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DESIGN AND DEVELOPMENT OF SMART NEONATAL HEALTH MONITORING SYSTEM

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Abstract:

In the world, the mortality rate of the neonates is high. There are many factors that causes the mortality rate to be high. One of the factors is the unavailability of the pediatric specialist in all of the region of the world. Specially in the remote areas and the sub-urban areas there is huge scarcity of the pediatric specialist. This causes the neonates to be in sever problem and are either dying or being disability person in the future. This problem can be solved by the use of Tele- medicine. The traditional tele-medicine system consists of the manual data taking of the patient, which may cause the error. The proposed system consists of the sensors which will give the temperature, ECG, heartbeat rate and SPO2 reading and a real-time web-portal. By accessing the real- time portal, the paediatric specialist can interact directly with the parents of the neonates or the available health person there and can read the data sent by the sensors directly. This system will solve the problem of traditional telemedicine system and will be helpful for proper medical care to neonates, who are in the remote and suburban areas of the world and specially to the neonates in the developing countries.

Keywords: Esp 32, Neonatal, LM 35 temperature sensor, AD8232 Sensor, MAX 30100, Health monitoring system

1. Introduction

There are many remote areas where there is no availability of the pediatric specialist and neonates need the emergency care, for this smart neonatal health monitoring system is proposed. So that the pediatric specialist can get the vital information regarding the neonates in online system as the tele-medicine. Wireless sensor network (WSN) can play an important role in healthcare services. This WSN is Merged with internet.

In the proposed system, temperature sensor, blood oxygen sensor, pulse rate measurement sensor, heart rate measurement sensors are used to monitor body temperature, blood oxygen level, pulse rate, respiratory rate and heart beat rate of neonates. The pediatric specialist accesses these data through the real time web portal, interact with health person or parents of neonate and takes the necessary action.

The existing tele-medicine system consists of taking these data manually and then send to the specialist, which may occur error. This system can also be deployed to the patient who are in emergency situation in the urban area also.

A Body Area System is defined by IEEE 802.15 as, 'a communication standard optimized for low power devices and operation on, in or around the human body to serve a variety of applications including medical, consumer electronics/personal entertainment and other'[1]. The wireless remote body region system is created to continuously monitor and record a individuals' health condition. It allows this data to be sent over long distances, making it easier to keep track of someone's health from a far. By using sensors placed on the body, the system can check vital signs like heart rate, temperature, and oxygen levels, and share this information in real time with healthcare providers. [2]
A Wireless Sensor Network (WSN) is a type of self-organizing system used to monitor physical and environmental factors such as temperature, pressure, vibration, sound, and motion. These sensors collect data and transmit it wirelessly to a central hub or server, where the data can be reviewed and analysed. The server serves as the interface between the network and its users.

WSNs can consist of a few to many sensor nodes that communicate with each other via radio waves and standardized communication protocols. Each node in the network is resource-constrained, with limited processing power, storage, and bandwidth. Once deployed, the nodes automatically organize into a functional network, often relying on multi-hop communication to transmit data. The sensors can operate either continuously or based on specific events.

Location tracking can be achieved using Global Positioning System (GPS) or other local positioning methods. Additionally, some WSNs include actuators that can respond to certain conditions, transforming the system into a Wireless Sensor and Actuator Network (WSAN).[3]

There are real-time modules, like sensors, that are connected to each other and send the data they gather to centralized repositories. In these repositories, the data is stored collectively and made available to authorized users. Unlike traditional wired or wireless networking systems, modern wireless technologies have distinct characteristics, particularly due to the larger number of communication devices involved.[4]

Literature Review

The paper entitled *"Design of an Integrated Wearable Multi-Sensor Platform Based on Flexible Materials for Neonatal Monitoring"* by Hongyu Chen et al. (2020) presents the development of a wearable multi-sensor platform designed specifically for continuous monitoring of neonatal vital signs. The platform is built using flexible, biocompatible materials that ensure better comfort and adaptability for newborns, addressing the limitations of traditional rigid sensor systems. By integrating various sensors into a single wearable device, the system is capable of measuring important parameters like heart rate, respiration rate, body temperature, and oxygen saturation simultaneously, which is critical for neonatal care in intensive care units (NICUs). The use of soft, flexible materials in the platform reduces the risk of skin damage and pressure sores, common issues in conventional neonatal monitoring systems. Additionally, the platform allows for real-time data acquisition and wireless transmission, enabling continuous and remote monitoring by healthcare professionals. Power management techniques are also employed to ensure low-power consumption, extending the device's operational time and minimizing interruptions caused by frequent battery changes or recharging. The primary application of this technology is in NICUs, where continuous, non-invasive monitoring is essential for newborns. Compared to traditional systems, this platform offers improved comfort and reduces risks associated with prolonged sensor use. The paper concludes that the integrated wearable multi-sensor platform holds great potential for improving neonatal care by offering more efficient, real-time monitoring while ensuring the comfort and safety of newborns.

