Jurnal Teknokes
International: Rapid Review: Open Access Journal **Vol. 16, No. 2, June 2023, pp. 66-72** **e-ISSN 2407-8964; p-ISSN 1907-7904**

RESEARCH ARTICLE OPEN ACCESS

Manuscript received February 18, 2023; revised May 20, 2023; accepted June 12, 2023; date of publication June 30, 2023
Digital Object Identifier (DOI):https://doi.org/10.35882/teknokes.v16i2.456

How to cite: Dwi Widyaningtyas, Muhammad Ridha Mak'ruf, Andjar Pudji, "Monitoring the Occurrence of Alarms in Internet of Things-Based HFNC With Analysis of Signal Increases Before Blockages Error", Jurnal Teknokes, vol. 16, no. 2, pp. 66–72, June. 2023.

Monitoring the Occurrence of Alarms in Internet of Things-Based HFNC With Analysis of Signal Increases Before Blockages Error

Dwi Widyaningtyas[1], Muhammad Ridha Mak'ruf[1], Andjar Pudji[1]
[1] Department of Electromedical Engineering, Surabaya Ministry of Health Health Polytechnic, Indonesia
Corresponding author: Muhammad Ridha Mak'ruf (e-mail: ridha@poltekkesdepkes-sby.ac.id).
"This work was supported in part by Department of Electromedical Enginnering Health Polytechnic Ministry of Health Surabaya"

ABSTRACT HFNC must be closely monitored by nurses to increase the flow rate when the patient's condition worsens. The monitoring occurs every hour to assess the results of HFNC administration. If the patient's condition persists, the flow given to HFNC will be increased. Thus, careful monitoring is essential during oxygen therapy with HFNC to ensure the patient's oxygen dose remains consistent. Despite debates about aerosol side effects, HFNC has proven effective in increasing blood oxygen levels and improving lung performance. This study aims to analyze HFNC errors leading to decreased flow. The research employs a temperature setting of 34ºC and a flow setting of 30-60 LPM. Under a flow setting of 30 LPM, the average pressure value before the error is 0 in process 2, and after the error, it remains 0, indicating a Blockage error as notified by IoT. Similarly, under the same flow setting, the average pressure value before the error is 0 in process 1, and after the error, it remains 0, indicating a leaking error based on the IoT notification and tool condition. The study reveals an average error of 3.8 for Blockage and 1.5 for Leaking conditions. Future research could explore developments such as employing a more sensitive pressure sensor, like the MPX5010DP, and incorporating batteries to enhance the module's portability without the need for a voltage source.

INDEX TERMS HNFC, Pressure Error, IoT

I. INTRODUCTION

Workload of medical personnel in handling COVID-19 is quite high due to limited personnel so that medical personnel who take a rest are always ready to increase their working hours thereby increasing the physical and mental burden. Exposure to infection for nurses causes instability in the number of workers[1][2]. Close supervision and clinical monitoring of the use of HFNC is very necessary during therapy for patients with poor saturation conditions [3]. When the HFNC is not able to provide sufficient support, the patient will be in a dangerous condition of respiratory failure, so that monitoring is not simple/special during the use of this HFNC [4]. We know that HFNC (High flow Nasal Cannula) is a method of giving supplemental oxygen to patients experiencing acute respiratory failure.[1][2][3], The use of HFNC in recent years is highly recommended as a solution to provide additional oxygen to patients [4][5], This is because in recent years there has been a virus that attacks the lungs and causes patients to experience respiratory system failure, which is a condition where there is fluid or softening of the patient's lungs, making it difficult for the body to maintain the concentration of oxygen in the blood, the virus is COVID-19[5][6][7]. Covid-19 has become a virus that has become a worldwide pandemic and this virus causes mass deaths because medical personnel find it difficult to treat patients when oxygen levels in the blood have dropped to critical levels. Several solutions to increase oxygen in the blood have been successfully carried out, including the use of a ventilator[8][9][10], but due to the increasing number of patients making the availability of ventilators [11][12][13]very limited to be given to all patients in need, therefore several studies were carried out to provide a solution to this, one of the recommendations in this study was the use of HFNC to support the body to maintain oxygen concentrations in the body. in the blood, so the patient does not enter a critical period[4][5].

