deciliter (μg/dL) or nanomoles per liter (nmol/L).
[39]	Galvanic Skin Response	GSR also indicates stress levels in the body.It can be recorded by noting the changes in skin conductance. Person in stress has increased sweat gland activity and higher skin conductance.	Electrodes are placed on the skin surface, usually on the fingers or palm, detecting changes in the skin's electrical conductance caused by sweat gland activity. The recordings are noted for GSR.	Skin conductance level (SCL), which represents the baseline conductance, and skin conductance response (SCR), which captures rapid changes in conductance in response to stimuli or events are the two main measures for GSR.The primary metric associated with GSR is skin conductance, measured in microsiemens (μS) or millisiemens (mS).

[40]	Electroencephalography	EEG measures stress levels by capturing the brain's electrical activity, which reflects cognitive and emotional processes, including stress responses. The type of brainwave patterns and frequencies can suggest different mental states like stress and relaxation. Increased beta activity, decreased alpha activity, or alterations in the power and coherence of specific frequency bands relate to different types of stress.	Multiple electrodes are placed on the scalp to detect and record the electrical signals generated by the brain which are then amplified and digitized for further analysis to detect stress levels.	EEG analysis is done using the following metrics and measures. Frequency Bands: signals of different frequency bands, such as delta (0.5-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz), and gamma (>30 Hz) are recorded. Changes in the power or coherence of specific frequency bands indicates stress-related brain activity. Spectral Power: Spectral power is the amount of energy within specific frequency bands. Increased power in higher-frequency bands (beta) or decreased power in lower-frequency bands (alpha) can be indicative of stress. Event-Related Potentials (ERPs): ERPs are specific components of the EEG signal that are time-locked to specific events or stimuli. Certain ERP components, such as the P300 or N170, can be regulated by stress and can be used to provide insights to stress-related processing.

5.IOT and Sensors used to measure sleep quality

Different sensors are available in the market which can be used to measure physiological parameters whose readings then can be analyzed to indicate sleep quality.Table 3 below lists these sensors.[44]

Table 3. Study of the types of sensors

References	**Sensors**	**Parameters**	**Analysis to make**	**Used in which type of sleep monitoring**

		measured		**device**
[41][42][43]	Accelerometers	measures movement	Can be used to detect changes in body position during sleep.	They are commonly found in wearable devices like smartwatches, fitness trackers, and sleep-tracking bands.
[41][42][43]	Heart Rate Monitors	measures the heart rate by detecting changes in blood volume.	Sensors track heart rate variability during sleep.	Heart rate monitors, such as photoplethysmography (PPG)
[42][43]	Respiratory Sensors	Detects breathing patterns.	provide information about respiration rate, depth, and regularity.	piezoelectric sensors, respiratory belts, or gadgets for flow sensors.
[41][42]	Electroencephalography (EEG) Sensors	Measures electrical brain activity.	Different patterns of brain activity can be observed in an EEG, including different frequencies and amplitudes of electrical waves.	EEG is to diagnose and analyze neurological conditions. EEG can be used in wearable devices .
[42]	Electromyography (EMG) Sensors	Measure muscle activity	Identify sleep disorders like periodic limb movement disorder or sleep-related movement disorders. Also Detects different sleep stages (e.g., REM, NREM) and identifies abnormalities in brain wave patterns.	polysomnography (PSG) studies conducted in sleep laboratories. EEG sensors can
[41][43]	Oxygen and pulse sensors	Measure blood oxygen saturation	They can be used to monitor breathing quality and detect	Pulse Oximeters

		levels and heart rate.	sleep-related breathing disorders like sleep apnea.	
	Sound Sensors/Microphones	Can capture audio during sleep.	monitor snoring, coughing, or other sleep-related sounds.	They are often integrated into sleep tracking apps or smart home devices.
[41]	Pressure Sensors:	Detects body movements and pressure distribution.	They are used to estimate sleep duration, sleep position, and assess sleep quality.	Can be embedded in mattresses or sleep surfaces
[41][43]	Temperature sensors	Measure changes in skin temperature during sleep.	They can provide insights into circadian rhythm variations and temperature regulation during different sleep stages.	Smart gadgets
[45][46]	Electrooculography (EOG) Sensors:	Detect eye movements, such as rapid eye movements (REM), during sleep.	They are used to identify REM sleep stages and provide insights into sleep architecture.	Gadgets to monitor sleep
[47][48]	Galvanic Skin Response (GSR):	Measure the electrical conductance of the skin,	Can indicate changes in sweat production and stress levels. These sensors may provide additional data on sleep quality and physiological arousal during sleep.	Gadgets to monitor sleep
[49][50]	Ambient Light Sensor	Can measure the level of light in the environment.	sleep/wake patterns and assess the impact of light exposure on sleep quality.	Smart watches and Gadgets to monitor sleep

[41][51]	Gyroscope	A gyroscope can detect rotational movements and changes in orientation.	identifying body position changes during sleep.	Smart watches and Gadgets to monitor sleep

