RESEARCH ARTICLE OPEN ACCESS

Manuscript received November 10, 2020; revised March 3, 2021; accepted April 21, 2021; date of publication July 28, 2021
Digital Object Identifier (DOI): https://doi.org/10.35882/jeeemi.v3i2.7

Long Distance Dual SpO2 Monitoring System for Premature Babies Using Bluetooth Communication

Priyambada C. Nugraha[1], Muhammad R. Mak'ruf[1], Lusiana[1], Sari Luthfiyah[1], and Wahyu Caesarendra[2]

[1] Department of Electromedical Engineering, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, Surabaya (60282), Indonesia
[2] Faculty of Integrated Technologies, Universiti Brunei Darussalam, Brunei Darussalam

Corresponding author Priyambada C. Nugraha (e-mail: pcn1967@poltekkesdepkes-sby.ac.id).

ABSTRACT Monitoring the baby's health status is essential, especially for babies born prematurely. Measurement of oxygen saturation levels in newborns can help detect early congenital abnormalities in infants. The baby is usually placed in a baby incubator located in a particular treatment room. The room is separate from the supervisory nurse's room. This study aims to design an equipment system to monitor oxygen saturation conditions in newborns. Additionally, this monitoring was conducted continuously using equipment connected wirelessly between the baby room and the nurse's room. This study developed long-distance SpO2 monitoring equipment from two babies in two infant incubators in a separate room with a monitoring room. Each incubator has a SpO2 detector which simultaneously sends data to a PC in the nurse's room. The Neonatal Fingertip sensor is attached to the baby's big toe then the signal and the value of SpO2 obtained are sent by the microcontroller to the PC via Bluetooth communication HC-05. The PC will display the oxygen saturation (SpO2) values and signals from the two incubators. Based on the results of tests and measurements in 5 different patients with a pulse oximeter comparison, the difference value of 1% in each patient's results was obtained. This system has successfully monitored the SpO2 of 2 babies in 2 baby incubators from separate rooms. The results of this study are beneficial in facilitating the work of paramedics in monitoring the vital conditions of newborn babies.

INDEX TERMS Monitoring, SpO2, Fingertip Neonatal, HC-05, Arduino.

I. INTRODUCTION

Health monitoring systems are highly dependent on technology [1]. In an agency such as a hospital, a monitoring tool is necessary to monitor the condition of patients who require rapid treatment so that any changes to the patient's condition must always be monitored [2]. This also applies to monitoring premature babies. Pre-term birth was defined as all births before 37 complete gestational weeks [3]. Eleven million premature babies are born each year worldwide [4]. According to another study, as many as 20 million babies are born prematurely, and it is estimated that 450 of them die every hour [5]. Premature birth is one of the main risk factors for newborn mortality [6]. Premature babies experience more complicated health conditions and cause death [7]. In contrast to term babies, premature babies are a group of babies who are at high risk. This is caused by the immaturity of the body's organ systems in premature infants, such as the lungs, heart, kidneys, liver, and digestive system [8]. Baby incubators play an important role in saving the lives of premature babies [9]. Continuous monitoring of health parameters is also important for premature infants admitted to the neonatal intensive care unit (NICU) in hospitals [10]. In the neonatal intensive care unit (NICU), heart rate, respiratory rate, and oxygen saturation are vital signs (VS) that are continuously monitored in infants [11] due to the importance of oxygen supply in the human body. One of the most important indicators of oxygen supply in the body is oxygen saturation (SpO2). Oxygen saturation can indicate whether hemoglobin can bind oxygen or not. The lack of oxygen is at risk of damage to essential organs in the body, and death can be overcome [12]. The percentage of normal oxygen saturation in humans is the same at all age levels, i.e., 95%-100% for both newborns and the elderly [13]. Oxygen saturation levels in newborns are critical to know because when the oxygen saturation levels in newborns are low, it is necessary to watch out for hemodynamic abnormalities in the baby. Measurement of oxygen saturation levels in newborns can help detect early congenital abnormalities in infants [14]. Therefore, SpO2 levels must be continuously monitored [15].

Currently, monitoring of premature babies who are placed in the baby incubator is still done manually, so medical personnel in the neonate room must visit the babies in the baby incubator one by one periodically to monitor the vital conditions of the babies inside. Therefore, to reduce the workload of medical personnel and reduce the possibility of data reading errors in patients, a device that can monitor vital conditions is needed. Additionally, the SpO2 vital parameters of several infants at a distance are far enough so that medical personnel can continuously monitor the vital conditions of a baby in one place.

