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ORIGINAL RESEARCH

Device for remote and realtime monitoring of neonatal vital signs in neonatal intensive care unit using internet of things: proof-of-concept study

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Abstract

Background Realtime and remote monitoring of neonatal vital signs is a crucial part of providing appropriate care in neonatal intensive care units (NICU) to reduce mortality and morbidity of newborns. In this study, a new approach, a device for remote and real-time monitoring of neonatal vital signs (DRRMNVS) in the neonatal intensive care unit using the internet of things (IoT), was proposed. The system integrates four vital signs: oxygen saturation, pulse rate, body temperature and respiration rate for continuous monitoring using the Blynk app and ThingSpeak IoT platforms.

Methods The Wemos D1 mini, a Wi-Fi microcontroller, was used to acquire the four biological biomarkers from sensors, process them and display the result on an OLED display for point of care monitoring and on the Blynk app and ThingSpeak for remote and continuous monitoring of vital signs. The Bland-Altman test was employed to test the agreement of DRRMNVS measurement with reference standards by taking measurements from ten healthy adults.

Results The prototype of the proposed device was successfully developed and tested. Bias [limits of agreement] were: Oxygen saturation (SpO2): -0.1 [−1.546 to +1.346] %; pulse rate: -0.3 [−2.159 to +1.559] bpm; respiratory rate: -0.7 [−0.247 to +1.647] breaths/min; temperature: 0.21 [+0.015˚C to +0.405˚C] ˚C. The proof-of-concept prototype was developed for $33.19.

Conclusion The developed DRRMNVS device was cheap and had acceptable measurement accuracy of vital signs in a controlled environment. The system has the potential to advance healthcare service delivery for neonates with further development from this proof-of-concept level.

Keywords Neonatal mortality and morbidity · Neonatal vital signs · Realtime and remote monitoring · NICU · IoT

1 Introduction

The first twenty-eight days of life, known as the neonatal period, are the most dangerous for infant survival, particularly for premature babies. As many as 2.4 million neonates died in 2020, [1, 2] high neonatal mortality is a serious and ongoing problem around the world. The vast majority of neonatal deaths occur in low- and middle-income countries, particularly in South Asia and Sub-Saharan Africa. Despite the fact that infant mortality has decreased in developed countries over the last two decades, the death rate in developing countries has remained steady [3, 4].

The majority of newborn deaths are caused by avoidable and curable causes such as diarrhea, pneumonia, sepsis, asphyxia, and preterm birth, which may be avoided by employing basic mother and child healthcare services [5, 6]. Because of these and other complications, newborn babies are frequently admitted to the NICU seeking constant follow-up and regular monitoring of vital signs by care givers since the vital signs fluctuate from time to time [7]. Premature babies have immature respiratory control, which makes them prone to apnea, hemoglobin oxygen deficiency, and bradycardia [8]. Throughout the hospital stay, vital sign indicators such as heart rate (HR), respiratory rate (RR), body temperature and pulse oximetry are regularly monitored [9–11]. But the existing monitoring of neonatal vital

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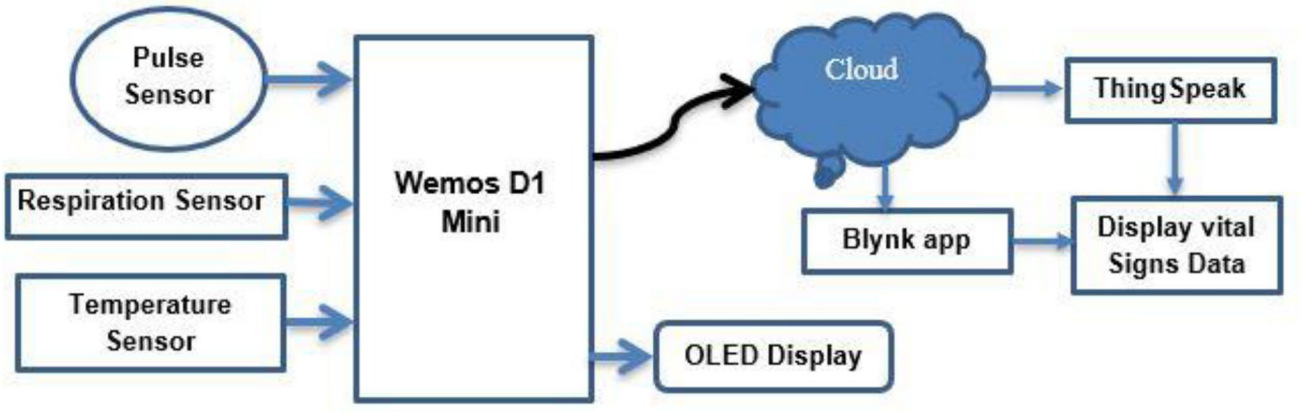

