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Research Article **Open access**

Design of Baby Vital Signs with BPM, SpO2, Skin Temperature, and Respiration Rate Parameters for Real-Time Monitoring

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Abstract

The purpose of this study is that the neonatal room requires special monitoring to determine the condition and development of the baby. Because of the importance of oxygen for the human body, the most important indicators needed for the human body are oxygen saturation (SpO2) and heart rate. Oxygen saturation and heart rate are very important because if the oxygen in the newborn is low, it must be watched out for abnormalities in the baby. Based on the description above, then in this study entitled "Design of Baby Vital Signs Monitoring Tool with BPM, SpO2, Skin Temperature and Respiration Rate Parameters in Real Time (BPM and SpO2)" will be made a baby vital sign tool to monitor BPM and SpO2 by using neonatal fingertip sensors and ESP32 as a microcontroller. the method used for this research is transmittance where the Finger sensor consists of IR, LED and Photodiode which faces one side under the fingertip and on the other side is on the back of the fingertip. This neonatal fingertip sensor is a sensor specifically used for babies so that babies feel comfortable and do not interfere with baby activities. From the design of this tool, data that has been compared with infant oxymetry using 5 respondents and 5 repetitions of measurements obtained an error value for the largest SpO2 which is 2.95% and for BPM which is 2.76%, it shows that the module is quite suitable and stable.

Keywords

BPM, SpO2, Sensor Fingertip Neonatal, Baby, Incubator

Specifications table

Hardware name	*Design of Baby Vital Signs with BPM, SpO2, Skin Temperature and Respiration Rate Parameters for Real-Time Monitoring (BPM and SpO2)*
Subject area	• *Electronics and Microcontroller system* • *Diagnostic* • *Life support*
Hardware type	• Field measurements and sensors • Electrical engineering and computer science • Mechanical engineering and materials science
Closest commercial analog	*This hardware provides wireless control for measuring vital signs in infants*
Open source license	*https://creativecommons.org/licenses/by-sa/4.0/*
Cost of hardware	*60 US$*
Source file repository	DOI 10.17605/OSF.IO/5D2YG

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OSHWA certification UID	ID000010

1. Hardware in context

Preterm birth is birth before 37 weeks gestation and is one of the main factors leading to newborn death [1]. Globally, preterm births increased by 8.5 percent between 2000 and 2014. Premature babies have complicated health problems that can lead to death. 16 percent of infant deaths are caused by premature birth and 35 percent cause newborn deaths [2]. Unlike babies born long enough or normal, premature babies are high-risk babies. It is caused by the immaturity of organs such as the heart, lungs, liver, kidneys and digestive system. Baby incubators play an important role in the survival of premature babies [3]. Currently, monitoring of premature babies placed under baby incubators is still done manually. This monitoring system is very important in modern technology that exists in hospitals, its presence is very important to monitor the patient's condition continuously. Especially in the monitoring of premature babies. This continuous monitoring is done for premature infants admitted to the Neonatal Intensive Care Unit (NICU) [4]. In the NICU room, vital signs are monitored: heart rate, and oxygen saturation. (SpO2). Due to the importance of oxygen for the human body, the most important indicators needed for the human body are oxyge saturation (SpO2) and also heart rate. Oxygen saturation and heart rate are important because if the oxygen in the newborn is low then it is necessary to be careful if there is an abnormality in the baby. A person can be said to suffer from hypoxemia if the oxygen saturation in the blood is less than 90%, while for normal SpO2 it has the presence of 95-100% [5]. Therefore, monitoring oxygen saturation levels in infants can help early detection of abnormalities in infants [6].The neonatal room requires special monitoring to determine the condition and development of the baby. Currently, medical personnel in the neonatal room must visit one baby at a time in the baby incubator regularly to find out the baby's vital condition. So, to reduce the workload of a medical worker and reduce the risk of errors in reading patient data, a device is needed that can monitor vital status, especially the vital parameters of BPM and SpO2 babies remotely, so that medical personnel can continue to monitor the state of the baby's vitality [3].