The use of HFNC is considered to be able to help patients to increase oxygen levels in the blood although there is some debate about the side effects of aerosols given to patients, but HFNC has been shown to increase oxygen levels in the blood, and relieve lung performance.[3][14]. Giving HFNC to COVID-19 patients starts in the flow range of 30-50 LPM with an oxygen concentration of 92%[15]. The use of HFNC should be strictly monitored by nurses because when the patient is in the same condition or worsens the nurse is required to increase the flow rate given to the patient, this monitoring is carried out every hour so that nurses can know the results of giving HFNC and if the patient's condition remains then the flow is given to HFNC will be upgraded[16][17], Therefore, during the administration of oxygen therapy using HFNC it must be monitored carefully, to monitor the dose of oxygen administration to the patient does not decrease or does not stop. [18].

On the HFNC device, there are also several errors during the process of administering oxygen therapy, one of which is a blockage error where there is a blockage or compression of the hose which causes the oxygen flow to the patient to decrease.[19], when that condition occurs the tool will provide information and alarm to the nurse so that the nurse will immediately respond to provide corrections to the tool, but in current conditions, when there are conditions where the patient is increasing, nurses sometimes do not know the alarms and warnings given by the tool, Therefore it is necessary to monitor the provision of oxygen continuously which can provide direct notification to the nurse when there is an error so that the occurrence of the error does not make the patient's condition worse

Some of the studies used as literature reviews in this study were Esuabom Dijemeni in 2013 who made a portable mobile real time oxygen monitoring auto-ventilation system.[20], This tool designed serves to ensure the flow of oxygen [1][21][22]supply to patients which can be monitored in real time, thus facilitating the process of monitoring oxygen therapy to patients, in this study the researchers concluded that mobile monitoring applications can improve service to patients and can speed up handling when errors occur.

Addition, there is also noviana widya ningrum in 2020, making an Arduino-based monitoring and control system for fluid flow and a website.[23], the tool designed has succeeded in determining the amount has succeeded in monitoring the flow of fluid flow and controlling the valve, and no errors were found for using the website as a medium for storing and displaying data flow, it is hoped that there will be more in-depth research on connection and data stability so that the system can be developed and applied to a wider area.

Another research is by Steven M. Doria in 2022, with the title piezoresistive conductive microfluids membranes for low-cost on-chip pressure and flow sensing[24], this study aims to test the use of piezoresistive as a substitute for flow sensors to measure microfluids with the aim of cutting the cost of making sensors, in this study researchers succeeded in making microflow sensors using the piezoresistive concept and cut the cost of making sensors up to 90%, further research to examine sensors is expected can add data for further use of this sensor.

Based on the background and review of previous research, we raise the title as follows "Monitoring the Occurrence of Alarms in IoT-Based HFNC With Analysis of Signal Increases Before the Occurrence of Blockage Errors (Pressure Parameters)" which will analyze errors in HFNC that cause a decrease in flow provision in HFNC. This analysis will aim to be able to do notifications and warnings to nurses before an increasingly fatal error occurs, therefore the researcher will make a tool as a monitor for giving oxygen therapy to patients and provide notifications in the form of a telegram to notify nurses directly when an error occurs, thus making nurses can provide direct treatment before the patient's condition worsens due to the error.

This study aims to monitor the occurrence of alarms on HFNC via IoT by analyzing the increase in pressure signals before the blockage error occurs. Several contribution for this study is as follows:

1) The study's focus on analyzing HFNC errors leading to decreased flow helps identify potential risks and challenges in administering oxygen therapy. By understanding common errors like Blockage and Leaking, healthcare professionals can take proactive measures to ensure patient safety during HFNC treatment. Regular monitoring and swift intervention in case of errors can prevent adverse outcomes and complications.
2) Despite debates about aerosol side effects, the study confirms the effectiveness of HFNC in increasing blood oxygen levels and improving lung performance. This validation can provide healthcare practitioners with greater confidence in using HFNC as a therapeutic option for patients with respiratory issues.
3) The study's suggestion to explore developments like using a more sensitive pressure sensor (e.g., MPX5010DP) and incorporating batteries for portability indicates an avenue for further research and technological improvements in monitoring equipment. These enhancements could lead to more accurate and efficient monitoring of HFNC therapy, potentially improving patient outcomes and streamlining healthcare practices.

II. METHOD

The research was conducted at RSUD Bhakti Dharma Husada Surabaya and focused on the use of High-Flow Nasal Cannula (HFNC) therapy. To achieve the study's objectives, a Pre-experimental research design was employed, specifically the After Only Design type. This design involved the use of a single group of subjects, where the researcher observed the results without initially measuring or knowing the subjects' baseline conditions. However, to enable comparison, there existed a separate comparison group. The primary independent variable in this investigation was the error condition in HFNC therapy. The dependent variable, on the other hand, was the pressure data recorded by the pressure sensor. Additionally, to maintain consistency and control in the study, the microcontroller board used, namely ESP32, was designated as the controlled variable. The module utilized in the research was designed according to the block diagram depicted in Figure 1. The module's structure encompassed three main components: process input, process, and process output. The input section incorporated a pressure sensor responsible for collecting essential input data, which was then relayed to the microcontroller for further processing. The process stage primarily involved the microcontroller's functionality, as it received the data from the pressure sensor and conducted the necessary processing to enable the display of the sensor's values on the connected display. The output process encompassed two crucial elements: the display of data and the transmission of notifications via the Internet of Things (IoT) technology.