In 2015 Mr. Mamun conducted research by making a wireless monitoring system for temperature, humidity, and light intensity in infant incubators [16]. In this study, there was no monitoring used for infant SpO2. In 2015 Pallerla Akshay Kumar et al. conducted a study by making real-time monitoring and control of infant incubators using LabVIEW [17]. In this study, the vital condition of the baby in the baby incubator was monitored closely. In 2016 M.Priya et al. conducted a study by creating a wireless patient health monitoring system using LabVIEW [18]. The study used Zigbee communication and was intended for adult patients. In 2017 Sujithanand A et al. conducted a study by making a baby incubator monitoring system with remote access but without the vital parameter SpO2 [19]. In 2017 Vikramsingh R. Parihar et al. conducted a study by creating a heart rate and temperature monitoring system for remote patients using Arduino, but they have not monitored SpO2 parameters [20]. In 2018 Lanny Agustine et al. conducted a study by making a heart rate monitoring device for arrhythmias using an android-based pulse oximeter sensor [21]. Researchers created a BPM monitoring system for arrhythmic patients using a pulse oximeter sensor but did not calculate SpO2. In 2019 Alexander Guber et al. conducted a study by making a pulse oximeter with a wrist sensor that allows prolonged patient monitoring [22]. Wrist sensors are not suitable for use in infants. In 2021, B. Annapurna et al. conducted a study to implement the max 30100/30102 sensor to detect viral infections based on the SpO2 pattern and heart rate [23], but the sensor is not suitable for use in newborns.

Based on identifying the problem, the researcher wants to design a piece of remote SpO2 monitoring equipment for two babies in 2 baby incubators in a separate room from the monitoring room. The Neonatal Fingertip sensor is attached to the baby's big toe then the signal and the obtained SpO2 value are sent by the microcontroller to the PC via Bluetooth communication HC-05. The PC will display the oxygen saturation (SpO2) values and signals from the two incubators. The nurse can monitor the SpO2 condition of 2 babies without having to go to the incubator.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

In this study, two modules were made that can monitor two patients (infants) simultaneously. This module sends SpO2 signal data to 1 PC with a considerable distance (1-5m). Data collection was carried out on five respondents with variations in the distance between the baby incubator and the PC.

B. MATERIALS AND TOOL

This study uses 2 SpO2 sensors (Neonatal Fingertip). The two sensor leads will be processed by Arduino and sent using the HC-05 and then displayed simultaneously on a PC.

C. EXPERIMENT

After the module was successfully created in this study, a test was carried out using pulse oximetry to compare the SpO2 results.

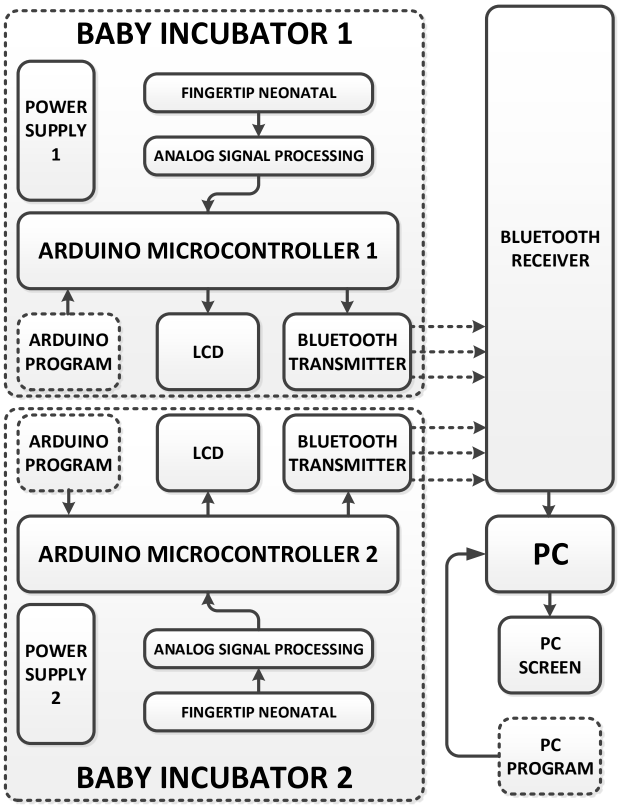

FIGURE 1. The block diagram of the system

D. THE BLOCK DIAGRAM

The system was built based on the block diagram as shown in FIGURE 1. Power Supply provides power for all components in one incubator. The neonatal fingertip serves to capture the SpO2 signal from the big toe of premature babies. The signal is processed by the analog signal processing circuit and forwarded to the Arduino Microcontroller. Arduino Program runs Arduino Microcontroller to display SpO2 value on LCD and sends SpO2 signal to PC via Bluetooth Transmitter.