Fig. 1 General block diagram of the proposed system

signs in NICU is usually done on a manual basis where nurses record the vital signs on the manual progress chart on an hourly basis, which could result in erroneous interpretation by physicians [7, 11, 12]. Moreover, the sensors of the conventional technologies used to monitor neonatal vital signs in NICU need to be attached to the fragile and sensitive skin of the babies, which could be damaged easily and subjected to infections [13, 14] .

Effective vital sign monitoring system for newborns admitted to NICU on a continuous basis is therefore important to minimize neonatal mortality and morbidity. However, for a limited number of healthcare personnel, this is a demanding activity, compounded by the difficulties of remaining in the NICU for an extended period of time owing to heat radiation from the radiant warmer device.

Some limited approaches have been made to automate the manual monitoring of neonatal vital signs in the NICU [15–18]. For instance, Zakaria et al. developed an IoT-based continuous neonatal body temperature measurement system that enables parents to remotely monitor the status of the baby through their mobile phones which is limited to a single parameter monitoring [15]. Sheril Amira et al. [16] on the other hand, have developed a method for remote monitoring of neonatal body temperature and pulse rate via Bluetooth network which is limited to some distance. Vital signs monitoring device with BPM and SpO2 notification using telegram application based on thinger.io platform was developed by Sari Luthfiyan et al. [19] but it only allows real time monitoring. In the same manner Hani Wisana et al. [20] developed a low cost health monitoring system based on IoT using Email notification which is used to monitor respiration rate only.

However, these works are either limited to one or two parameters, have problem with accuracy due to limited use of robust sensors, limited monitoring distance and attachment with neonates' skin. Therefore, we need a device design that can remotely and continuously monitor the four important vital signs of neonates in NICU with a limited contact of sensors with neonate's skin.

2 Materials and methods

2.1 Block diagram and schematic diagram

The general block diagram of the proposed IoT-based neonatal vital signs monitoring system is shown in Fig. 1. The system measures the body temperature of neonates using a non-contact infrared (IR) temperature sensor, MLX90614, while the MAX30100 sensor is used to measure the blood oxygen saturation and pulse rate. A negative temperature coefficient (NTC) thermistor sensor was used to accurately measure the respiration rate by placing it in front of the nostrils. The Wemos d1 mini (ESP8266Mod) is used to acquire and process the vital signs from the sensors and to communicate the sensors' data to ThingSpeak and Blynk app IoT platforms. The reading from the pulse sensor and IR temperature sensor is communicated to the microcontroller through I2C protocol while the respiration sensor data is supplied to the microcontroller using analog pin. Wemos d1 mini process the data and display it on OLED through I2C protocol and also send the data over the internet using Wifi network to Thingspeak and connected Blynk app on smartphone. The Graphical user interface (GUI) was designed on Blynk app and Thingspeak IoT platform separately for each biomarker. The reading of each sensor is updated every time as long as the device is connected to the internet.

The schematic diagram of the proposed DRRMNVS showing the detailed wiring between each component is shown in Fig. 2.