The paper entitled *"Development of Smart Healthcare Monitoring System in IoT Environment"* by Md. Milon Islam, Ashikur Rahaman, and Md. Rashedul Islam (2020) presents a smart healthcare system that utilizes Internet of Things (IoT) technology to monitor patient health and environmental conditions in hospital rooms. The system is designed to track essential health signs, such as heart rate and body temperature, along with environmental factors like room temperature, humidity, and the levels of carbon monoxide (CO) and carbon dioxide (CO2). The system uses five sensors to gather this data, which is then transmitted through a web portal, allowing medical staff to monitor patients' conditions in real time and analyze their current health status remotely. The conclusion of this paper emphasizes that the developed system achieves more than 95% accuracy in tracking patient vitals and room conditions, making it a reliable tool for healthcare monitoring. This real-time data access is particularly useful for medical staff in managing epidemics or crises, such as during the COVID-19 pandemic, where quick analysis of medical data is crucial. Additionally, the system has potential to include video features for face-to-face consultations between doctors and patients, enhancing telemedicine capabilities. The prototype is simple to design and easy to use, making it a practical solution for improving patient care, especially in situations requiring remote monitoring and treatment.

The paper entitled *"Neonatal Health Monitoring System with IoT Application"* by Sheril Amira, Nor Asmira, Tengku Nadzlin, Mohd Helmy A., Omar A.H., Muhammad Shukri A., and Ahmad Alabqari M.R. (2019) presents a neonatal health monitoring system designed for use in Neonatal Intensive Care Units (NICUs). The system aims to address the lack of early warning alerts in many hospitals, which can delay timely interventions by physicians when a neonatal health issue arises. The system incorporates the LM35 temperature sensor and a pulse sensor, all controlled by an Arduino Uno using C/C++ programming. It uses Bluetooth technology to enable remote monitoring through an Android application, which can be downloaded from Google Play. The system allows users, including healthcare professionals and even parents or caregivers outside of the NICU, to monitor the condition of neonates remotely. Information about the neonate's health, such as temperature and pulse, is also displayed on an LCD screen. In conclusion, the neonatal health monitoring system is capable of measuring, displaying, and recording vital health parameters such as body temperature, heart activity, pulse rate, and respiratory rate. The system is designed as a user-friendly structural monitoring tool that enables home health checking. By integrating sensors with Arduino, the system provides real-time monitoring and early warning alerts, ensuring that immediate action can be taken if a neonate's

condition becomes critical. This innovation holds significant potential for improving neonatal care and safety by allowing continuous monitoring both inside and outside the NICU.

The paper entitled *"Non-invasive IoT Sensing and Monitoring System for Neonatal Care"*by Jose Ilton de Oliveira Filho, Otacilio da Mota Almeida, Nadya Yousef, and Khaled Nabil Salama (2019) presents a non-invasive system for monitoring neonatal vital signs, particularly focusing on temperature regulation in neonatal incubators. The system utilizes infrared (IR) thermography, a non-invasive method that allows monitoring from a distance. By combining IR thermography with Internet of Things (IoT) technology, the authors developed a risk management system capable of monitoring and reacting to sudden changes in the neonate's temperature. This system aims to detect hypothermia or hyperthermia early, allowing for immediate action to prevent serious complications. One of the key features is its ability to monitor multiple areas of the neonate's body temperature, detecting early signs of hypothermia before any noticeable change in core temperature occurs. The system captures thermal images every 0.5 seconds and uploads the data to the cloud every 20 seconds for real-time analysis. In the event of any abnormal temperature changes, alarms are activated, and notifications are sent to caregivers or medical staff within a maximum delay of 2 minutes. The system segments the thermal distribution into four distinct images, each of which helps identify the boundaries between warm and cold regions, providing a detailed spatial analysis of temperature variations. In addition to monitoring temperature, the system stores the data on a cloud web service and sends alerts to users' smartphones, ensuring timely intervention in case of any potential risks to the neonate.

The paper titled *"Intelligent Health Monitoring System Based on Smart Clothing"* by Chung-Chih Lin, Chih-Yu Yang, Zhuhuang Zhou, and Shuicai Wu (2018) introduces a health monitoring system that leverages smart clothing to track vital signs and detect potential health issues. The system consists of three primary components: smart clothing equipped with sensors for electrocardiography (ECG) signal collection and heart rate monitoring, a control platform for care institutions, and a mobile device for remote access. The smart clothing serves as a wearable device that collects and processes ECG data while monitoring the wearer's heart rate. To improve the accuracy of ECG signals, the authors propose the use of a fast empirical mode decomposition (Fast-EMD) algorithm to filter out noise and enhance signal quality. Additionally, the system incorporates a hidden Markov model (HMM)-based algorithm to detect falls, a critical feature for elderly care. The system provides eight key services, including the surveillance of vital signs, tracking of physiological functions, monitoring of activity fields, anti-lost features, fall detection, emergency call functions, device wearing detection, and low battery warnings. These features ensure comprehensive health monitoring, especially for the elderly, who may need assistance in emergency situations or if they experience a fall. The Fast-EMD algorithm is an enhanced version of the empirical mode decomposition (EMD) algorithm, specifically optimized for wearable devices to reduce motion artifacts, improving the accuracy of the health data collected. This intelligent system offers a robust and multi-functional solution for real-time health monitoring.

1. Problem Definition

The neonatal health monitoring system that are presently deployed are basically for monitoring the health conditions of the neonates they are in NICU. Most of these systems does not implement the IOT. Some modules for the system are described using IOT, but these modules can give the data for specific environment in the NICU. Furthermore, in the developing countries, where there is unavailability of specialist doctors, Tele-medicine is being used since long ago. These tele-medicine systems generally do not use automated system to take the data of the patients. The manually taken data may cause the error and sometimes this may be dangerous hazard to the patient. The neonates are more sensitive for their health condition and the small mistakes for their health status data may cause serious problem for them.