The PC program runs the PC to receive the SpO2 signal data via the Bluetooth Receiver and displays the SpO2 signal from the two babies on the PC screen.

E. THE FLOWCHART

The baby incubator and the program on the Arduino are built based on a flowchart, as shown in FIGURE 2. The SpO2 sensor will be used to take input data in the form of oxygen saturation values and signals. When the sensor is installed, it detects the oxygen level in the blood (SpO2) and gets the lead value on the sensor, and the results will be processed in an analog signal processing circuit.

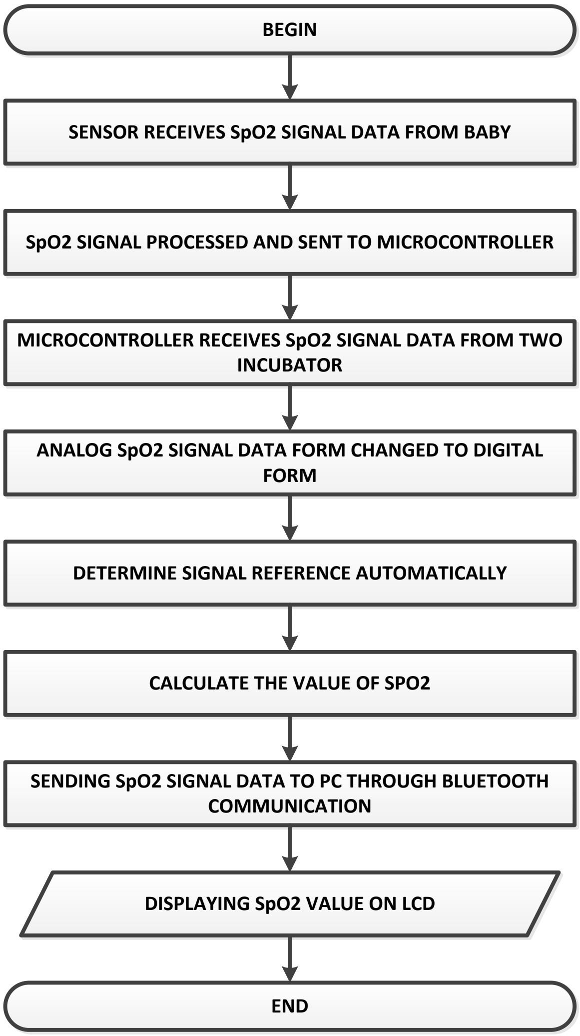

FIGURE 2. The Process in Baby Incubator

The output of the analog signal processing circuit will enter and be processed by the microcontroller. In the microcontroller, there is the processing of incoming data from the output of the analog signal processing circuit, such as changing the shape of the signal from analog to digital, determining the signal reference automatically, and calculating the SpO2 value. Furthermore, the microcontroller will send the processed data to the PC via Bluetooth communication. Finally, the microcontroller will display the SpO2 value data on the LCD.

The program in the PC is shown in FIGURE 3. The process on the PC begins with the connection to the wireless module. If the module installed on the baby incubator is already connected to the PC, the wireless module on the PC will function as a receiver. The data received by the wireless module contained in the PC will be prepared for display. Next, the PC will display the SpO2 value and signal on the screen.

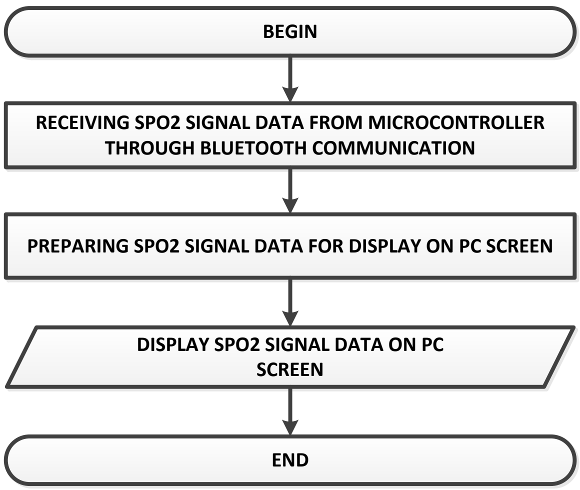

FIGURE 3. The Program in the PC

III. RESULTS

In this study, measurements were made on random respondents. Measurement results obtained normal SpO2 percentage for each respondent, which is between 97%-100%

FIGURE 4. The System design

A. CALCULATION OF SPO2 VALUE

FIGURE 4 is the physical form of the system that has been made. In FIGURE 4, it can be seen that each module is being installed with three sensors, namely the SpO2 sensor, temperature sensor, and BPM sensor (temperature and BPM are not discussed here). The collecting of the SpO2 signal can be explained from FIGURE 5 below.