The device incorporates point-of-care monitoring of vital signs through an OLED 128×64 display and remote

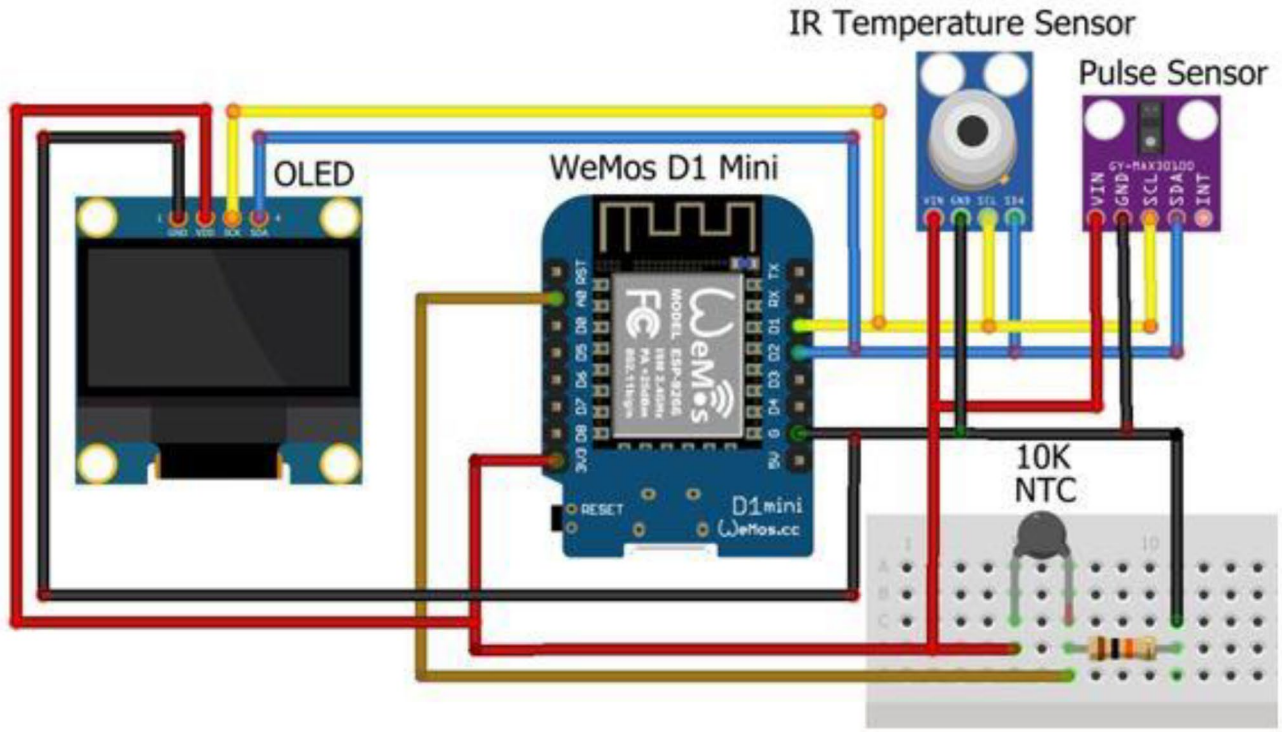

Fig. 2 Schematic diagram of the proposed DRRMNVS

Table 1 Bill of materials used for development of the prototype

SN	Item Name	Specification	Cost (USD)
1	Temperature Sensor	IR temperature sensor (MLX90614)	16.34
2	Pulse Sensor	MAX30100	5.71
3	Respiration sensor	10K NTC thermistor	0.31
4	Microcontroller	ESP8266Mod	4.78
5	Display	OLED 128 × 64 Display	5.07
6	Wire	Jumper wire	0.48
7	Cover	Plastic	0.5
		Total cost of items	**33.19**

monitoring of vital signs using the Blynk app and ThingSpeak over the internet. Therefore, the users can monitor the newborn using the three mechanisms. The details of materials used and cost of each item is summarized in Table 1.

2.2 Experimental method

After completion of the design, the measurement data was taken from 10 healthy adults to evaluate the accuracy of the four vital sign measurement by comparing the measurement taken by the developed device with the measurement taken by standard medical devices. The reference standards used for measurement are Edan pulse oximeter for measurement of oxygen saturation and pulse rate, commercially available IR Thermometer for temperature measurement and auditory manual count for respiration rate. The sample data was sent to Thingspeak and Blynk app IoT platform to check the system functionality.

