SLEEP APNEA DETECTION AND PREVENTION FOR INFANTS USING CLOUD AND MACHINE LEARNING

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Abstract - *This paper presents a fully integrated system for the detection and prevention of sleep apnea in infants. Apnea has been one of the leading causes of death worldwide with an approximation of about 200 deaths of premature neonatal infants a year. Currently, for the diagnosis of apnea the patients need to go through overnight sleep study in the laboratory, which is very expensive. The proposed device will be a solution for both monitoring and preventing the condition using accurate readings and also judging and giving suggestions on when the patient needs medical help using cloud and artificial intelligence. And all this done in the respective homes of the patients.*

Keywords— Sleep Apnea, Cloud, Machine Learning, Edge, Heart rate.

1. INTRODUCTION

This Infant sleep apnea is a disorder related to breathing while the baby is asleep. It is basically a condition where the breathing has pauses and limitation or reduction that occur during an infant's sleep. Partial reductions in the process of breathing are called hypopneas. Similarly, complete pauses in the process of breathing are called apneas. During infancy the frequency of such events increases at the stage of rapid eye movement (REM) sleep. It is mainly caused by the brain's breathing control center disorder. There are 3 types of apneas: (1) Central apnea: a pause in alveolar ventilation due to a lack of diaphragmatic activity. In other words, there is no signal to breathe being transmitted from the CNS (Central Nervous System) to the respiratory muscles. This is due to immaturity of brainstem control of central respiratory drive resulting the body to decrease or stop its effort to breathe; (2) Obstructive Apnea: during deep sleep a pause in the alveolar ventilation due to obstruction of airflow within the upper airway, particularly at the level of the pharynx. The pharynx collapses from negative pressure generated during inspiration, because the muscles responsible for keeping the airway open, the genioglossus and geniohyoid are too weak in the premature infant. Once collapsed, mucosal adhesive forces tend to prevent the reopening of the airway during expiration; (3) Mixed Apnea: this type of apnea involves central apnea that is directly followed by obstructive apnea. Technologies presented in recent literatures for apnea include monitoring the oxygen levels using sensors and, in some cases, include chest belt, strain gauge, etc. These methods are not suitable for neonatal respiratory monitoring because babies cannot wear these devices due to the sensitive nature of their skin. The proposed device uses a spo2 sensor, that represents a very small form factor and consumes very small amount of power which makes it suitable for daily home usage.

1.1 APNEA DETECTION AND PREVENTION

The proposed device consists of a spo2 sensor (MAX30102) which takes the blood oxygen levels from the index finger/toe of the baby and gets the reading. There are 3 cases of oxygen levels: (1) Normal level: Above 90%; (2) Abnormal level: Below 90%; (3) Critical level: Below 82%. The device detects the above 3 cases and acts accordingly, at the normal level it continues to read the blood oxygen levels. If the reading goes to the abnormal level the device immediately vibrates the bed containing the baby such that it wakes the baby from deep sleep-in order to activate the inactive brain which controls the breathing processes. By this sleep apnea could be prevented. But incase this also doesn't make a change in the oxygen levels, i.e., the reading goes to critical level, then the device immediately alerts the parents and nearby hospitals to provide medical help.

1.2 HEART RATE AND ROOM TEMPERATURE READING

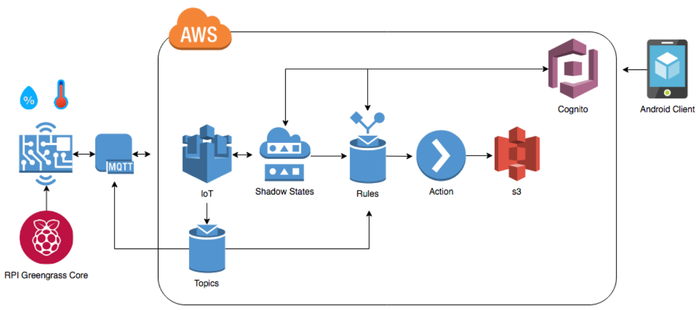
The sensor (MAX30102) is used to detect the heart rate and also the body temperature. The heartbeat detection is based on the principle of photo plethysmography. It measures the change in volume of blood through any organ of the body which causes a change in the light intensity through that organ (a vascular region). The flow of blood volume is decided by the rate of heart pulses and since light is absorbed by blood, the signal pulses are equivalent to the heartbeat pulses. On the other hand, the MAX30102 consists of an on the chip temperature sensor which would correct or adjust the temperature dependence of the Spo2 subsystem which in turn also detects the room temperature. The temperature sensor has a default resolution of 0. 0625°C. The output data of the device is fairly insensitive to the wavelength of the IRLED, in which the Red LED's wavelength is censorious to correct the interpretation of the data provided. An algorithm used with the MAX30102 (For Spo2) output signal can make up for the error associated with Spo2 readings with ambient temperature changes. By this the device could help notify the variations in the heart rate of the baby which is caused due to the variations in oxygen levels leading to complications. This also detects the room temperature from which we can make sure it's apt for the baby.