The proposed system is to overcome the problem that are faced in tele-medicine. The system allows to take the health status data of neonates by using different sensors in the real time environment. The paediatric specialist, who are not present in the remote areas can examine the neonates by observing these real time data from his/ her cabin through the real-time web portal.

2. Methodology

There will be some sensors like temperature sensor, blood oxygen sensor, pulse rate measurement sensor, heart rate measurement sensors are used to monitor body temperature, blood oxygen level, pulse rate and heart beat rate of neonates. For this we will need sensors, ESP 32 and a power source. After taking the reading from the neonates, the data will be sent to

the ESP-32. Doctor can see the reading from a distant area only by logging into his/her account. Both the patient and doctor can interact with each other through the real-time web-portal. Internet connection is mandatory to use this system.

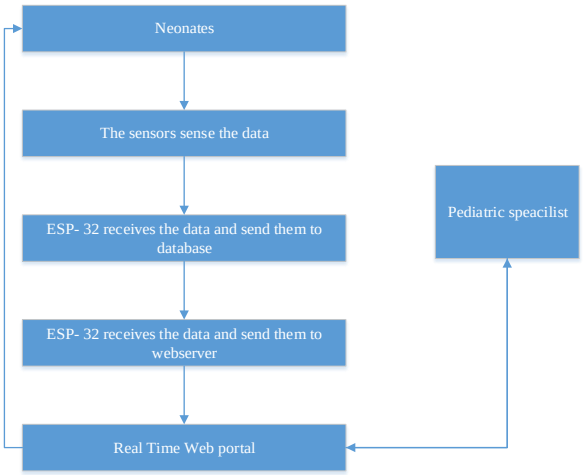

Figure 1 Work flow of the system

4.1. Functional Block Diagram

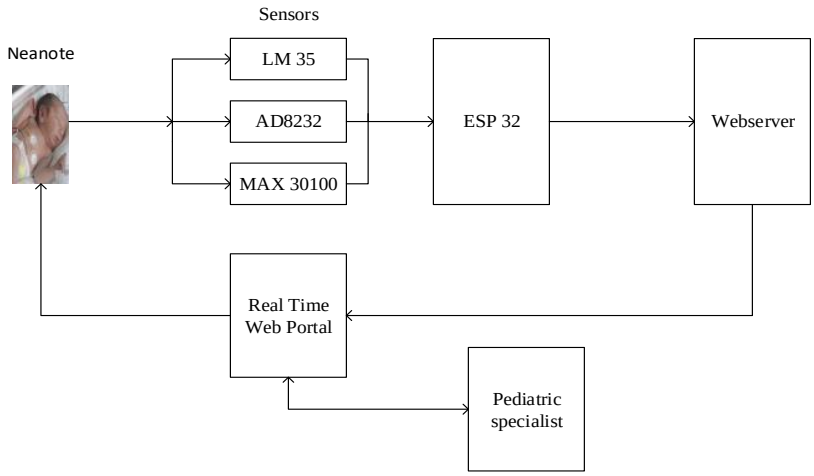

Figure 2 Functional Block Diagram

Hardware Description

ESP-32

The ESP32 is a versatile and powerful embedded Wi-Fi and Bluetooth LE microcontroller unit (MCU) designed for a wide range of applications. Its uses span from low-power sensor networks to more complex tasks like voice encoding, music streaming, and MP3 decoding. At the heart of this module is the ESP32 chip, which is known for its scalability and adaptability. The chip features two CPU cores, which can be managed independently, with a clock frequency that can be adjusted between 80 MHz and 240 MHz. Additionally, a low-power coprocessor allows for energy-efficient tasks like peripheral monitoring without using the main CPU.

The ESP32 comes with a rich array of peripherals, including capacitive touch sensors, an SD card interface, Ethernet, high-speed SPI, UART, I2S, and I2C. Its integration of both Bluetooth and Wi-Fi makes it suitable for a wide variety of applications.

The Wi-Fi connectivity provides a large physical range and internet access through a router, while the Bluetooth feature allows convenient connections to smartphones or low-energy broadcasting for detection. With a sleep current of less than 5 μA, the ESP32 is ideal for battery-powered devices and wearable electronics. It supports data transfer rates of up to 150 Mbps and delivers 20 dBm output power at the antenna, ensuring strong signal coverage.

The ESP32 runs on the FreeRTOS operating system with LwIP and includes TLS 1.2 with hardware acceleration for security. It also supports secure, encrypted over-the-air (OTA) updates, enabling users to easily upgrade their products even post-release with minimal effort and cost.[6]

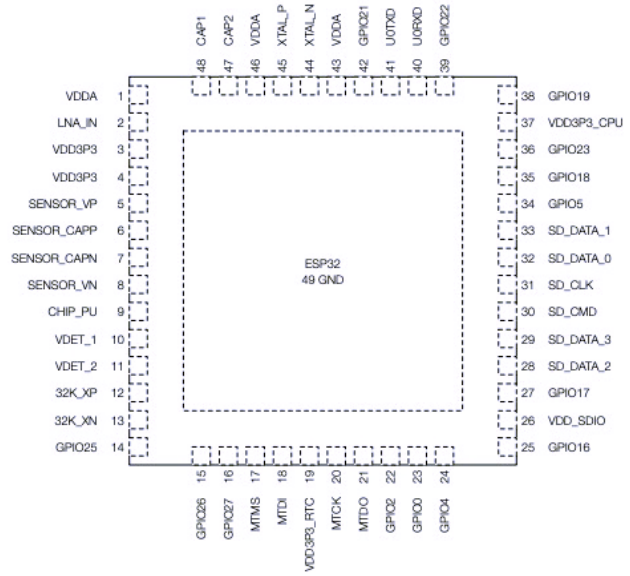

Figure 3 ESP32 pinout [6]