Referring to Figure 2, the experimental procedure involved a step-by-step operation. Once the module was powered on using the ON button, the initialization process was initiated. Upon its completion, the subsequent sections of the experiment followed suit. The input pressure setting, conforming to HFNC therapy requirements, was then performed, facilitating the subsequent sensor value reading process. After the data was successfully displayed, the module proceeded to a crucial pressure validation process. During this validation process, the pressure detected by the sensor was meticulously examined to ensure it adhered to the predetermined standard range. If the pressure recorded was within the established standard, the process would loop back to the sensor value reading section to continue ongoing monitoring. However, in the event that the pressure exceeded the predefined standard, the module would activate the IoT notification system. This notification mechanism was designed to promptly alert healthcare providers of any deviations from the desired pressure levels, enabling them to take timely and appropriate actions to rectify the situation.

In conclusion, this research utilized a Pre-experimental research design to investigate HFNC therapy errors, with a specific focus on pressure variations during the therapy's administration. The module developed for this study encompassed three main parts: process input, process, and process output. The study followed a systematic experimental procedure, involving initialization, pressure setting, sensor value reading, and pressure validation stages. Through this research, valuable insights were gained to enhance patient safety and validate the efficacy of HFNC therapy, while also laying the groundwork for potential future advancements in monitoring technology for oxygen therapy.

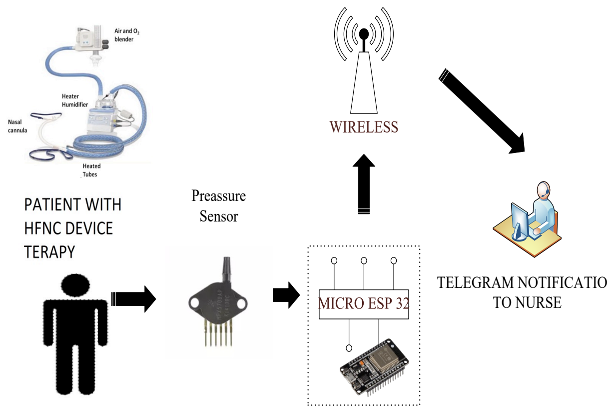

FIGURE 1. The Diagram Block of the System in Research HFNC Using MPX5700GP Sensor

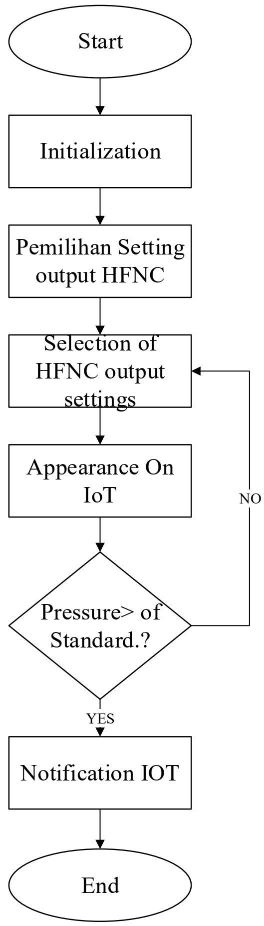

FIGURE 2. Flowchart system in Research HFNC Using MPX5700GP Sensor

A. DATA ANALYSIS

The measurements of each parameter, flow from 30 – 60 LPM, and pressure were all repeated 5 times. The average value of the measurement is obtained by using the mean or the average by applying the equation (1). The average is the number obtained by dividing the number of values by the number of data in the set.:

$$\overline{x} = \frac{x1+x2\ldots+xn}{n} \quad (1)$$

where $\overline{x}$ indicates the mean (average) value for n-measurement, x1 indicates the first measurement, x2 shows the second measurement, and xn indicates the n measurement. The standard deviation is a value that indicates the level (degree) of variation in a group of data or a standard measure of deviation from its mean. The standard deviation (SD) formula can be shown in equation (2):

$$\mathrm{SD} = \sqrt{\frac{\sum(xi-\overline{x})^2}{(n-1)}} \quad (2)$$

where xi indicates the amount of the desired values, x indicates the average of the measurement results, n shows the number of measurements. Uncertainty (UA) is doubt that appears in each measurement result. The uncertainty formula is shown in equation (3):

$$UA = \frac{SD}{\sqrt{n}} \quad (3)$$

where UA indicates the uncertainty value from the total measurement, SD shows the resulted standard deviation, and n shows the amount of measurement. the %error shows the error of the system. The lower value Error is the difference between the mean of each data. The error can show the deviation between the standard and the design or model. The error formula is shown in equation [25][26](4).