2. OUR PROPOSED METHOD

The basic idea of our proposed concept is to detect the blood oxygen levels and heart rate of the patient. This is done in order to detect the apneic episodes in babies. Which is implemented by using the algorithm where the calculations are done using the raw ADC data from the LEDs.

Once these readings have been detected the next step would be prevention, i.e., activating the baby to come out of the deep sleep if the blood oxygen levels fall below the abnormal condition (less than 90%). Activating the brain is the crucial part of device as all the breathing processes are controlled by the brain, and if the baby goes into deep sleep, brain activity reduces which in turn makes the baby vulnerable to loss of oxygen intake resulting in chocking or also called obstructive apnea. And this activation is done using a vibration motor which vibrates the bed containing the baby resulting in an active brain which will control the breathing processes. But if in case the oxygen level still reduces; the device immediately alerts the parents and the nearby hospitals for medical emergency. The device at the same time monitors the heart rate at Beats Per Minute (BPM) to understand the condition of the baby. The device then stores all the data in cloud and processes it on a weekly basis using AI (Artificial Intelligence), such that it can detect what kind of apnea the baby is suffering from and also suggest what type of actions could be taken in order to find a solution for the situation.

Working model has components such as Raspberry Pi or Arduino Mega, Sensor SpO2, Esp8266 or a Wi-Fi shield, a 16x4 LCD display unit, some resistors and jumper wires. The working diagram is given below.



2.1 Max30102

The MAX30102 is an integrated heart-rate monitor and pulse oximetry sensor. It integrates 2 LEDs (Red and IR), a photo detector, optimized optics, and a low-noise analog signal processing to detect pulse oximetry and heart-rate signals. It is entirely configurable using software registers, and the digital output data is stored in a 32-deep FIFO inside the device.

MAX30102 operates on a supply in the range of 1.7 to 2V. It can be used in wearable devices, fitness assistant devices, medical monitoring devices, etc.

It consists of an integrated temperature sensor used for calibrating the temperature dependence of the pulse oximetry system. It also has proximity detection function which is used to reduce the power consumption of the sensor and also a visible light is emitted when the user's finger is not placed on the sensor.

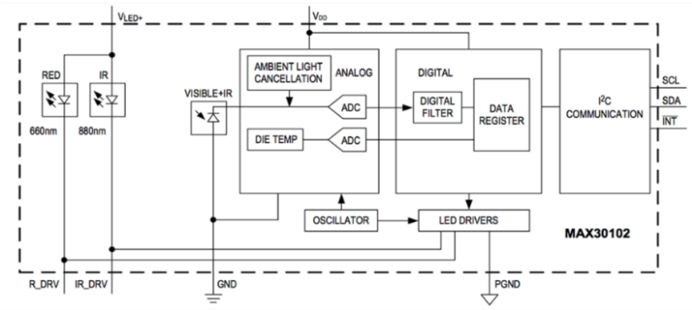


Figure 1: Circuit Diagram

It consists of an I2C digital interface which is used to communicate with a host microcontroller. The pulse oximetry subsystem in MAX30102 consists of an ambient light cancellation (ALC), 18-bit sigma delta ADC, and proprietary discrete time filter. It has an ultra-low-power operation which makes it ideal for battery operated systems.