LM-35 sensor:

The LM35 sensor is a precision temperature sensor that produces an output voltage directly proportional to the temperature in Celsius. Unlike sensors calibrated in Kelvin, the LM35 offers the advantage of providing readings in Celsius without the need for additional calculations. It does not require external calibration or trimming, offering high accuracy with a typical error of ±¼°C at room temperature and ±¾°C across its operating range of −55°C to 150°C.

The sensor is cost-effective due to its trimming and calibration done at the wafer level. Its low output impedance, linear voltage response, and built-in calibration make it easy to integrate with readout or control systems. It operates with either single or dual power supplies and consumes only 60 μA, resulting in minimal self-heating of less than 0.1°C in still air. The LM35 is designed to work within a temperature range of −55°C to 150°C, while the LM35C model covers a range from −40°C to 110°C with improved accuracy at lower temperatures.

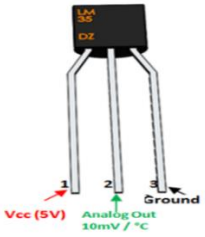

Figure 4 LM35 with pinout

AD8232 ECG sensor:

The AD8232 is an integrated signal conditioning module specifically designed for ECG and other biopotential measurement applications. It extracts, amplifies, and filters small biopotential signals, even in noisy environments, such as those caused by motion or distant electrode placement. This makes it easier for an ultralow-power analog-to-digital converter (ADC) or embedded microcontroller to capture the output signal.

The AD8232 features a two-pole high-pass filter to eliminate motion artifacts and electrode half-cell potentials. This filter works seamlessly with the amplifier's architecture to provide both high gain and filtering in a single stage, optimizing space and cost. Additionally, it includes an uncommitted operational amplifier that can be used to create a three-pole low-pass filter to reduce additional noise, with customizable frequency cut-offs to fit different applications.

To improve noise rejection, particularly of line frequency interferences, the AD8232 includes an amplifier for driven lead applications, like the right leg drive (RLD). It also features a fast restore function, which shortens the recovery time after an abrupt signal change, such as when electrodes are disconnected. This allows the system to return to accurate measurements quickly after reconnection.

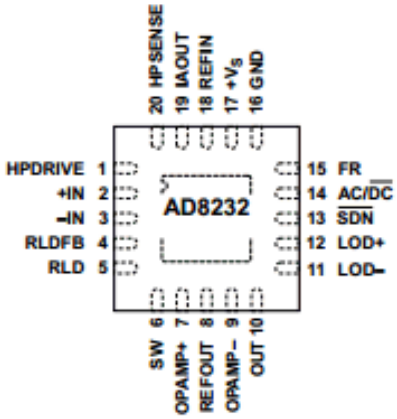

Figure 5 AD 8232 pin diagram[7]

Technical Specifications of AD8232 sensor

Analog Output: Provides continuous analog signal output.

- Operating Voltage: 3.3V DC, suitable for low-power systems.
- Low Power Consumption: Draws only 170 µA, ideal for battery-operated devices.
- Noise Rejection: Capable of rejecting 60Hz noise with a high rating of 80 dB.
- High Gain Amplification: Features a gain of 100, along with DC blocking for accurate signal amplification.
- Right Leg Drive (RLD): Integrated right leg amplifier for better noise reduction.
- RFI Filtering: Built-in filtering to minimize radio frequency interference.
- Power Management: Equipped with a shutdown pin for conserving power.
- Electrode Connection: Uses a standard 3.5mm mini plug for electrode input.
- Flexible Electrode Configuration: Can be used with 2 or 3 electrodes based on the application.

How to Read an ECG:

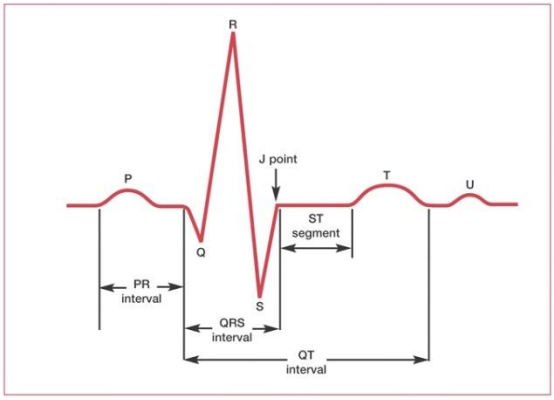

Figure .6 Typical example of heart beat[8]

The normal rhythm of an electrocardiogram (ECG) is characterized by three key components: the P wave, the QRS complex, and the T wave. To interpret an ECG effectively, it's essential to assess the presence, shape, and duration of these waves, along with the ST segment. The ST segment represents the time between the end of ventricular depolarization and the beginning of repolarization. A normal ST segment measures less than 1 mm; if it exceeds this, it may indicate conditions such as infarction or ischemia.