2.3 Statistical method

A Bland-Altman statistical test was used to test the agreement of the proposed device with the reference standards. The mean difference, or bias, between the DRRMNVS and the reference standards, and the 95% confidence interval (CI) (+/- 1.96 SD), or limits of agreement, were determined for all vital signs data. American National Standards Institute standard for cardiac monitors, heart rate meters, and alarms defines accuracy as a "readout error of no greater than ± 10% of the input rate or ± 5 beats per minute (bpm), whichever is greater" [21]. Therefore, the acceptable error between measurements were set to ± 5 bpm for pulse rate and ± 5 breaths per minute for respiration rate in this study. For temperature measurement the priorly defined mean error (bias) within ± 0.2˚C and limits of agreement within ± 0.5˚C was considered as the clinically acceptable bias [22]. In the same manner, the clinically acceptable bias for oxygen saturation measurement was defined to be < 1% [23].

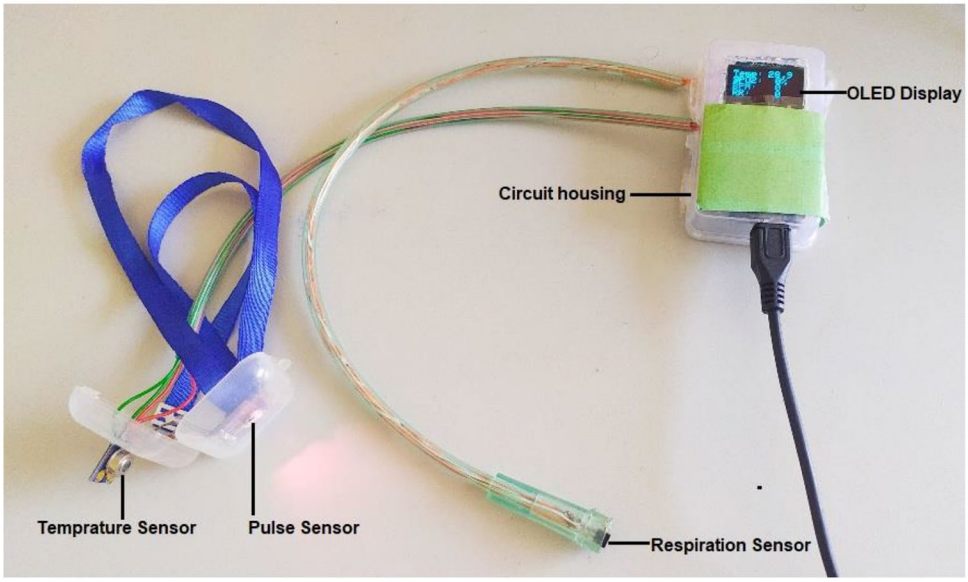

Fig. 3 The prototype of the proposed DRRMNVS

3 Results

The prototype of the proposed DRRMNVS was successfully developed and tested as shown in Fig. 3. The non-contact IR temperature sensor and pulse sensor were combined together to measure the vital signs from the forehead. The attachment is made with a head belt. The respiratory sensor was developed independently and the measurement is made by attaching it to a face mask. The device is powered from main AC power supply using 5v charger.

The output of the system on the Blynk app and ThingSpeak IoT platforms is also tested successfully, as shown in Fig. 4 with sample pictures taken during the measurement of vital signs.

The measurements were taken from 10 healthy volunteers in order to check the functionality of the developed system. Oxygen saturation, pulse rate, body temperature, and respiration rate were recorded using our device and compared with the measurements taken by standard medical devices.

The Bland-Altman statistical test was implemented to evaluate the agreement between the measurements from the proposed device and standard medical devices.

The result from the Bland-Altman plots for the four vital signs are shown on Fig. 5. The plot quantifies the mean bias (0.1%) and the limits of agreement (− 1.546% to + 1.346%) for oxygen saturation measurement, the mean bias (0.3 bpm) and the limits of agreement (− 2.159 bpm to + 1.559 bpm) for pulse rate measurement, and the mean bias of 0.7 breaths/min and the limits of agreement (− 0.247 breaths/min to + 1.647 breaths/min) for respiration rate measurement. On the other hand, a significant bias of 0.21˚C and limits of agreement (+ 0.015˚C to + 0.405˚C) was obtained for the temperature measurement. Except for temperature, DRRMNVS showed clinically acceptable bias for the other three vital signs.