$$\%\mathrm{ERROR} = \frac{(x_n - \mathrm{x})}{x_n} \times 100\% \quad (4)$$

where x_n is the value measured from the calibrator machine. The x is the value measured from the design.

III. RESULT

In this study the module has been tested. The design shown in FIGURE 3.

FIGURE 3 . Modul HFNC with breathing circuit

The digital part consists of the ESP32 microcontroller which is the main board of the device and the MPX5700GP[27][28] Pressure sensor. The overall circuit in this study can be seen in FIGURE 4.

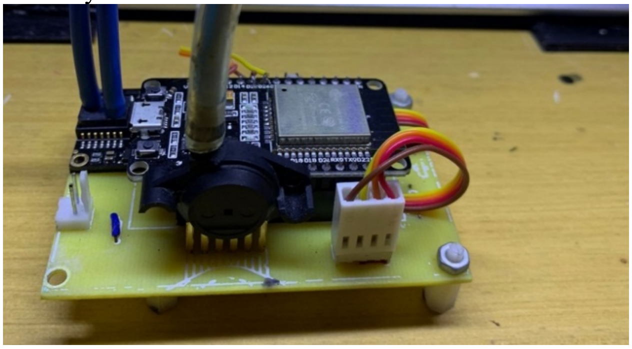

FIGURE 4 . Overal circuit design in research on HFNC with Preassure Sensor MPX5700GP

Data collection for the module in RSUD Bhakti Dharma Husada Surabaya using the HFNC tool. In this data collection, settings are used for parameters Flow 30, 40, 50, and 60 LPM

TABLE 1
Error Comparison Value of Each Flow Setting In Blockage Error Conditions

Setting flow	flow before error(%)	flow in process(%)
30	0,013	37,33
40	0,005	27,80
50	0,012	33,40
60	0,007	36,00

Error is the difference from the actual value compared to the measured value of the pressure parameter with the Blockage Error condition. It can be seen in the table below that the lowest error value at the time of flow before the process is when setting flow at 60 lpm with a value of 0.007%. While the lowest error value when flow in the process is when setting flow at 40 lpm with a value of 27.80%. then for the highest error value at the time of flow before the process is at the time of setting flow at 30 lpm with a value of 0.013%. While the highest error value when flow in the process is when setting flow at 30 lpm with a value of 37.33%. This explanation can be referred to in **TABLE 1**.

TABLE 2
Comparison Value of Standard Deviation of Each Flow Setting in Blockage Error condition

Setting flow	flow before error(%)	flow in process(%)
30	0,548	6,91
40	0,447	7,73
50	0,548	12,22
60	0,548	9,08

From the measurement results of the overall error calculation, an analysis is obtained that the flow value before the error has a very small error value when compared to the

International: Rapid Review: Open Access Journal Vol. 16, No. 2, June 2023, pp. 66-72 e-ISSN 2407-8964; p-ISSN 1907-7904

value of the flow setting, meaning that the flow value obtained is stable compared to the HFNC output setting. while the error value in the process flow is very large, which shows that when the module has an error value of the flow value in the process, it can be concluded that a blockage is occurring. It can be seen from the table above that the standard deviation obtained from measurements with the HFNC module has a good value because the standard deviation value does not exceed the average value of the HFNC module measurement. The standard deviation of the flow before the error proves that the standard deviation of the entire device at the flow setting is ±0.

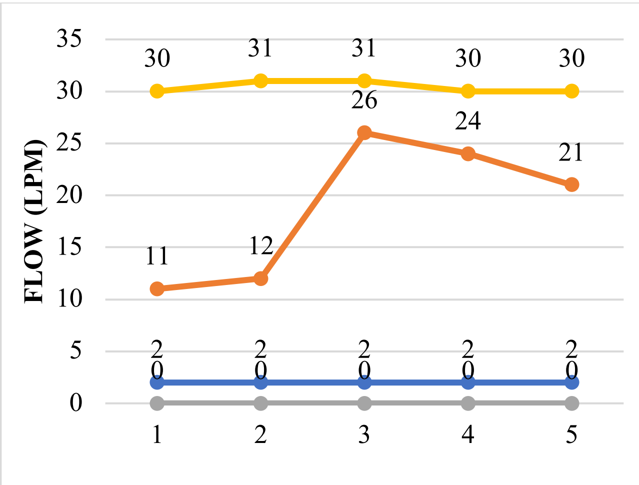

FIGURE 5. Pressure Measurement Results in Blockage Error 30LPM (yellow line is the the flow before error, the blue line indicates the pressure in th process, the orange line indicates the flow on the process, the grey line indicates the pressure before the error)