The P waves help determine the interval between heartbeats, appearing as a straight line connecting the lowest and highest points on the ECG trace. The T wave, which follows the QRS complex, signifies the conclusion of the heartbeat and represents a subtle, detectable beat. Throughout the ECG recording, the intervals between the P waves and T waves should remain relatively consistent. If there is noticeable variability in these intervals during the test, it may suggest an irregular heartbeat.[8]

MAX30100

The MAX30100 is an integrated sensor solution for pulse oximetry and heart rate monitoring. It combines two LEDs, a photodetector, optimized optics, and low-noise analog signal processing to accurately detect pulse and heart rate signals. The sensor can operate with power supplies of 1.8V to 3.3V and features a software-controlled power-down mode with negligible standby current, allowing for constant connection to the power supply.

Features of MAX30100:

- Low Power Consumption: Operates efficiently from 1.8V to 3.3V.
- Ultra-Low Shutdown Current: Typically consumes only 0.7 µA in shutdown mode.
- Fast Data Output Capability: Enables quick and efficient data transmission.

Working Principle of the MAX30100 Pulse Oximeter and Heart Rate Sensor:

The MAX30100 uses two LEDs: one emits red light, and the other emits infrared light. For measuring pulse rate, only the infrared light is required, while both light sources are utilized to assess oxygen levels in the blood. When the heart pumps, there is an increase in oxygenated blood, resulting in a higher volume of blood. As the heart relaxes, the volume of oxygenated blood decreases. By analyzing the time interval between the increase and decrease in oxygenated blood, the device can determine the pulse rate. Oxygenated blood absorbs more infrared light and allows more red light to pass through, while deoxygenated blood absorbs red light and permits more infrared light. The MAX30100 reads the absorption levels of both light sources, storing the data in a buffer that can be accessed via I2C communication.

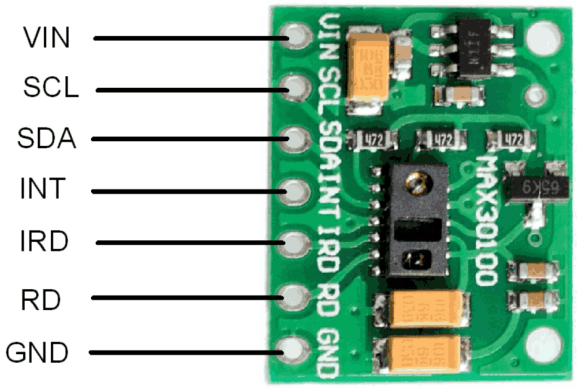

Figure 7 MAX 30100 Pin diagram

MAX30100 Pin Description

- VIN: Power supply pin connects in the range of
- GND: Connect to Supply ground.
- SCL: Serial Clock pin for I2C Serial Communication.
- SDL: Serial Data pin for I2C Serial Communication.
- INT: Active Low Interrupt pin.
- IRD: IR LED Cathode and LED Driver Connection pin.
- RD: Red LED Cathode and LED Driver Connection pin.

Total interfacing Diagram

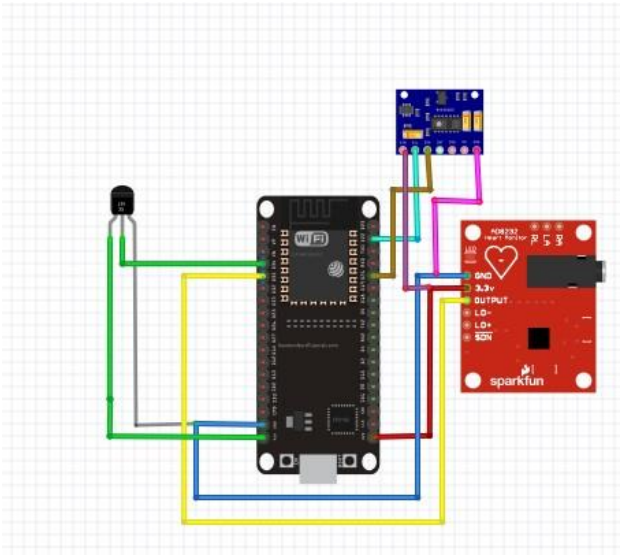

Figure 8 Total interfacing Diagram

5. Observations

Observations for LM35 sensor after interfacing with ESP32

The LM35 temperature sensor, AD8232 and MAX301000 sensers are individually interfaced with ESP32 and first individual results are taken.

The figure 12 below shows the connection of LM 35 with ESP32, the code screen shot and the serial monitor output.