6.Use of ML and DL Algorithms for Sleep Monitoring

Machine Learning and Deep Learning are used by many to study sleep related parameters and do analysis for detecting the quality of sleep and thus help maternal health monitoring. Use of ML algorithms like the naive bayes, random forest, SVM and deep learning algorithms like the CNN and RNN can be done for Sleep stage classification like wakefulness, rapid eye movement sleep and non-REM sleep[52].Data required for this can be collected through sensors like the accelerometers, heart rate sensors, air flow sensors ,ECG signals etc . Assessing sleep quality during pregnancy can be done using ML models to estimate sleep efficiency, sleep fragmentation, or sleep depth. Sleep disorders like obstructive sleep apnea (OSA) or restless leg syndrome (RLS) can also be detected in its early stages and hence prevented using ML algorithms[53].Sleep data along with other vital signs and maternal characteristics can be further used to predict complications in pregnancy like the gestational diabetes, preeclampsia, or preterm birth and hence aid in addressing the health risks involved for maternal health[54].

All this data can be used to suggest adjustments that need to be made to enhance the sleep quality by suggesting changes in individual practices.

7.Design of an Affordable and Efficient System

A system can be designed having a wearable device having sensors embedded on it, which can collect body signals or parameters and store it on the cloud storage. Research says that only a few parameters like the temperature, blood pressure, heart rate and oxygen will be sufficient to correctly classify the quality of sleep[55]. This has been verified through the experimental results obtained discussed in the experiments and results section. Server can then read this data and apply ML algorithms to make risk predictions or suggestions to improve lifestyle and sleep behavior.The output of the system can be transmitted and presented to the user via their phones or tablets.

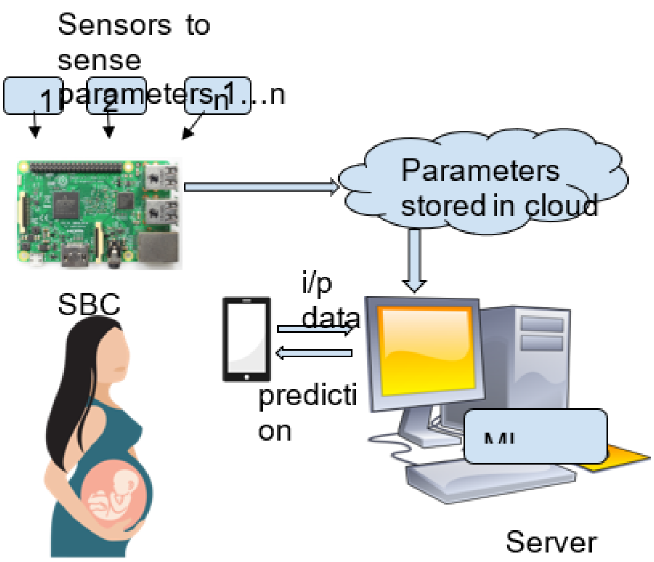

Fig. 1. Architecture of Machine Learning based pregnancy monitoring systems.

8.Experiments and Results

The IoT network was set up and real time data was collected in the form of measurements of health parameters like temperature, pulse rate, blood oxygen level of the user from the wearable device.The wearable device was designed using sensors and a small single-board computer (SBC).

The MAX30102 pulse oximeter sensor was used for measuring the values of heart rate and blood oxygen levels. It is supposed to be placed on the user's wrist. The LM35 temperature sensor was used for measuring the temperature. It can sense the temperature if applied to the index finger. This sensor data was stored in the firebase database for accessing it through a mobile application.

The dataset from the kaggle was used for training the Machine Learning model for

the prediction of stress level.The real-time health parameters like heart-rate, temperature, blood oxygen level, pulse rate were used as the dependent variables. A threshold was set if a value of any parameter exceeded the threshold. A comparative study of 5 Machine Learning algorithms is done to decide with the most suitable algorithm applicable for this prediction model.These algorithms were applied on the same dataset used for training the model and were evaluated on the basis of accuracy(%) given as an output by each one of them. Results show that Linear regression has proved to have the highest accuracy and can be applied. The actual prediction model is built by using the TensorFlow Lite framework.The Prediction of stress level is given in terms of percentage. A mobile application was created as a user interface.The user initially needs to install the application on his mobile device.The user is then able to monitor his heart rate, temperature, blood oxygen level and get predictions on stress levels.

Table 4 below shows the results of different ML algorithms that have been applied to the dataset from Kaggel [59] using all these parameters as dependent variables.Figure 2 shows the graphical representation of the same.

There is a strong correlation between sleep and stress which is shown using a heat map in figure 3. Stress can significantly impact sleep quality and duration, while poor sleep can also contribute to increased stress levels[56]. Hence if we monitor physiological parameters during sleep we can get the prediction on stress levels too by applying ML algorithms. The data set taken for the experiment shows the relationship between the target variable which is the Stress level and values that can be sensed by sensors during sleep which are the snoring range of the user, respiration rate, body temperature, limb movement rate, blood oxygen levels, eye movement, number of hours of sleep, heart rate in the dataset .