In FIGURE 5 is the result of pressure measurement under blockage error conditions at 30lpm setting. The experiment was carried out for 5 repetitions in each In the experiment with a flow setting of 30lpm, the average value of the output pressure before the error was 0, the average value of pressure in process 2 and the average value of the pressure after the error was 0. The average value of time each error is 3.3 seconds with an average telegram notification time of 1.3 seconds. In the telegram notification and the condition of the tool it shows a blockage error condition.

In FIGURE 6 is the result of pressure measurement under blockage error conditions at 40lpm setting. At the flow setting of 40lpm the average value of the pressure output before the error is 0, the average value of the pressure in process 2 and the average value of the pressure after the error is 0. The average value of each error time is 3.78 seconds with an average time 1.42 second telegram notification. In the telegram notification and the condition of the tool it shows a blockage error condition.

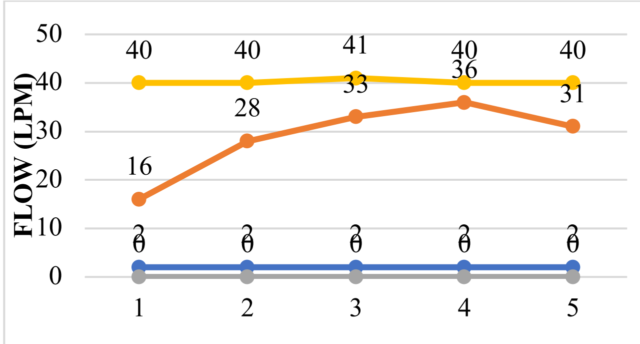

FIGURE 6. Pressure Measurement Results in Blockage Error 40LPM (yellow line is the the flow before error, the blue line indicates the pressure in th process, the orange line indicates the flow on the process, the grey line indicates the pressure before the error)

In FIGURE 7 is the result of pressure measurement under blockage error conditions at 50lpm setting. At the flow setting of 50lpm the average value of the output pressure before the error is 1, the average value of pressure in process 2 and the average value of the pressure after the error is 0. The average value of the error time each is 4.02 seconds with the average telegram notification time 1.68 seconds. In the telegram notification and the condition of the tool it shows a blockage error condition.

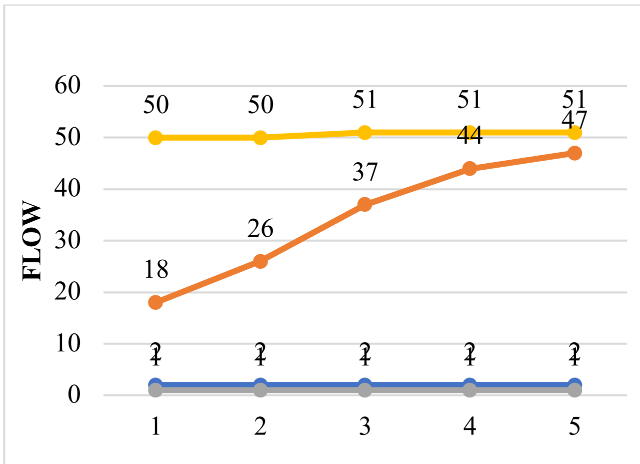

FIGURE 7. Pressure Measurement Results in Blockage 50LPM (yellow line is the the flow before error, the blue line indicates the pressure in th process, the orange line indicates the flow on the process, the grey line indicates the pressure before the error)

FIGURE 8 is the result of pressure measurement under blockage error conditions at 60lpm setting. At the flow setting of 60lpm the average value of the output pressure before the error is 1, the average value of the pressure in the process 3 and the average value of the pressure after the error is 0. The average value of each error time is 5.04 seconds with an average time 1.86 second telegram notification. In the telegram notification and the condition of the tool it shows a blockage error condition.