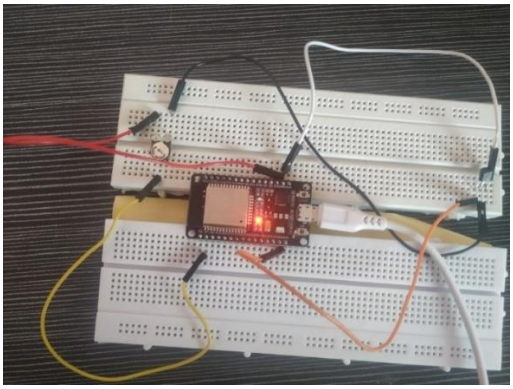

Fig 9 LM 35 connection

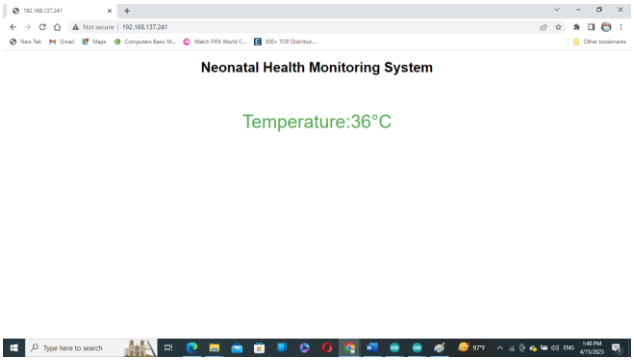

Fig 10 LM35 web-portal

Figure 11 LM35 code in Arduino IDE

The LM35 temperature sensor operates within a temperature range of -55°C to 150°C and offers an accuracy of ±0.4°C at room temperature. It outputs a voltage that is directly proportional to the temperature it measures. The proportional factor, also known as the scaling factor or resolution, is set at 0.01 V/°C. This means that for each degree Celsius increase in temperature, the LM35 provides an output of 100 mV.

When the LM35 sensor is interfaced with ESP32 and connected with Arduino IDE and the code is run, the output of LM35 sensor can be viewed in serial monitor. The code written here can show the temperature reading in the Celsius. At the same time if the ESP32 is connected with the Wi-Fi, we can view a Real-time web-portal displaying the same data that is displayed in the serial monitor. The Real-time web-portal is accessible by anywhere if it is hosted in the internet. For this project we can access the web-portal by using local IP address. The Local IP address is generated and displayed in the serial monitor.

The voltage drop of LM35 is unstable, thus the temperature reading is also being drastically change. To solve this problem, we can use RC Damper Circuit and a Decoupling Capacitor.

Observations for AD8232 sensor after interfacing with ESP32

The AD8232 sensor enables the recording of the heart's electrical activity by obtaining an electrocardiogram (ECG). It detects signals generated by heartbeats, as electrical signals travel along specific pathways within the heart to initiate the heartbeat. These electrical signals can be captured using electrodes placed on the skin, typically on the chest, arms, and legs.

The AD8232 module is equipped with specially calibrated signal amplifiers and noise filters tailored for ECG signals. It effectively suppresses 60 Hz noise commonly generated by household electrical sources. Since the module outputs an analog signal, it is essential to solder header pins and connect it to a microcontroller with analog input capabilities, such as Arduino, ESP32, or ESP8266. In the accompanying program, analog-to-digital conversion must be performed to visualize the ECG data on the Arduino IDE plotter.

The figure below shows the circuit connection and code on Arduino IDE.

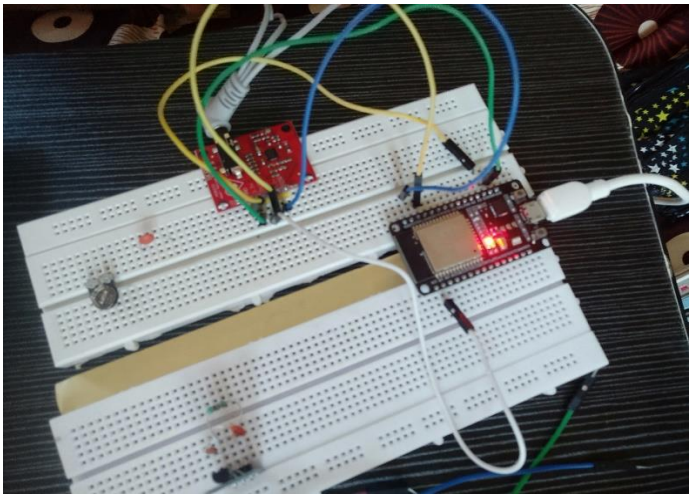

Figure 12 connection of AD8232 with ESP 32

AD8232new | Arduino 1.8.19 (Windows Store 1.8.57.0)

File Edit Sketch Tools Help

AD8232new

```
#endif
 prevData[roundrobin] = newData;//store previous value
}

void setup() {
  Serial.begin(115200);
}

void loop() {
  newData = analogRead(34);
  freqDetec();
  if (period!=lastperiod) {
     frequency = 1000/(double)period;//timer rate/period
     if (frequency*60 > 20 && frequency*60 < 200) { // supress unrealistic Data
      beatspermin=frequency*60;
#ifndef PLOTT_DATA
        Serial.print(frequency);
        Serial.print(" hz");
        Serial.print(" ");
        Serial.print(beatspermin);
        Serial.println(" bpm");
#endif
        lastperiod=period;
     }
  }
  delay(1000);
}
```

Figure 13 Source code for AD8232 on IDE

Observations for MAX30100 sensor after interfacing with ESP32

The MAX30100 Pulse Oximeter is a device that is used to measure blood oxygen saturation levels, heart rate, and pulse strength for medical purpose. It is used to measure oxygen saturation levels in the blood by using a non-invasive method. This module has a pair of LEDs that emit a monochromatic red light at a wavelength of 660nm and infrared light at a wavelength of 940nm. As the photodiode emits light, it touches the finger and gets absorbed by the oxygenated blood remaining light is reflected through the finger and falls on the detector. The detector detects and processes the signals and gives the output.