2.2 Algorithms

Here there are two basic algorithms used to detect spo2 and heart rate readings, which are PBA and SKA. PBA (Peripheral Beat Amplitude) algorithm is used in identifying and separating beats from arterial pulse waveforms which is obtained using the principle of plethysmography. The PBA algorithm looks for zero crossings using a slow threshold and completes its evaluation cycle with each sampling point, so it has no output delay. In contrast, the SKA algorithm waits for three seconds and then looks for a peak; it cycles at a higher rate of once per second, but it requires a more-complex math operation. Also, PBA requires much less data space and code space compared to SKA.

ALGORITHM	DELAY	MEMORY	DATA SPACE
PBA	None	5772	870
SKA	3s	31160	52723

Table 1: Algorithms

The algorithm is processed every 1s, but it requires a more complex math operation. The user needs to present 3s FIFO data to algorithm. Heart rate is from average of 3s of data. Each of these algorithms has its own advantage.

PBA (Peripheral Beat Algorithm):

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Algorithm used for identifying and separating beats from pulse records. The algorithm is used to register the pulse wave generated by the sensor and real time digital filtering is done to reject the baseline drift and low frequency signal noise. This helps in smoothening the pulse waveform. The advantage of using digital filters is its simple implementation with minimal computing resources and facilitate the user to interpret the waveform easily. For detection of pulses and filter out the sensor uses first order filters which has a very small band pass between about 0.5 to 12Hz with a sampling frequency of 250Hz and an amplitude resolution of 8 bits were used.

High pass filter is used in filtering of real time base line drift reduction. The filter process is quite similar to ECG base line drift reduction. This filter takes N samples of data from the sensor which is predefined and then averages them to get an accurate pulse signal with less noise. Below shows the equation for high pass filter:

$$y[i] = x[i] - \frac{1}{N} \sum_{j=-(N-1)/2}^{(N-1)/2} x[i + jD],$$

Equation 1: High Pass Filter Eq.

From the above equation:

x[i] represents the input signal and

y[i] is the output signal.

for the sample frequency a total of over 25 samples distanced by 15 samples are considered for average with a cut-off frequency of 0.5Hz i.e. the lowest heart rate 30BPM and a zero at 50Hz. The time interval for the filter is 1.5s, which is the optimal time delay of the filter output.

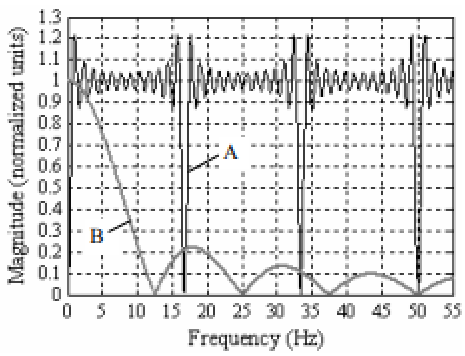

Figure 3: Frequency response of filters, A- represent high pass filter, B-represents smooth filter.

The Smoothing filter is a low pass filter which allows low frequencies operates by averaging N consecutive points from the input signal. Below shows the low pass smoothing filter equation:

$$y[i] = \frac{1}{N} \sum_{j=-N/2}^{N/2} x[i + j],$$

Equation 2: Smooth Filter Eq.

- The identification of upper peaks and lower peaks of individual pulses.
- The identification is done effectively by dividing the waveform into 200ms time intervals and the absolute upper peak are determined for every segment.
- The upper peaks lying near to or below the threshold amplitude or near the middle line of the waveform are filtered or rejected.
- The normal threshold was kept to 3 bits above the middle line. This is to ignore a very low noise amplitude.
- When there is less than or equal to 200ms distance between the two upper peaks, the lower amplitude upper peak is filtered. This will also remove the false peaks along the slopes of the waveform.
- Lower peak identification can be done if a lower peak is above the predefined threshold near the middle line of the waveform the lower peak is filtered. The threshold was set to 3 bits below the middle line. This is to ignore a very low noise amplitude.
- The lower amplitude peak of the two maximums adjacent to a rejected minimum is also discarded too.