Jurnal Teknokes
International: Rapid Review: Open Access Journal Vol. 16, No. 2, June 2023, pp. 66-72 e-ISSN 2407-8964; p-ISSN 1907-7904

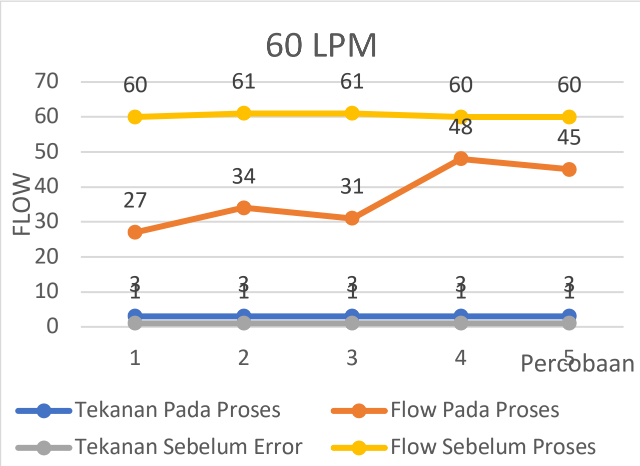

FIGURE 8. Pressure Measurement Results in Blockage 60LPM

.IV. DISCUSSION

The experiment aimed to determine the accuracy of the MPX5700GP pressure sensor output and the SEN0343 Differential Pressure sensor as a flow sensor. The research involved conducting experiments to collect pressure and flow values before, during, and after the occurrence of errors. The module's results for different flow rates were as follows:

- In the 30 LPM experiment, the error value at the time of blockage was 37.33%, with a stable module value of 0.013% before blockage occurred.
- In the 40 LPM experiment, the error value at the time of blockage was 27.80%, with a stable module value of 0.005% before blockage occurred.
- In the 50 LPM experiment, the error value at the time of blockage was 33.40%, with a stable module value of 0.012% before blockage occurred.
- In the 60 LPM experiment, the error value at the time of blockage was 36.00%, with a stable module value of 0.007% before blockage occurred.

These results indicate that higher error flow values in larger processes contribute to blockages. It was observed that when an error value arises during a process, the process either remains the same or deteriorates further with a high error value. Blockages take longer to clear, and the error value under pressure increases. Both HFNC and the module send an error notification in case of process failure. By incorporating IoT-based alerts and data processing, early detection of blockages in the HFNC output interval can be achieved, thus enhancing patient care and error handling.

The implication of this research is that the IoT-based HFNC monitoring tool with signal analysis before blockage errors has been successfully developed and can be effectively utilized. The tool demonstrates the application of pressure sensors and the Telegram application in monitoring alarm occurrences during blockage error conditions. However, the module has certain limitations and areas for improvement. Future research could explore the use of medical-grade standard pressure sensors for enhanced accuracy and sensitivity [17][29][30]. Additionally, advancements in planning, manufacturing, and module functionality can be pursued to overcome existing shortcomings and enhance the module's overall performance.

1. Small Sample Size: The study's reliance on a small sample size may limit the statistical power and generalizability of the findings. With a limited number of participants, the results may not adequately represent the broader population or diverse patient groups that could experience HFNC errors.
2. Lack of Clinical Validation: The study's failure to conduct clinical validation of the developed monitoring module and its comparison to established medical-grade pressure sensors or existing HFNC error detection systems raises concerns about its real-world reliability and accuracy. Without clinical validation, the module's performance in actual patient care settings remains uncertain.
3. Limited Error Types and Scope: The study's narrow focus on blockage errors in HFNC therapy overlooks other potential error types and complications that may impact patient outcomes. A more comprehensive exploration of various error scenarios and their effects would provide a more holistic understanding of HFNC error management and intervention.

In conclusion, this study has successfully developed an IoT-based monitoring tool for HFNC, providing valuable insights into the occurrence and management of blockage errors. By addressing the identified limitations and further refining the module, the healthcare industry can benefit from improved patient care and error detection during HFNC therapy.

IV.CONCLUSION

The purpose of this study is to monitor the occurrence of alarms on HFNC via IoT by analyzing the increase in pressure signals before a blockage error occurs. When the error value occurs during the process remains the same or even increases with a large error value and the blockage is not handled quickly and the error value at pressure is greater than before the process occurred, the HFNC and the module will issue an error notification. the lowest error value at the time of flow before the process is when setting flow at 40 lpm with a value of 0.50%. While the lowest error value when flow in the process is when setting flow at 40 lpm with a value of 28%. then for the highest error value at the time of flow before the process is at the time of setting flow at 30 lpm with a value of 1.33%. While the highest error value when flow in the process is when setting flow at 30 lpm with a value of 38.33%. There are several developments that can be developed in this research, the use of the pressure sensor used, can use a more sensitive pressure sensor. Pressure sensor that can be used in further research is the MPX5010DP. Addition of the use of batteries so that no voltage source is needed, so the module is more portable to use.