Fig.1. placement of the sensor on the patient

In a previous study conducted by M. Subramanian et al, in 2018 entitled "Security And Health Monitoring System Of the Baby Incubator" using IR sensors to detect heart rate and Arduino Atmega328 microcontrollers. The study only looked at the heart rate, temperature, and also pressure of babies in baby incubators. Then further research has been carried out by Sukamto in 2020 entitled "Smart Incubator Prototype Design Based on the Internet of Things" In this study, the baby smart incubator system was applied for baby monitoring, which included temperature, baby weight, baby's heart rate. The system is built using a mobile application using Android programming based on the Internet of Things. (IoT). However, there is no SpO2 parameter[8]. In 2021, Hanifa Septa Gisella conducted a study titled "Temperature and BPM Vital Signs in Infants Wirelessly" using SEN11574 sensors for BPM. This study only discusses BPM and temperature, there are no SpO2 parameters. And obtained values 2 – 5 for BPM which means there are still errors [9]. Then research was also conducted

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by Mirza Fissabila with the title "Development of Central Monitoring Center SpO2 for Neonate Space with Wireless System" using 2 sensors, namely neonatal fingertips and MAX30100 for spO2 and HC-05 measurements. In this study there are no BPM parameters and still use 2 tool modules. From this research still obtained errors. And for further development, the device was made portable and could be used on more patients simultaneously [3].Based on the description above, the study entitled "Design of Baby Vital Sign With BPM, SpO2, Skin Temperature and Respiration Rate Parameters for Real Time Monitoring (BPM And SpO2)" will create a baby vital sign tool to monitor BPM and SpO2 using neonatal fingertip sensors and ESP32 as microcontrollers. The design of the device will be portable or minimal so that it is easy to carry or move and the results will be displayed on Nextion LCDs and smartphones using the Mit inventor application and accompanied by a buzzer notification on the device then equipped with patient data storage with email display. The device can also be used for two power supplies DC (Battery).

2. Hardware description

in **Fig. 2** is a block diagram view of our tool which consists of BPM and SpO2 sensors, temperature sensors and RR sensors, next there is the ESP-32 microcontroller, PSA circuit, and Nextion TFT display, smartphone and email sending

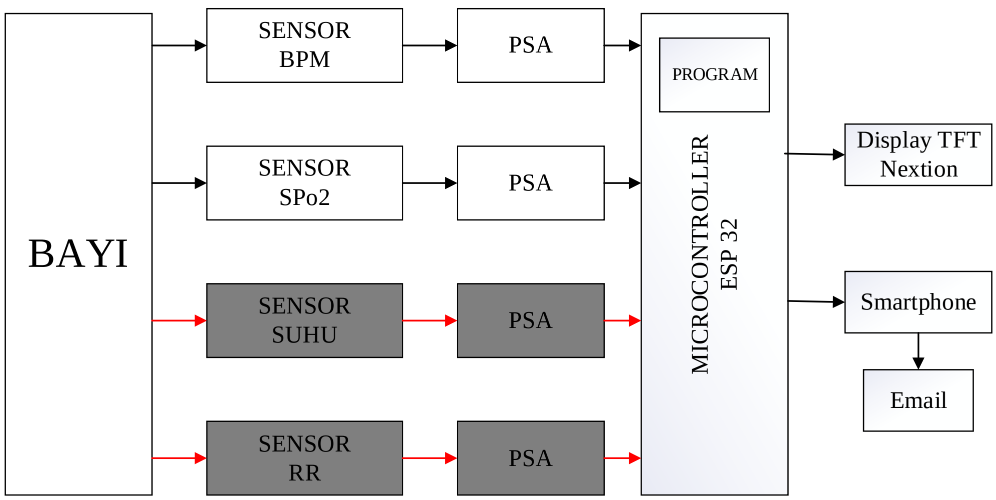

Fig. 2. The diagram block of the Baby Vital Sign

indicates that neonatal patients will use fingertip sensors for BPM and SpO2 readingsOn the baby's legs there is a neonational fingertip sensor that will detect the oxygen saturation (SpO2) and heart rate (BPM) of the baby. The result of the BPM and SpO2 readings will enter the Psa network for reinforcement. Next on the process on the ESP32 microcontroller. Then after the BPM and SpO2 values data in the process then will be displayed on the Nextion TFT display. On the display will display BPM and SPO2. Then the data will also be sent to the smartphone via Wi-Fi that is a value and sent to Email.

2.1. Baby Vital Sign hardware

This baby's vital signs consist of a box measuring 20 x 20 which is designed using solid works, and in the box there is a place for the Nextion LCD screen and below it there is a place for the NTC sensor to measure the baby's skin temperature, next to it there is an RR sensor which is used to measure the respiratory rate the baby, and next there are BPM and SpO2 sensors which are used to measure the baby's oxygen saturation and heart rate. on the side of the box there is an on/off switch. for display on smartphones where data is sent via WiFi in the form of displaying Temperature, RR, BPM and SpO2 values as shown in **Fig.3**.