4 Discussion

Continuous monitoring of neonatal vital sign in NICU is often performed using a variety of monitoring devices, including pulse oximeters, electrocardiograms (ECG), respiratory belt transducers, nasal thermocouples, and piezoelectric transducers [22, 23]. These devices frequently include adhesive transducers and electrodes that are directly applied to the fragile skin of infants, resulting in skin injury and infections [14, 24]. In addition, the current monitoring system in NICU is being performed manually and it is difficult to access the complete vital sign measurement data to make the right decision.

In this work, real-time and remote monitoring of newborn vital signs with limited sensor contact with the neonates' skin was developed to enable monitoring at the point of care and remotely utilizing a mobile app and the ThingSpeak IoT platform. Sending vital sign data via IoT platform is critical for accessing continuous data overtime that was overlooked by traditional monitoring systems such as manual progress charts. Obtaining longitudinal data of the identified biomarkers; oxygen saturation, respiration rate, pulse rate, and body temperature, has the potential to assist doctors in making the right decision and providing appropriate care. The DRRMNVS has the advantages of simultaneously monitoring four vital signs, allowing the user to perform point of care monitoring, monitoring through mobile app and ThingSpeak using the internet, and above all, it allows

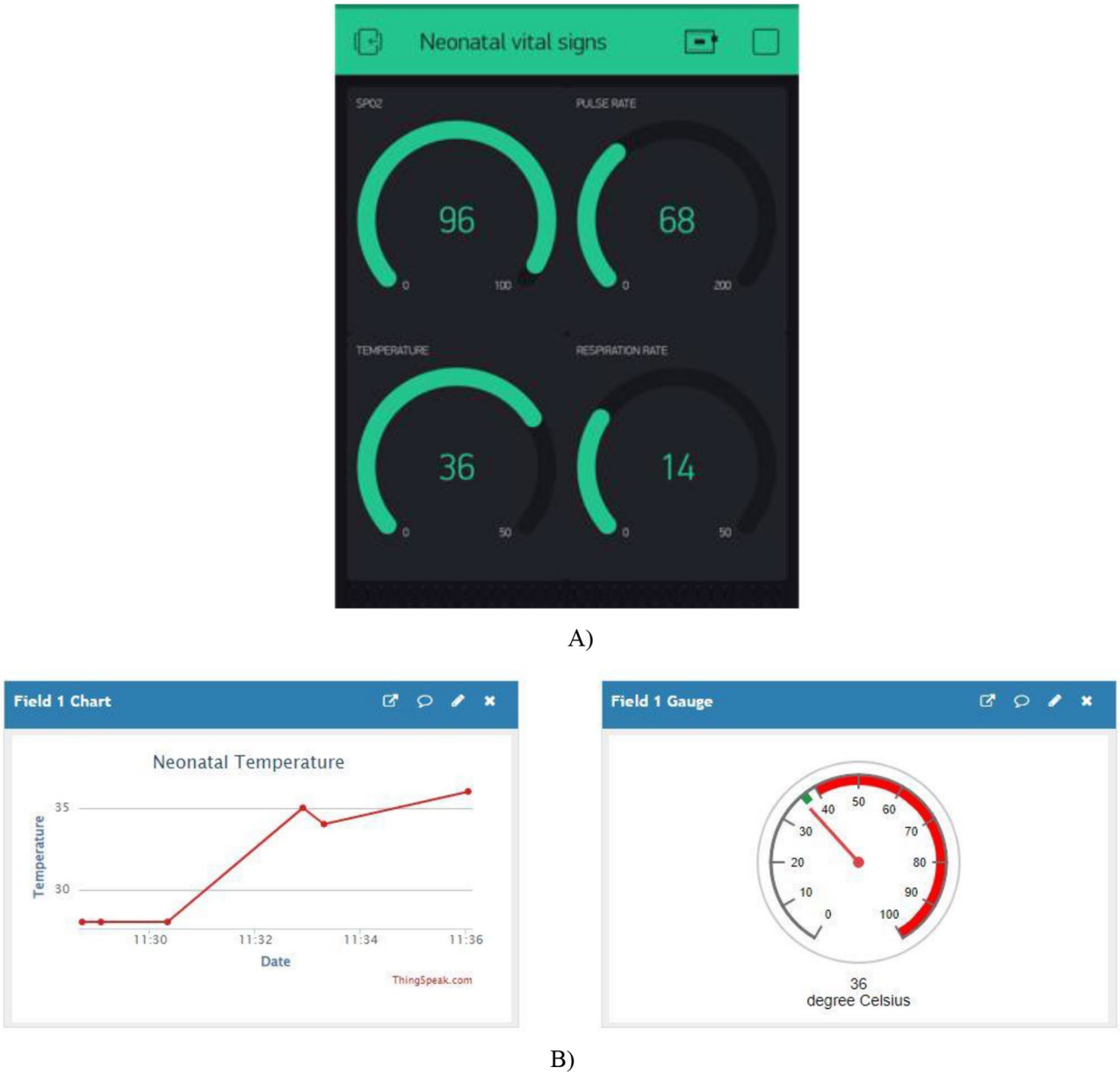

Fig. 4 Sample pictures showing the measurement output on Blynk app (A) and ThingSpeak (B). ThingSpeak's graphical output displays the continuous measurement result, allowing caregivers to see the past trend without missing data

the physician to access the continuous data by storing the changes in parameters over time.

The lower bias obtained for all vital signs except temperature indicates a good agreement agreement between DRRMNVS and standard medical device. The current bias on temperature measurement could be improved with further development and taking more data since the current study is a proof-of-concept study.

The results obtained in this study are the baseline for further studies in the advancement of neonatal health monitoring, and the application of this kind of development in neonatal intensive care units has the potential to save millions of lives [25, 26].

As a limitation, the tests were done on healthy adults with close values of biomarkers since it was difficult to test the device on neonates with various complications due to ethical clearance issue. In addition, the current prototype is a low-fidelity prototype that needs further work to produce it as a ready-to-use product. The use of an NTC thermistor with a low response time is also recommended since the accuracy of respiration rate measurement is affected by the response time of the thermistor used. Cyber security issue