Results show that the Random Forest algorithm gives very high and same accuracy of stress prediction regardless of the parameters chosen for regression. Linear regression can be used to get the best accuracy if sensor based parameters are used.Polynomial regression also gives very high accuracy of prediction of stress.

Table 5. Results

ML Algorithm	**Accuracy using all parameters**	**Accuracy using sensor based parameters**
SVR (Support vector regression)	85.9%	59.6%
Random forest regression	98.4%	98.4%
Decision tree regression	87.6%	91.6%
Polynomial regression	88.9%	99.6%
Linear regression	66.8%	100%

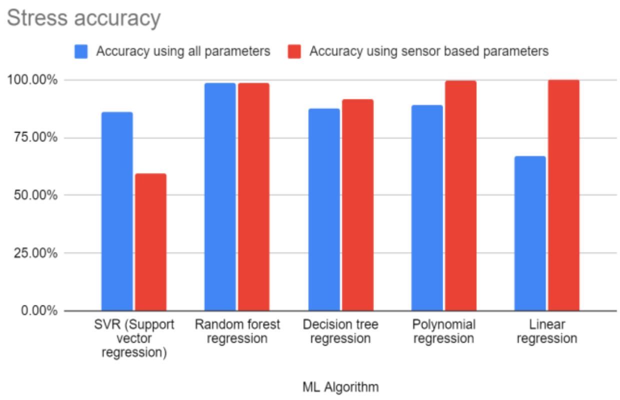

Fig. 2. Accuracy for prediction of stress using different ML prediction algorithms

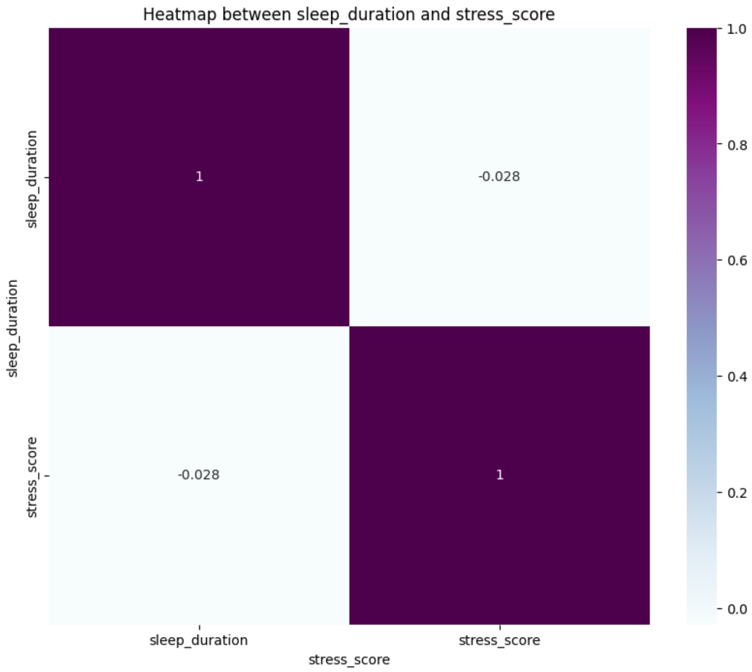

Fig. 3. Heat Map for finding correlation between stress score and sleep duration.

9.Conclusion

Prenatal care is important and can be ensured by monitoring the pregnancy. Stress, anxiety, or depression can have adverse effects on the mother as well as her unborn baby like, preterm birth, low birth weight, and gestational hypertension.It can also.Stress hormones of the mother can travel through the placenta and affect the baby's neurodevelopment.There is a strong bidirectional correlation between stress and sleep.Stress disrupts sleep patterns.Cortisol ,the stress hormone gets released when a person is stressed. Inadequate and poor sleep increases stress and sufficient and good quality sleep regulates stress levels.Stress can be managed by good quality sleep and thus it's important to monitor sleep quality. Different sensors are available in the market which can be used to measure physiological parameters whose readings can then be analyzed to indicate sleep quality.

An IOT based economical wearable device can be designed using sensors and a small single-board computer. A mobile application can be developed as a part of the system to get notifications and alerts for risk prediction. Different ML algorithms can be used for risk prediction using minimal physiological features as dependent variables.

Thus a wearable device having a few sensors is sufficient to get an accurate estimate on the quality of sleep and indirectly the level of stress.

10.Future Enhancements

The accuracy of the results of this system can be increased by using more relevant biosensors for collection of comprehensive data.Further more the efficiency of the algorithms can be improved by modifying the algorithm. Stress management alone is not sufficient to discover all risks associated with pregnancy and hence it is necessary to have a full solution which will cater to the needs of a pregnant woman who needs to be monitored in the form of a wearable device.This device can be build for accurate prediction of risks that can be identified using physiological parameters using bio sensors .[39][40][41] Various other biological parameters can be considered for the design of such a device like the Cervical length, Baby kicks,lactic acid sensor, biometric parameters of the baby, exhaled breath for disease diagnosis etc. for increased accuracy and scope of risk detection. [58][62] Nutritional deficiencies also can be monitored using sensors.[61]

The efficiency of the IOT system can be increased using algorithms for improving the performance of the system [60].

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