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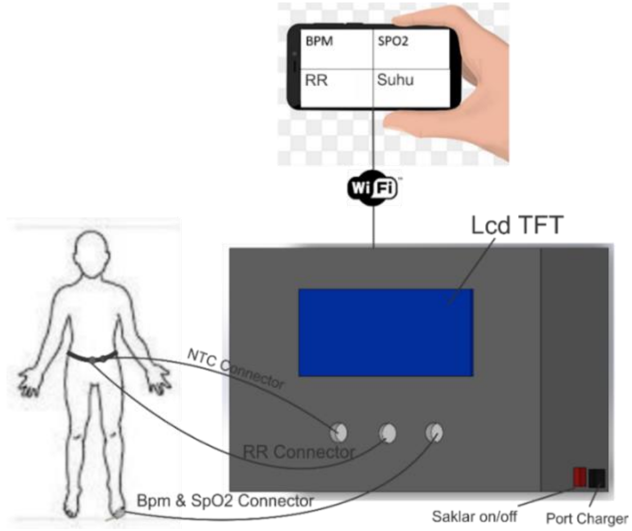

Fig. 3. Baby Vital Sign Hardware

2.2. Hardware Circuit

The hardware circuit consists of two main parts, master and slave, as shown in **Fig. 5** and **Fig. 6**. In addition, it also consists of an ESP32 microcontroller [24][25]. In this study, the ESP32 is a built-in mini Wemos D1 which is powered by Xtensa® dual-core 32-bit LX6 microprocessor(s) with specification as explained in the Table 1. In the master section, the hardware is composed of a microcontroller ESP32 mini Wemos D1, I2C multiplexer TCA 9548, and five IMU sensors. The IMU sensor is based on the GY-521 module composed of MPU6050. The I2C pin, GPIO21, and GPIO22 are connected to the SCL and SDA input of TCA9548. Meanwhile, the I2C multiplexer TCA9548 communicates to the five IMU sensors alternately.

Table 1
Summary of ESP32 Specification

Items	Specification
MCU	Xtensa Dual Core 32-bit LX6, 600 DMIPS
802.11 b/g/n Wi-Fi	Yes, HT40
Power Input	3,0 – 5 VDC
Typical Frequency	160 MHz
SRAM	512 kBytes
Flash	SPI Flash up to 16 MBytes
GPIO	36
Hardware/ Software PWM	1/ 16 channels
SPI/ I2C/ I2S/ UART	4/2/2/2
ADC	12-bit
CAN	1
Ethernet MAC Interface	1
Touch Sensor	1
Temperature Sensor	YES
Working Temperature	-40 °C -12 °C

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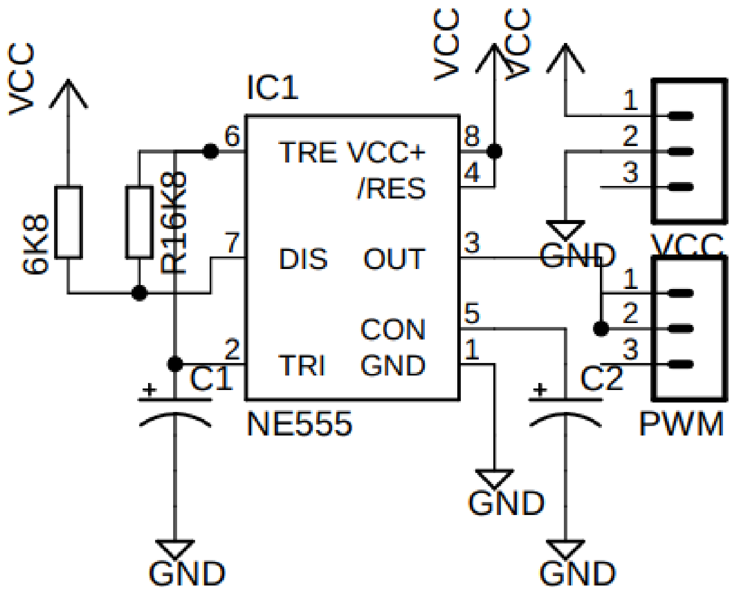