REFERENCES

[1] M. S. Alshahrani *et al.*, “High-Flow Nasal Cannula Treatment in Patients with COVID-19 Acute Hypoxemic Respiratory Failure: A Prospective Cohort Study,” *Saudi J Med Med Sci*, vol. 9, no. 3, pp. 1–9, 2021, doi: 10.4103/1658-631X.325256.

[2] J.-P. Frat *et al.*, “High-Flow Oxygen through Nasal Cannula in Acute Hypoxemic Respiratory Failure,” *N. Engl. J. Med.*, vol. 372, no. 23, pp. 2185–2196, 2015, doi: 10.1056/nejmoa1503326.

[3] S. Park, “High-flow nasal cannula for respiratory failure in adult patients,” *Acute Crit. Care*, vol. 36, no. 4, pp. 275–285, 2021, doi: https://doi.org/10.4266/acc.2021.01571.

[4] Z. P. Sullivan, L. Zazzeron, L. Berra, D. R. Hess, E. A. Bittner, and M. G. Chang, “Noninvasive respiratory support for COVID-19 patients: when, for whom, and how?,” *J. Intensive Care*, vol. 10, no. 1, pp. 1–10, 2022, doi: 10.1186/s40560-021-00593-1.

[5] D. Giustivi, F. Bottazzini, and M. Belliato, “Respiratory monitoring at bedside in covid-19 patients,” *J. Clin. Med.*, vol. 10, no. 21, pp. 1–7, 2021, doi: 10.3390/jcm10214943.

[6] N. Hamahata, R. Sato, K. Yamasaki, S. Pereira, and E. Daoud, “Estimating actual inspiratory muscle pressure from airway occlusion pressure at 100 msec,” *J. Mech. Vent.*, vol. 1, no. 1, pp. 8–13, 2020, doi: 10.53097/jmv.10003.

[7] Y. Zhou, Z. Ni, Y. Ni, B. Liang, and Z. Liang, “Comparison of Actual Performance in the Flow and Fraction of Inspired O2among Different High-Flow Nasal Cannula Devices: A Bench Study,” *Can. Respir. J.*, vol. 2021, 2021, doi: 10.1155/2021/6638048.

[8] L. Roesthuis, M. Van Den Berg, and H. Van Der Hoeven, “Advanced respiratory monitoring in COVID-19 patients: Use less PEEP!,” *Crit. Care*, vol. 24, pp. 1–4, 2020, doi: 10.1186/s13054-020-02953-z.

[9] N. T. Hamahata, R. Sato, and E. G. Daoud, “Go with the flow - Clinical importance of flow curves during mechanical ventilation: A narrative review,” *Can. J. Respir. Ther.*, vol. 56, no. July, pp. 11–20, 2020, doi: 10.29390/cjrt-2020-002.

[10] A. Ashish *et al.*, “CPAP management of COVID-19 respiratory failure: A first quantitative analysis from an inpatient service evaluation,” *BMJ Open Respir. Res.*, vol. 7, no. 1, pp. 1–9, 2020, doi: 10.1136/bmjresp-2020-000692.

[11] M. Elizabeth, C. Yoel, M. Ali, M. S. Loebis, H. Arifin, and P. Sianturi, “Comparison of ventilation parameters and blood gas analysis in mechanically-ventilated children who received chest physiotherapy and suctioning vs. suctioning alone,” *Paediatr. Indones.*, vol. 56, no. 5, p. 285, 2017, doi: 10.14238/pi56.5.2016.285-90.

[12] J. Rondón-Carvajal, F. Rodríguez-Vega, L. Pérez-Lugo, K. MaderaGutiérrez, and F. Clavijo-Tinoco, “Incidental Finding of Mediastinal Mass in A Patient with A Confirmed Diagnosis of Moderate to Severe COVID-19: Case Report,” *Front. Med. Case Reports*, vol. 01, no. 05, pp. 1–8, 2020, doi: 10.47746/fmcr.2020.1508.

[13] D. Gómez-alzate, S. Pérez-buitrago, M. Córdova, M. Bornas, and B. Castaneda, “Quality characteristics of the Masi Peruvian mechanical ventilator manufacturing process *,” pp. 1557–1561, 2021.

[14] S. G. Peters, S. R. Holets, and P. C. Gay, “High-flow nasal cannula therapy in do-not-intubate patients with hypoxemic respiratory distress,” *Respir. Care*, vol. 58, no. 4, pp. 597–600, 2013, doi: 10.4187/respcare.01887.