2.3 Central Control Unit:

Control unit is the central processing unit of the system which must take decisions and process them accordingly. The core part of the control unit can be a low powered micro-processor or a microcontroller. This is used to receive the data from the sensor every second and process it. This microcontroller is coded with instructions which perform certain tasks depending on the data received by the MAX30102 sensor. The control unit is interfaced with an LCD display which can output the real time monitoring of the Oxygen and Heart rate. We also have a Wi-Fi module attached to control unit with which we can have internet connection. This results in real time monitoring of the device through internet. The control unit is also connected to the vibration motor which is connected to the infant's bed. When the Oxygen level goes down below 90% then the vibration motor is triggered which helps baby to get out of deep sleep. If it goes below 85% then it is critical condition, then the messages are automatically sent to the parents through internet.

2.4 Cloud Computing and Machine Learning:

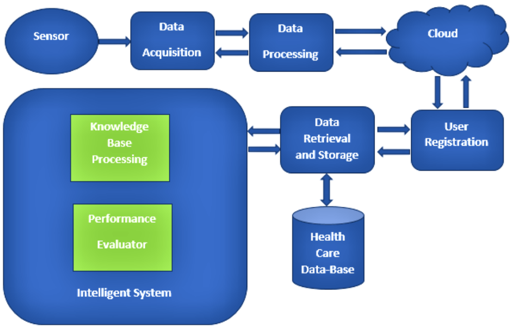

Figure 4: Diagram of Cloud and ML

Cloud computing is used to access remote servers which can store, manage, and process large data rather than using a local machine.

The sensor data received is sent to cloud for computing and predicting the type of sleep apnea. The patient's data is collected and observed for a week to find the anomalies to propose the appropriate treatment and to generate patient's record for doctor's analysis. An edge computing technology is used to detect the anomalies in real time and trigger the alarm in emergencies thereby reducing the latency. The edge device acts like in field hub, process the real-time data based on the previous predictions generated by the cloud and later sends the current data to the cloud.

The complete cloud and edge computing is done using AWS (Amazon web services) services such as AWS IoT core, AWS green grass and the communication is established using MQTT protocol.

The stored data is computed by AWS Lambda to determine the type of sleep apnea and to predict the future occurrences. The data is initially tested on machine learning algorithms such as K means clustering, nearest neighbor and neural networks and the errors are compared.

3. LITERATURE SURVEY

From recent studies infants with sleep apnea are provided with breathing support, in certain condition this disorder is usually treated in over-night sleep labs, by polysomnography, which is an extravagant priced method. Multiple systems have been proposed to address this situation, in other situations sets of embedded system were coined-in that inspects and investigates patient's case using sensors to detect physiological signals that are automatically analyzed by algorithms. Majority of the studies included monitoring and detection of apneic episodes some included single-channel electrocardiogram signal which developed a time-domain analysis to meet the stringent resources constraints of embedded systems to compute the sleep apnea score for comparison.

Our device on the other hand focuses on detection and prevention of sleep apnea in a more effective and efficient way using accurate readings, such that taking respective actions becomes simpler. The proposed device also uses recent technologies such as edge technology, cloud computing and artificial intelligence making the device a trustworthy and intelligent system to rely upon.

4. RESULTS

The proposed concept has been successfully implemented such that an integrated system with the capability of detecting and preventing sleep apnea, which could be the solution for SIDS (Sudden Infant Death Syndrome), is obtained. This device also monitors and vibrates the bed containing the baby so that the brain stays active in order to keep the breathing processes active as both are related to each other. The device also processes data on a weekly basis using edge technologies and artificial intelligence, making it possible to predict the future conditions and alert parents and nearby hospitals during critical conditions. Hence making the device reliable and apt for both online and offline conditions.

5. CONCLUSIONS

Sleep Apnea has been one of the leading causes of deaths worldwide. Detection of it was possible till now, but a solution for this condition was possible with medications and constant monitoring. This project is one among the initial initiatives focusing on not only the detection but also the prevention which could save a lot of time and money as its very efficient and accurate in all of its processes, also since it uses the recent technologies it's also among the intelligent systems available in the market.

Future enhancements may include processing multiple data in order to predict the conditions with the highest accuracy rate. This could also include taking a final opinion from the doctors of the nearest hospitals directly by sending the report of the baby which has already been processed by the device for a particular span of time, making the entire hospitalization process available for the baby right at their respective homes.

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BIOGRAPHIES

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