Fig. 4. PWM circuit

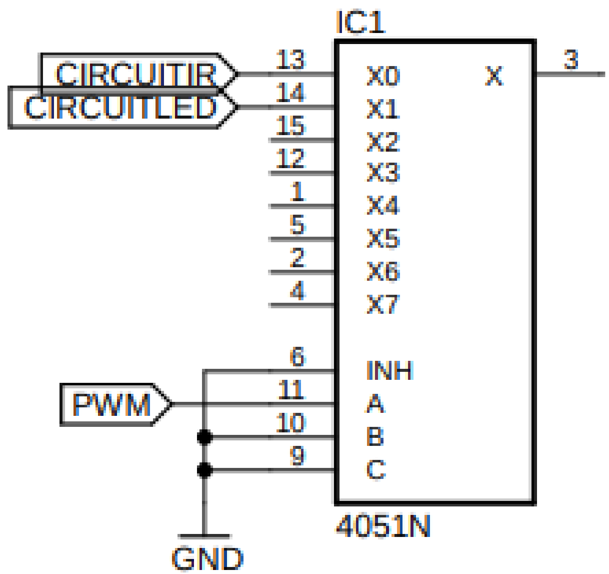

Fig. 5. Demultiplexer circuit

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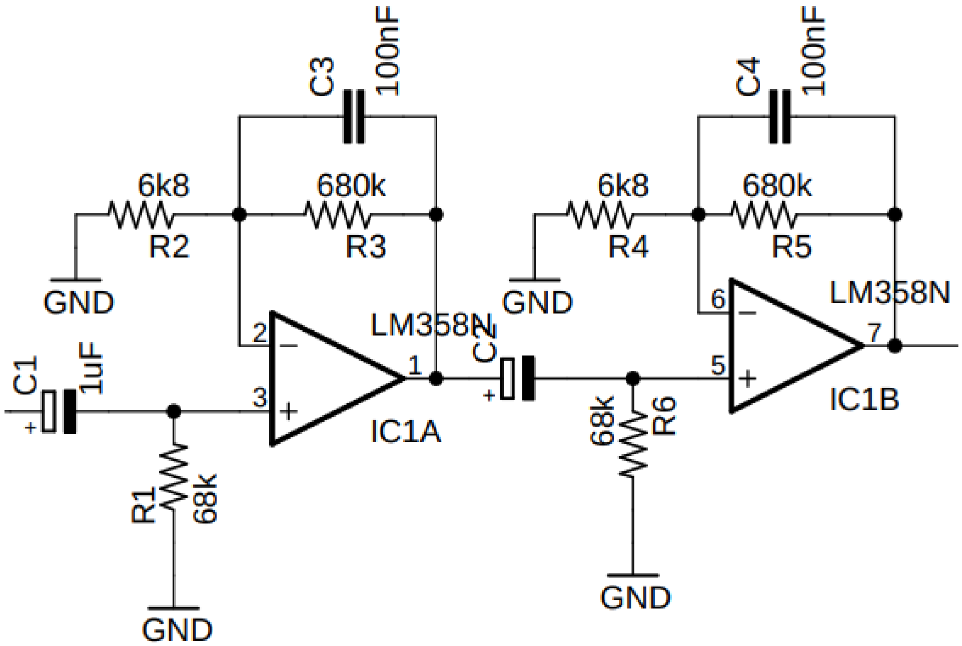