[15] R. Scala, “High-flow nasal oxygen therapy in acute respiratory failure,” *Geriatr. Care*, vol. 4, no. 3, pp. 408–413, 2010, doi: 10.4081/gc.2018.7799.

[16] F. Montecchia *et al.*, “Pharyngeal and esophageal pressure measurements to evaluate respiratory mechanics in infants on high flow nasal cannula: A feasibility study,” *2015 IEEE Int. Symp. Med. Meas. Appl. MeMeA 2015 - Proc.*, pp. 234–239, 2015, doi: 10.1109/MeMeA.2015.7145205.

[17] B. Sztrymf, J. Messika, T. Mayot, H. Lenglet, D. Dreyfuss, and J. D. Ricard, “Impact of high-flow nasal cannula oxygen therapy on intensive care unit patients with acute respiratory failure: A prospective observational study,” *J. Crit. Care*, vol. 27, no. 3, pp. 324.e9-324.e13, 2012, doi: 10.1016/j.jcrc.2011.07.075.

[18] D.-L. Salvador *et al.*, “Things to Keep in Mind in High Flow Therapy: As Usual the Devil is in the Detail,” *Int. J. Crit. Care Emerg. Med.*, vol. 4, no. 2, pp. 1–8, 2018, doi: 10.23937/2474-3674/1510048.

[19] J. P.-R. Laura García-Pereña, Violeta Ramos Sesma, María Lucía Tornero Divieso, Alfonso Lluna Carrascosa, Sara Velasco Fuentes, “Benefits of early use of high-flow-nasal-cannula (HFNC) in patients with COVID-19 associated pneumonia,” *Med. Clin. (Barc).*, vol. 158, no. 11, pp. 540–542, 2022, doi: DOI: 10.1016/j.medcle.2021.05.024.

[20] E. D. Dijemeni and R. Dickinson, “Portable mobile real time oxygen monitoring auto-ventilation system,” *2013 E-Health Bioeng. Conf. EHB 2013*, pp. 98–101, 2013, doi: 10.1109/EHB.2013.6707383.

[21] N. Sianturi, M. Prastawa, and A. Tetra, “Analysis of Input Pressure Differences at CPAP Bubble Output Concentration Show TFT,” vol. 2 no. 1, pp. 1–8, 2020.

[22] R. L. Read, L. Clarke, and G. Mulligan, “VentMon: An open source inline ventilator tester and monitor,” *HardwareX*, vol. 9, p. e00195, 2021, doi: 10.1016/j.ohx.2021.e00195.

[23] G. C. P. and Q. L. T. Ken Junyang Goh1 , Hui Zhong Chai, Thun How Ong, Duu Wen Sewa, “Early prediction of high flow nasal cannula therapy outcomes using a modified ROX index incorporating heart rate,” *J. Intensive Care*, vol. 8, no. 41, pp. 1–14, 2020, doi: https://doi.org/10.1186/s40560-020-00458-z.

[24] M. N. Islam, S. M. Doria, X. Fu, and Z. R. Gagnon, “Piezoresistive Conductive Microfluidic Membranes for Low-Cost On-Chip Pressure and Flow Sensing,” *Sensors*, vol. 22, no. 4, 2022, doi: 10.3390/s22041489.

[25] R. Farré *et al.*, “Performance of mechanical ventilators at the patient’s home: A multicentre quality control study,” *Thorax*, vol. 61, no. 5, pp. 400–404, 2006, doi: 10.1136/thx.2005.052647.

[26] N. Dugarte, A. Alvarez, E. Dugarte, N. Alvarado, and S. Bhaskar, “Practical design of flow meter for mechanical ventilation equipment,” *J. Comput. Sci. Technol.*, vol. 21, no. 1, pp. 42–48, 2021, doi: 10.24215/16666038.21.e5.

[27] I. Freescale Semiconductor, “Datasheet MPX5700,” *Time*, no. 2, pp. 1–9, 2012.

[28] NXP Semiconductors, “Technical Data Sheet: MPXV5010DP, 0 to 10 kPa, Differential, Gauge, and Absolute, Integrated, Pressure Sensors,” 2012.

[29] F. Duprez *et al.*, “Accuracy of Medical Oxygen Flowmeters: A Multicentric Field Study,” *Health (Irvine. Calif).*, vol. 06, no. 15, pp. 1978–1983, 2014, doi: 10.4236/health.2014.615232.

[30] R. L. Parke, M. L. Eccleston, and S. P. McGuinness, “The effects of flow on airway pressure during nasal high-flow oxygen therapy,” *Respir. Care*, vol. 56, no. 8, pp. 1151–1155, 2011, doi: 10.4187/respcare.01106.