FIGURE 5 shows the process that occurs in the analog signal processing circuit. There is a 1 kHz astable circuit that functions to regulate the on and off of the red lamp and infrared; the circuit will be active alternately by providing logic one and logic 0. The output of the astable circuit is connected to a transistor circuit that functions as a driver for the photodiode in the neonatal fingertip sensor. So, the sensor will work to detect the blood flow that passes through the sensor according to the logic given. Then, the resulting output will be connected to a demultiplexer circuit which will separate the finger sensor leads into an infrared signal and a red lamp signal.

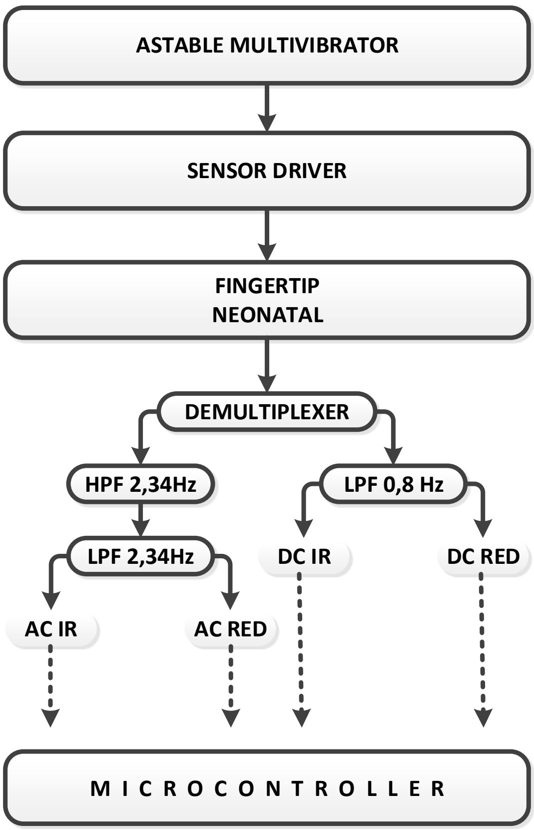

FIGURE 5. The Analog Signal Processing of SpO2

This circuit serves as a switching so that no output comes out simultaneously. The demultiplexer output will be used as input to 2 filters, namely the 0.8 Hz LPF filter, to get a DC signal from infrared (DC IR) and red lamp (DC RED). And the demultiplexer output is also an input to the BPF filter circuit to generate AC infrared (AC IR) and red lamp (AC-RED) signals. This BPF filter consists of a 2.34 Hz passive HPF filter and an active 2.34 Hz LPF filter. The HPF filter has a function to pass frequencies above the cut-off frequency, and the LPF filter functions to pass frequencies below the cut-off frequency and amplifies the output. Output signals AC IR, AC RED, DC IR, and also DC RED are connected to analog pins on Arduino where pin A1 is AC RED, pin A2 is AC IR, pin A3 is DC RED, and pin A6 is DC IR. Furthermore, the process of calculating the value of SpO2 can be seen in Fig.6. The first process is to calculate the multiplication of AC RED and DC IR. Then calculate the multiplication of AC RED and DC RED. Furthermore, the results of the first process are divided by the results of the second process. The result is multiplied by 25 and subtracted by 110. The final result is the SpO2 value (FIGURE 6).