Fig. 6. Amplifier and Filter circuit

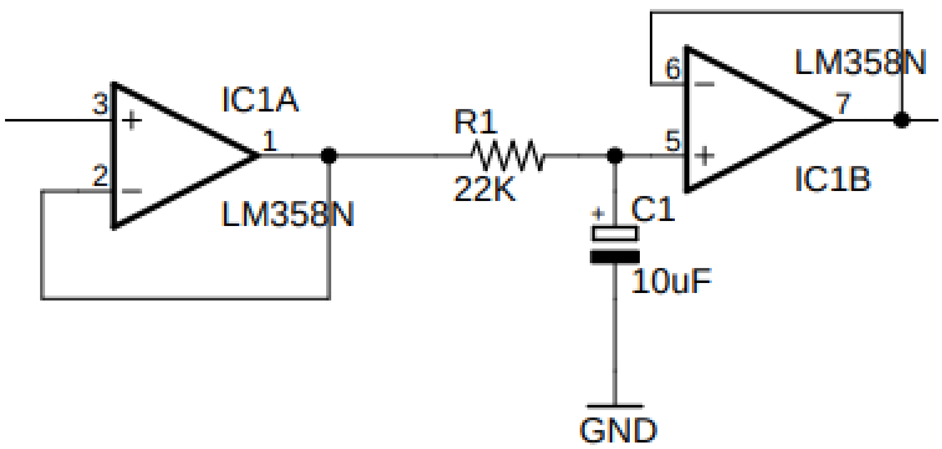

Fig. 7. LPF 0,8Hz circuit

In this SpO2 and BPM circuit using a PWM circuit, Demultiplexer circuit, 0.8Hz LPF circuit and 2.34Hz amplifier and filter circuit. This PWM circuit uses IC NE555 and requires an input voltage of +5VDC and GND. In this circuit, the supply from the battery is connected to +5Vdc then check the output of the circuit using an oscilloscope. Then there is a demultiplexer circuit that is used to separate the output of the finger sensor into red and ir signals. This circuit uses IC CD4051 and requires input voltages of +5VDC, -5VDC and GND. After that there is a 0.8Hz LPF circuit which requires an input voltage of +5VDC, -5VDC and GND and uses the LM358 IC. This circuit is used to remove the AC signal and pass the DC signal. Then there is a 2.34Hz Amplifier and filter circuit that uses a gain of 101 times and the filter used has a cut-off frequency of 2.34 Hz. This BPF filter consists of a passive HPF filter and an active LPF. The output of the demultiplexer leg 13 or leg 14 will be connected to the capacitor on the HPF filter as a coupling to block the DC voltage and only pass the AC signal. The second filter is used to suppress the amplitude when passing through the cut off. The results obtained are AC IR and AC RED outputs.

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2.3. Baby Vital Sign Flowchart

In the flowchart above, when the device gets a voltage supply, it will initialise the program. Then input BPM and SpO2 data from the patient. After inputting BPM and SpO2 data, the neonatal fingertip sensor is detected. If the sensor is not detected, the program will re-initialise. Furthermore, the data is processed on the ESP32 and the value will appear on the LCD nextion and also on the smartphone. Then the measurement data is sent and stored in email.

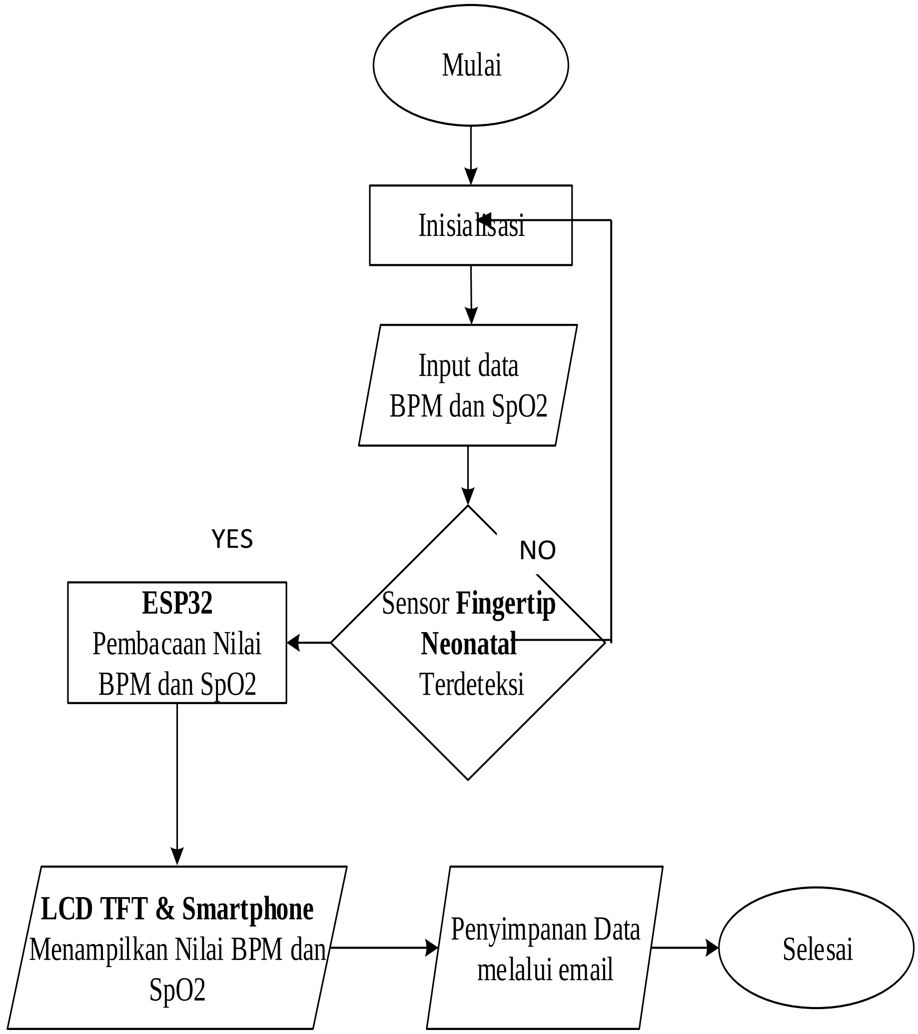

Fig. 8. Firmware flowchart of EHR for slave

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2.4. Easy to control the Baby Vital Sign

The advantages of the module we developed are that this tool has a simple and portable design. This module is also equipped with a display on the android application making it easier for users to monitor babies in the baby incubator. This module is also equipped with a TFT nextion LCD screen display so that users can easily see the value of the parameters in our module. This module has a light weight so that it is easy to carry and move easily. This module has the feature of sending data via email so that it can facilitate data collection on patients.