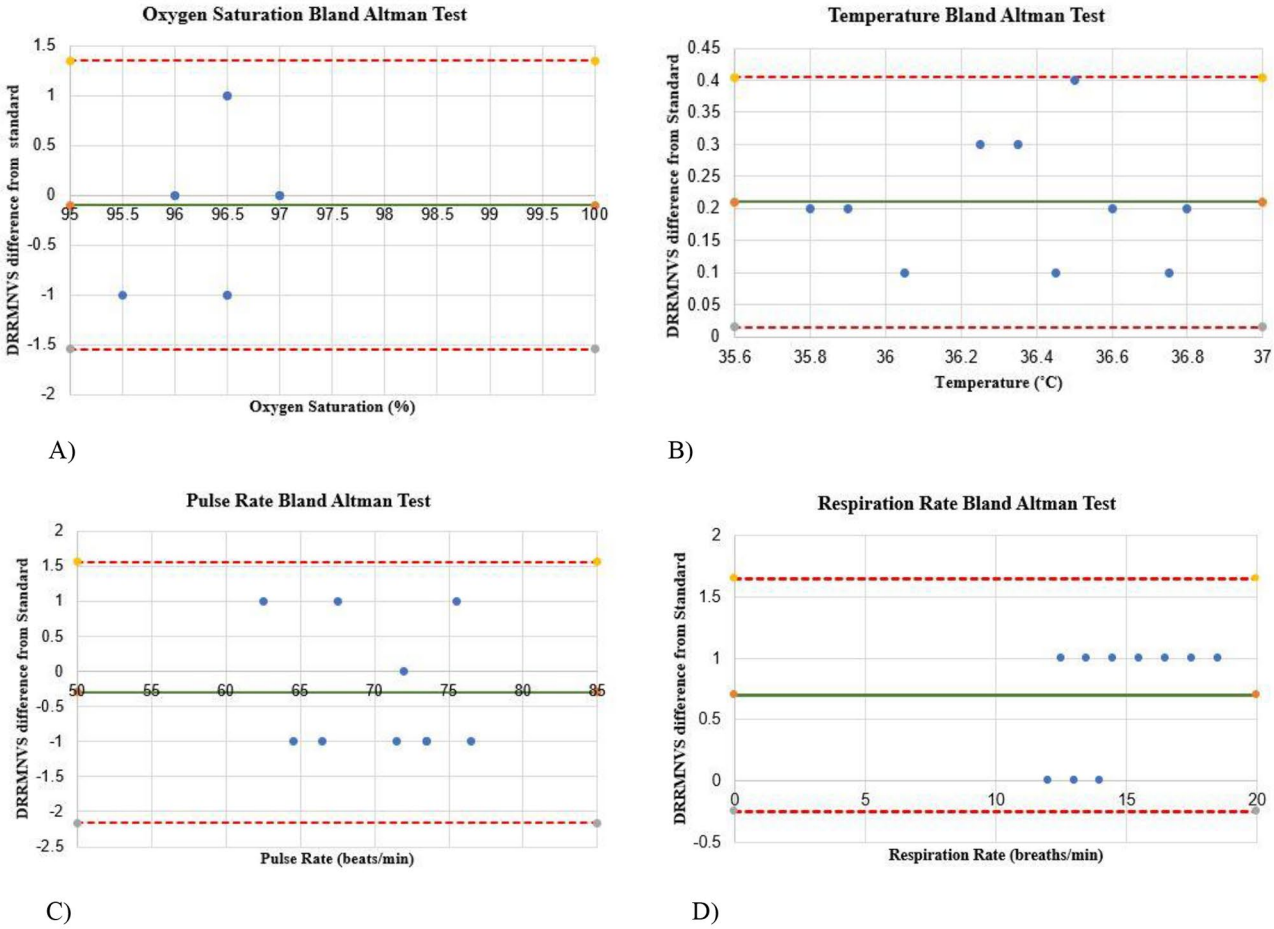

Fig. 5 Bland-Altman Plot, showing the average values of simultaneous (A) Oxygen Saturation, (B) Temperature, (C) Pulse Rate, and (D) Respiration Rate as measured with DRRMNVS and Standard devices in X-axis versus their difference in Y-axis. The green solid reference line represents the mean error (bias), and the dashed reference lines are the upper and the lower limits of agreement between DRRMNVS and Standard devices

is the main challenge for IoT application in health but this could be resolved by using a more secure IoT development platform, appropriate authentication and network segmentation during the practical implementation.

5 Conclusion

The aim of this study to simultaneously monitor four vital signs of neonates admitted to a neonatal intensive care unit was achieved by developing a device that allows point-of-care monitoring using an OLED display and remote monitoring using the internet of things (Blynk app and Thing speak). The device has successfully monitored oxygen saturation, body temperature, respiration rate and heart rate using the customized sensors over the Thingspeak and Blynk IoT platforms. The functionality and accuracy of the device were tested by comparing them with standard devices, and it was confirmed that there was no clinically significant difference between them except for temperature measurement.

Using the developed DRRMNVS system helps to prevent misdiagnoses by providing complete data of vital signs recorded over time using the ThingSpeak internet of things platform, and it has the potential to advance healthcare service delivery for neonates. In the future works, incorporation of detection of abnormalities in the signals and disease prediction from the measured vital signs will be considered to make the decision easier for care givers.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s10877-022-00929-8.

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Authors' contributions All authors made a significant contribution to

the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article. The first draft of the manuscript was written by Hundessa Daba Nemomssa and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Statements & declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

Ethical approval We have carried out our work according to the Code of Ethics of the World Medical Association (Declaration of Helsinki). Moreover, this project work was compiled with the Ethiopian National Ethics Review Guideline, which was prepared by the FDRE Minister of Science and Technology in September 2014, Fifth Edition.

Consent to participate Informed consent was obtained from all individual participants included in the study.

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