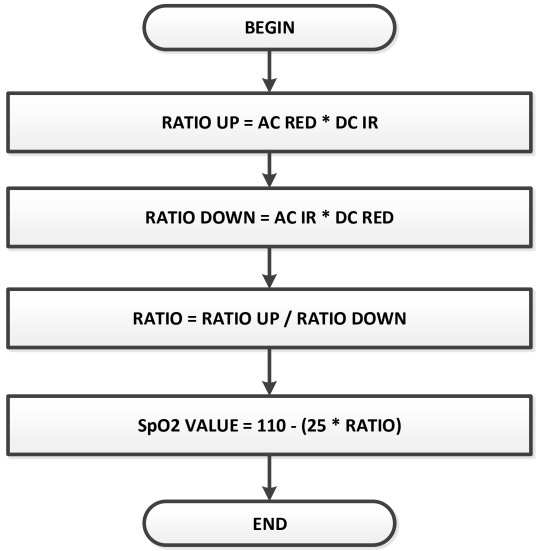

FIGURE 6. The Calculation Flowchart of SpO2 Value

Then the data (signal and value) of SpO2 will be sent by the microcontroller to the PC via Bluetooth HC-05.

B. THE MEASUREMENT RESULT

The validation of the SpO2 value shown in the Delphi programming was compared with the pulse Oximetry device. The error was shown in TABLE 1 (for incubator 1) and TABLE 2 (for incubator 2).

TABLE 1
The error of measurement for spo2 parameter between the design and calibrator on baby incubator 1

Respondent	Error(%)
1	2,91
2	0,99
3	0.99
4	0
5	1,96

Table 2
The error of measurement for SpO2 parameter between the design and calibrator on Baby Incubator 2

Respondent	Error(%)
1	0,97
2	0,99
3	0.99
4	0,98
5	0,97

Table 3
The test results of the success of data sending to the measurement distance

Measurement Distance	From Baby Incubator (1)	From Baby Incubator (2)
1 meter	sent	sent
2 meter	sent	sent
3 meter	sent	sent
4 meter	not sent	not sent
5 meter	not sent	not sent

IV. DISCUSSION

TABLES 1 and TABLE 2 are data recorded in each incubator with a neonatal fingertip sensor placed on the tip of the respondent's right big toe and compared directly with pulse oximetry placed on the tip of the left big toe. In each respondent, there is a difference of 1% against the comparison. TABLE 3 is the result of testing the distance between the module and the PC that displays the results on the patient. The distance test is done by changing the distance of the computer to the device with the sensor position being used by the patient. The result is that at a distance of 4 meters, the module is unable to send data to the PC. The weakness of the system that has been built is that it can only monitor two incubators, and the furthest distance is 3 meters with obstacles. The results of this study are beneficial in facilitating the work of paramedics in monitoring the vital conditions of newborn babies.

V. CONCLUSION

Based on the discussion results, it can be seen that a system with a neonatal fingertip sensor can perform its function in displaying oxygen saturation values and signals. The Bluetooth module also works well, so the system created can monitor two patients (infants) simultaneously at a long distance. It is far enough in accordance with the plans that have been made. The average error of measurement is 1%. The next development is to increase the number of incubators that can be monitored and try to use a more robust wireless system.