Table 2
The weight comparison among other studies

Design	Box (kg)
[3]	0.570
[4]	0.570
Proposed design	0.465

2.5. Cost

The high price of vital sign products on the market (>1000 USD) and the use of tools that can only be used in the neonate room, especially for nurses to monitor the vital signs of babies. However, this design has a low cost, which is 60 USD for one product. In addition, this design is open source so that other researchers can develop it with other features and improvements.

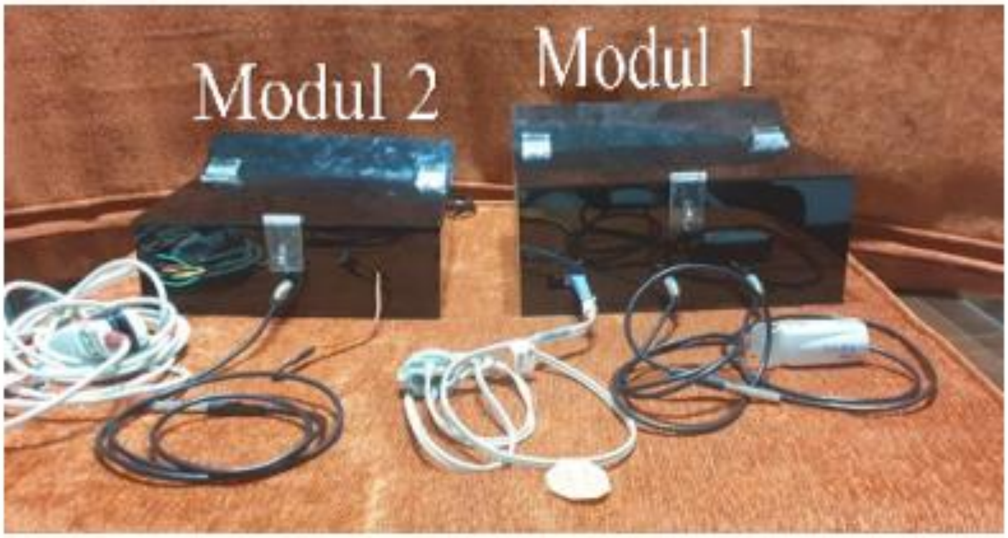

Fig. 9. Design Baby Vital Sign

2.6. Summary

Based on the results of the overall discussion, it can be concluded that:
1.This system consists of Neonatal Fingertip sensor, SpO2 and BPM circuit, ESP32 microcontroller.
2.Neonatal Fingertip Sensor is a sensor consisting of IR, LED and Photodiode.
3.Measurement results can be displayed on the Nextion TFT LCD and Android by using the MIT App application.
4.Improper sensor placement can affect the reading results.
5.Each baby respondent can be taken data 5 times from 5 different baby respondents. The largest SpO2 and BPM error values were obtained, namely 2.95% and 2.76%.

3. Design files summary

3.1. Design file

This section describes the design files generated, both the hardware design (schematic and printed circuit board (PCB)), and microcontroller for data processing as well as the baby vital sign box design file.

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Table 3
Design file summary of exoskeleton for hand rehabilitation

Design file name	File type	Open source license	Location of the file
Pwm.sch	schematic, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
PWM.brd	board, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
Demultiplexer.sch	schematic, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
Demultiplexer.brd	board, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
LPF 0,8Hz.sch	Schematic, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
LPF 0,8Hz.brd	Board, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
Filter HPF.sch	Schematic, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
Filter HPF.brd	Board, eagle file	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG
BPM SpO2.ino	Arduino	CC BY-SA 4.0	DOI 10.17605/OSF.IO/5D2YG

3.2. Schematic and Board
Baby Vital Sign was designed using the Eagle application programme (6.3.0, free version for Windows, CadSoft Computer GmbH, Germany). The schematic file consists of PWM, Demultiplexer, LPF and HPF circuits. these circuits are used to bring up the SpO2 and BPM signals or values.

3.3. Program
baby vital sign is designed using ESP-32 microcontroller with arduino programme. The ESP 32 microcontroller programme is made to process data from SpO2 and BPM values using the Neonatal Fingertip sensor. The value reading programme from SpO2 and BPM will convert into values and send the results on the TFT nextion screen and Mit App application on the smartphone.