When MAX 30100 is interfaced with the ESP 32, the connection diagram and output will be as shown below

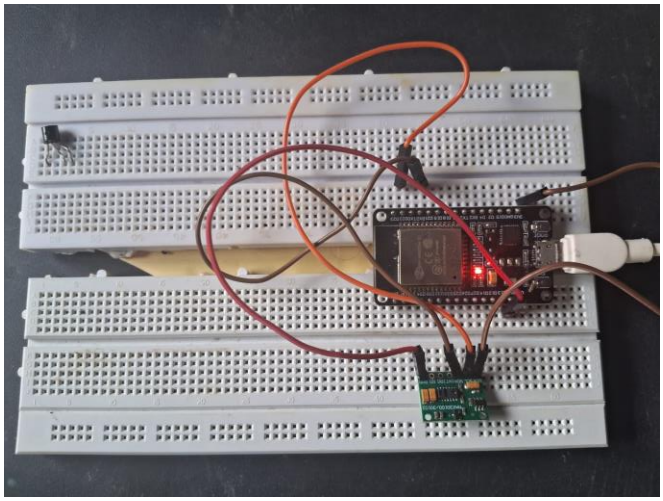

Figure 14 Connection of MAX 30100 with ESP 32

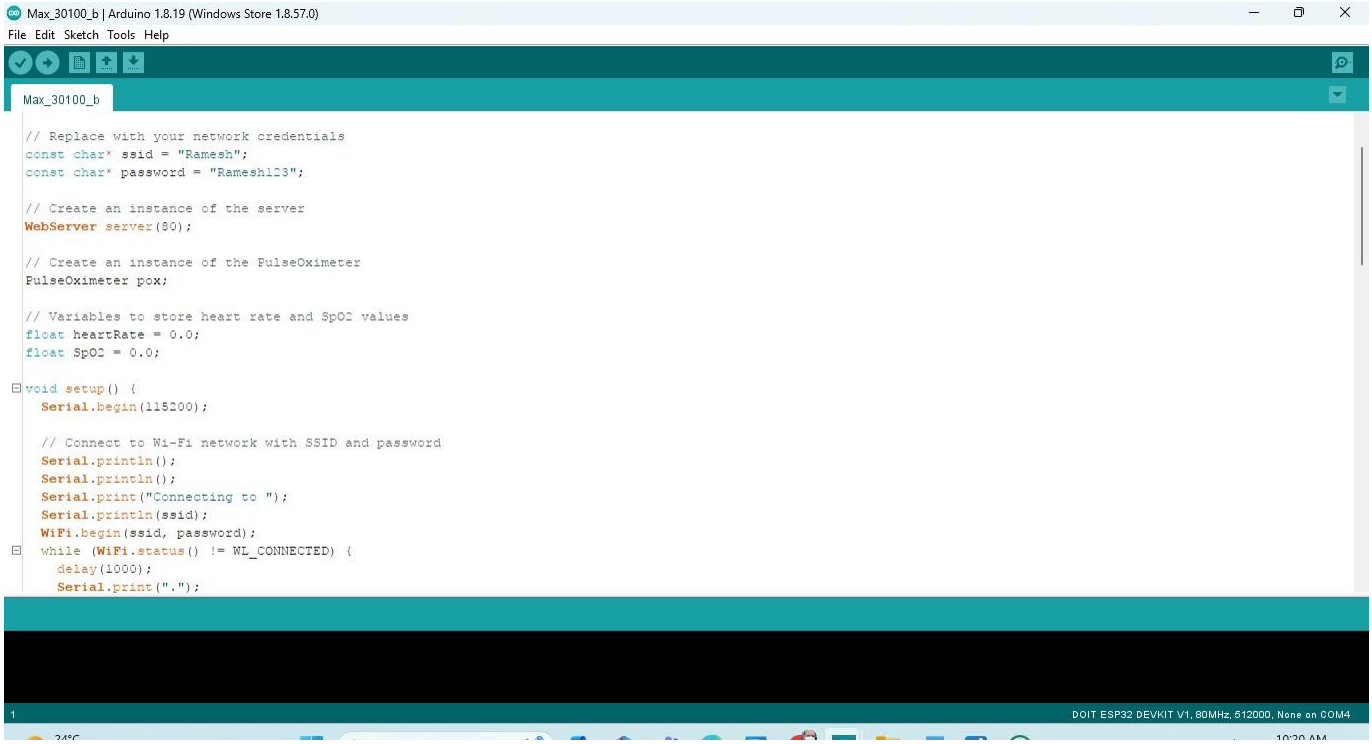

Figure 15 source code for MAX 30100 on IDE

Observations for LM35, AD8232 and MAX 30100 sensor after interfacing with ESP32

When all the sensors LM 35 temperature sensor, AD 8232 sensor and MAX 30100 sensor are interfaced with ESP 32 and as per this project the final web portal is observed successfully. The final connection and output is shown in the figure below.