REFERENCES

[1] A. G. Shabeeb, A. J. Al-Askery, and Z. M. Nahi, "Remote monitoring of a premature infants incubator," *Indones. J. Electr. Eng. Comput. Sci.*, vol. 17, no. 3, pp. 1232–1238, 2019.
[2] D. Putri, P. Indriani, and E. L. Utari, "Perancangan Pulse Oximetry Dengan Sistem Alarm Prioritas Sebagai Vital Monitoring," *Vol . IX Nomor 27 Nop. 2014 - J. Teknol. Inf.*, pp. 93–107, 2014.
[3] F. A. Mahapula, K. Kumpuni, J. P. Mlay, and T. F. Mrema, "Risk factors associated with pre-term birth in dar es salaam, tanzania: A case-control study," *Tanzan. J. Health Res.*, vol. 18, no. 1, pp. 1–8, 2016.
[4] M. F. Silveira, C. G. Victora, B. L. Horta, B. G. C. Da Silva, A. Matijasevich, and F. C. Barros, "Low birthweight and pre-term birth: Trends and inequalities in four population-based birth cohorts in Pelotas, Brazil, 1982-2015," *Int. J. Epidemiol.*, vol. 48, no. June 2018, pp. I46–I53, 2019.
[5] S. Sowmiya, V. Smrithi, and I. Lorettag, "Monitoring of Incubator using IoT," vol. 8266, no. 03, pp. 635–638, 2018.
[6] L. Doukkali, F. Z. laamiri, N. B. Mechita, L. Lahlou, M. Habibi, and A. Barkat, "The Issue of Care Given to Premature Infants in the Provincial Hospital Center of Missour," *J. Biosci. Med.*, vol. 04, no. 05, pp. 76–88, 2016.
[7] M. V. Narayana, K. Dusarlapudi, K. Uday Kiran, and B. Sakthi Kumar, "IoT based real time neonate monitoring system using arduino," *J. Adv. Res. Dyn. Control Syst.*, vol. 9, no. Special issue 14, pp. 1764–1772, 2017.
[8] F. R. Ratu and Lia Yuliana, "Faktor-Faktor yang Memengaruhi Kematian Bayi Prematur di Indonesia," vol. 1, no. November, 2017.
[9] M. Subramanian, T. Sheela, K. Srividya, and D. Arulselvam, "Security and health monitoring system of the baby in incubator," *Int. J. Eng. Adv. Technol.*, vol. 8, no. 6, pp. 3582–3585, 2019.
[10] W. Chen, S. B. Oetomo, L. Feijs, S. Bouwstra, I. Ayoola, and S. Dols, "Design of an integrated sensor platform for vital sign monitoring of newborn infants at Neonatal Intensive Care Units," *J. Healthc. Eng.*, vol. 1, no. 4, pp. 535–554, 2010.
[11] K. B. Long C., Saedler K., "Myocardial Extraction from Newborn Rats," *Physiol. Behav.*, vol. 176, no. 1, pp. 139–148, 2016.
[12] M. . Kemalasari, Ir., "Rancangan Bangunan Pulse Oximetry Digital," 2010.
[13] H. F. Dian Bagas Setyo Budi, Rizal Maulana, "Sistem Deteksi Gejala Hipoksia Berdasarkan Saturasi Oksigen Dengan Detak Jantung Menggunakan Metode Fuzzy Berbasis Arduino," *J. Pengemb. Teknol. Inf. dan Ilmu Komputer.*, vol. 3, no. 2, pp. 1925–1933, 2019.
[14] A. Kaunang, R. Wilar, and J. Rompis, "Perbandingan Kadar Saturasi Oksigen Hari Pertama," *J. e-Clinic*, vol. 3, no. April, pp. 397–401, 2015.
[15] L. Valizadeh, M. Mahallei, A. Safaiyan, F. Ghorbani, and M. Peyghami, "The effect of plastic cover on regulation of vital signs in pre-term infants: A randomized cross-over clinical trial," *Iran. J. Neonatol.*, vol. 8, no. 2, pp. 24–30, 2017.
[16] O. Access, "A Wireless Based Temperature , Humidity and Light Intensity Monitoring System for Child Incubators," vol. 2, no. 3, pp. 67–71, 2015.
[17] R. Dilip, "Design And Development Of Intelligent System For Human Body Design,", J. Intelligent Sys., no. July, pp. 0–3, 2019.
[18] M. Shelar, J. Singh, and M. Tiwari, "Wireless Patient Health Monitoring System," *Int. J. Comput. Appl.*, vol. 62, no. 6, pp. 1–5, 2013.
[19] Sujithanand A, Srinivasan S, Abishek K, and Nagaraju N, "Infant Incubator Monitoring system with Remote Access (IIMRA)," *Int. J. Innov. Res. Sci. Eng. Technol.*, vol. 6, no. 3, pp. 266–271, 2007.
[20] V. R. Parihar, A. Y. Tonge, and P. D. Ganorkar, "Heartbeat and Temperature Monitoring System for Remote Patients using Arduino," *Int. J. Adv. Eng. Res. Sci.*, vol. 4, no. 5, pp. 55–58, 2017.
[21] Agustine, L., Muljono, I., Angka, P. R., Gunadhi, A., Lestariningsih, D., & Weliamto, W. A. (2018, November). Heart rate monitoring device for arrhythmia using pulse oximeter sensor based on android. In 2018 International Conference on Computer Engineering, Network and Intelligent Multimedia (CENIM) (pp. 106-111). IEEE.
[22] Guber, A., Epstein Shochet, G., Kohn, S. *et al.* Wrist-Sensor Pulse Oximeter Enables Prolonged Patient Monitoring in Chronic Lung Diseases. *J Med Syst* **43,** 230 (2019). https://doi.org/10.1007/s10916-019-1317-2
[23] Dr. B. Annapurna, Asha Priyadarshini Manda, A. Clement Raj, Dr. R. Indira, Dr. Pratima Kumari Srivastava, Dr. V. Nagalakshmi. (2021). Max 30100/30102 Sensor Implementation to Viral Infection Detection Based On Spo2 and Heartbeat Pattern. Annals of the Romanian Society for Cell Biology, 25(2), 2053–2061.