4. Bill of materials summary

Table 4
Bill of materials of a baby vital sign

Designator	Component	Number	Cost per unit (USD)	Total cost (USD)	Source of materials	Material type
U1	ESP32	1	2.1600	2.1600	https://www.aliexpress.com/item/1005005704190069.html	Semi-conductor
C1, C2, C3, C4	Capacitors	4	1.5500	7.7500	https://www.aliexpress.com/item/32889741541.html	Plastic, Metal, and semi-conductor
R1, R2, R3, R4, R5, R6	Variable resistor	6	0.1760	0.7040	https://www.aliexpress.com/item/32315929780.html	Metal and ceramic
SW1	Switch push button	1	0.1750	0.1750	https://www.aliexpress.com/item/10000275217379.html	Plastic, metal
IC1	NE555	1	0.3500	0.3500	https://www.aliexpress.com/item/1005002340099086.html	Semi-conductor
IC2	CD4051N	1	0.2560	0.5120	https://www.aliexpress.com/item/1005006589547296.html	Semi-conductor

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IC1	LM358	3	0.3450	1.0350	https://www.aliexpress.com/item/1005002784643392.html	Semi-conductor
J1	Connectors	1	0.0890	0.0890	https://www.aliexpress.com/item/1005003429370278.html	Plastic, metal

5. Build instructions

5.1. Circuit

In this SpO2 and BPM circuit using a PWM circuit, Demultiplexer circuit, 0.8Hz LPF circuit and 2.34Hz amplifier and filter circuit. This PWM circuit uses IC NE555 and requires an input voltage of +5VDC and GND. In this circuit, the supply from the battery is connected to +5Vdc then check the output of the circuit using an oscilloscope. Then there is a demultiplexer circuit that is used to separate the output of the finger sensor into red and ir signals. This circuit uses IC CD4051 and requires input voltages of +5VDC, -5VDC and GND. After that there is a 0.8Hz LPF circuit which requires an input voltage of +5VDC, -5VDC and GND and uses the LM358 IC. This circuit is used to remove the AC signal and pass the DC signal. Then there is a 2.34Hz Amplifier and filter circuit that uses a gain of 101 times and the filter used has a cut-off frequency of 2.34 Hz. This BPF filter consists of a passive HPF filter and an active LPF. The output of the demultiplexer leg 13 or leg 14 will be connected to the capacitor on the HPF filter as a coupling to block the DC voltage and only pass the AC signal. The second filter is used to suppress the amplitude when passing through the cut off. The results obtained are AC IR and AC RED outputs.

5.2. Arduino Programme

The ESP 32 microcontroller programme is made to process data from SpO2 and BPM values using the Neonatal Fingertip sensor. The programme will convert the value of SpO2 and BPM into a value and send the results on the TFT nextion screen and Mit App application on the smartphone.

Fig. 10 Arduino Programme

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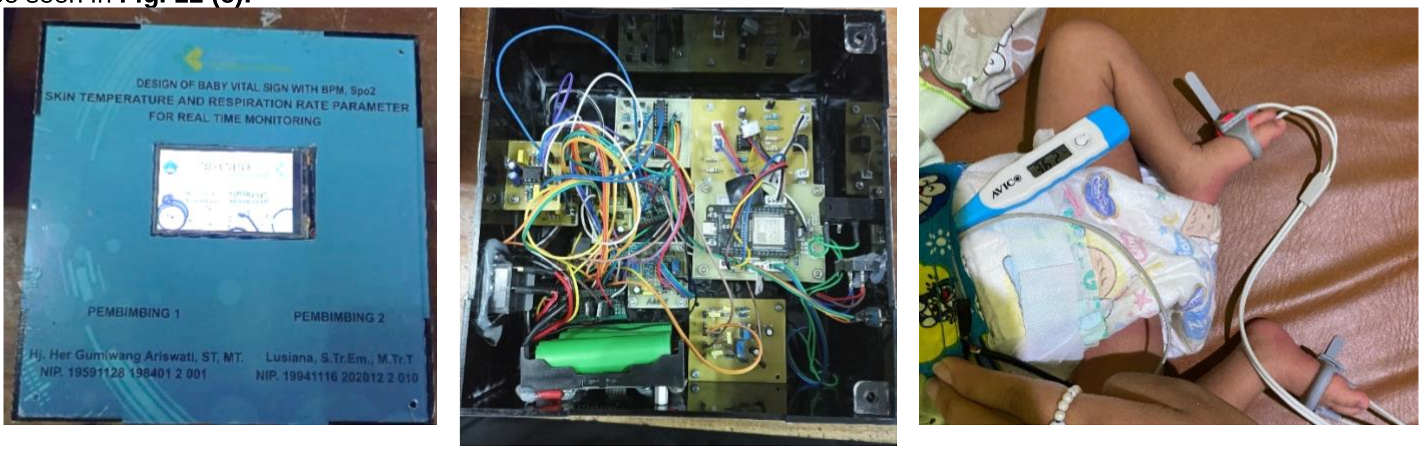
5.3. Hardware Circuit