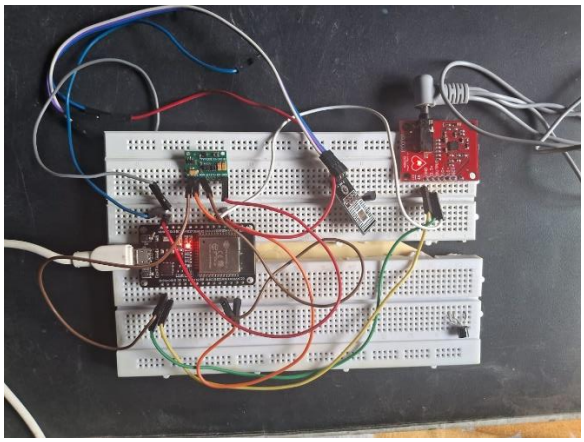

Figure 16 Total sensors connected with ESP 32

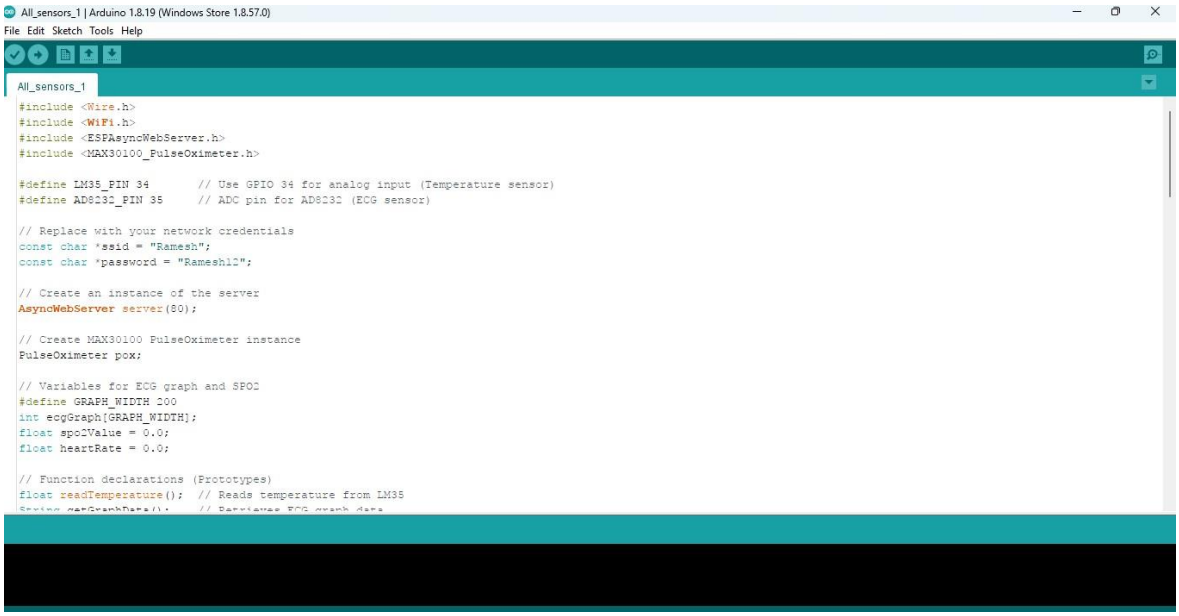

Figure 17 Final code

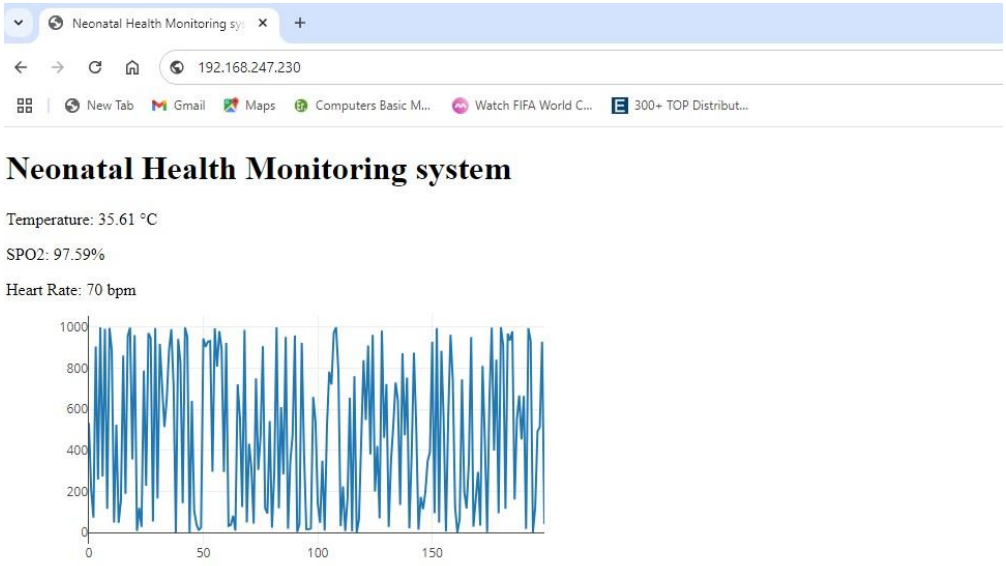

Figure 18 final output on the web portal

6. Conclusion

This project aims to solve the problem of tele-medicine for neonates. Here in this project, mainly three sensors are supposed to be used to measure the body temperature, ECG, heart beat rate and SPO_2. These sensor values obtained are directly uploaded in the Real-Time web-portal. The real- time web-portal can be accessed by pediatrician directly and he/she can observe the values obtained by these sensors and do the necessary examine. This project will be very helpful for the area in the developing countries where there is unavailability of the pediatrician easily. Generally, pediatricians are available in urban areas and the neonates in the rural and suburban areas does not get the opportunity to get medical support from the pediatrician.

In this project, The LM 35, AD 8232 and MAX 30100 sensors are completely interfaced with ESP 32 and a complete real time web-portal is developed. The real time web-portal will give the information regarding the temperature, body oxygen level(SPO2), heartbeat and ECG graph of neonates in the real time.

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