Below is the hardware of the tool, where there is a PWM circuit used for the next signal generator demultiplexer circuit which is used to separate the two sensor outputs, namely RED and IR, next there is a 0.8 Hz LPF circuit which is used to filter frequencies that are above the cut off and pass frequencies below the cut off after passing through this LPF circuit the filter will be re-amplified with an amplifier circuit and a 2.3Hz HPF circuit. Then for the use of BPM and SpO2 sensors can be seen in **Fig. 11 (c).**



(a) Front View (b) Hardware (c) sensor placement

Fig. 11. Circuit hardware build instruction

6. Operation instructions

Here are the steps to operate the baby vital sign tool:
1. Attach the neonatal fingertip sensor to the baby's thumb or sole.
2. turn on the ON switch to start the measurement.
3. press on the next LCD layer to see the results of BPM and SpO2 measurements.
4. after the measurement results are read, the user can press send on the layer and the results will be sent via email.
5. After being sent to email the data can be stored on the user's smartphone.
6. when finished, remove the accessories on the patient and put them in their original place..

7. Validation and characterization

Data collection on infant respondents was carried out for 5 measurements and each measurement recorded the value of SpO2 and heart rate (BPM). Sensors to detect SpO2 and BPM are placed on the soles or toes of the baby's feet and the error value will be calculated.

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Responden	Alat ukur	Pengukuran SPO2 (%)					Mean	SD	Error (%)
		1	2	3	4	5			
1	Modul	97	97	98	98	97	97,4	0,55	0,62
	Pembanding	97	99	96	95	97	96,8	1,48	
2	Modul	97	98	98	99	97	97,8	0,84	0,20
	Pembanding	97	97	98	99	97	97,6	0,89	
3	Modul	97	98	97	99	97	97,6	0,89	1,46
	Pembanding	95	95	97	98	96	96,2	1,30	
4	Modul	97	97	97	99	98	97,6	0,89	2,95
	Pembanding	93	95	97	96	93	94,8	1,79	
5	Modul	97	97	96	98	98	97,2	0,84	0,21
	Pembanding	95	98	99	97	98	97,4	1,52	

Fig. 12 Spo2 measurement

Responden	Alat ukur	Pengukuran BPM					Mean	SD	Error (%)
		1	2	3	4	5			
1	Modul	122	123	130	122	139	127,2	7,40	2,45
	Pembanding	139	124	130	120	139	130,4	8,62	
2	Modul	122	120	119	123	124	121,6	2,07	0,33
	Pembanding	123	122	120	123	118	121,2	2,17	
3	Modul	118	120	120	119	124	120,2	2,28	0,50
	Pembanding	119	118	120	122	119	119,6	1,52	
4	Modul	119	120	122	124	120	121	2,00	0,33
	Pembanding	120	123	119	119	122	120,6	1,82	
5	Modul	119	125	124	126	120	122,8	3,11	1,66
	Pembanding	117	120	122	119	126	120,8	3,42	

Fig. 13 BPM Measurement

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(a) (b)

Fig. 13. (a) Parameter View on Display, (b) Sensor Placement

8. Conclusion

Based on the results of the overall discussion, it can be concluded that:

1.This system consists of Neonatal Fingertip sensor, SpO2 and BPM circuit, ESP32 microcontroller.

2.The ESP 32 microcontroller is used for the value reading programme from SpO2 and BPM which will convert the data into values and send the results on the TFT nextion screen and Mit App application on the smartphone.

3.Each baby respondent can be taken data 5 times from 5 different baby respondents. The largest SpO2 and BPM error values were obtained, namely 2.95% and 2.76%.

Ethics statements

The author confirmed that informed consent was obtained from the subjects. This research has passed the ethical examination conducted by Health Research Ethics Committee Poltekkes Kemenkes Surabaya, Indonesia, No.EA/1245/KEPK-Poltekkes_Sby/V/2022

Credit author statement

Her Gumiwang A.: Conceptualization, Methodology, and Software. **Lusiana**: Data collection and measurement.**Bella Dwi Andriani**: Mechanical Design.

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Declaration of interests

The authors declare that there is no conflict of interest.

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