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Design and Build a Ventilator Tester with a Peak Inspiratory Flow Waveform Display as Validation using the F1031V Sensor

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ABSTRACT One of the important parameters that must be monitored is PIF (Peak Inspiratory Flow) which is the peak inspiratory flow rate given through the ventilator. PIF that is too high or too low can cause side effects in the patient. PIF monitoring can be seen through the PIF value and waveform on the PIF. Monitoring the PIF waveform will be very useful for improving ventilatory outcomes. The purpose of this study was to obtain the accuracy and precision of the sensor to display the waveform of the ventilator output. The implication of this research for the community is that this research can be used as a comparison of the output of the ventilator used. The procedure carried out is to use the F1031V sensor to detect the flow generated by the ventilator and then detect the PIF value and PIF waveform. From this study, the conclusion of the measurement results obtained that the accuracy and precision of the F1031V sensor to detect PIF and produce a waveform graph is said to be good. This is because the highest error value is ±2.04% at 20 LPM setting. Meanwhile, the largest standard deviation value at 30 LPM setting is 1.517 and the greatest uncertainty value at 30 LPM setting is 0.061. Then the biggest correction value is in the setting of 20 LPM and 30 LPM, which is 0.4. The advantage of this research is the availability of a waveform display as a validation of the ventilator output as a support for calibration on the ventilator device.

INDEX TERMS PIF, Signal, Sensor P1031V

I. INTRODUCTION

Respiratory activity[1][2][3] is an involuntary activity and supports respiratory function in humans . Patients will need respiratory support for certain conditions, such as during surgical operations involving general anesthesia or because normal breathing cannot support the body's oxygen needs. In this condition the patient requires ventilator assistance[4][5], There are two types of medical ventilators: such as mechanical ventilators and non-invasive ventilators. For the ventilator is needed. in the case of the covid 19 pandemic[6][7][8], the virus causes damage to the lungs. And cause a decrease in SpO2 because the patient is difficult to breathe. Ventilator is used to help the patient's breathing by pushing air into the lungs with the aim of increasing oxygen levels. Because the ventilator is a very important support for breathing needs, the ventilator must always be in good condition and condition. So there are several parameters that must be monitored specifically, such as the measurement of pressure and flow rate used in the ventilator system, the accuracy of which must be in accordance with the accuracy of the respirator[4][9][10]. Some of the parameters that must be considered include, Tidal Volume (TV), Respiratory rate (RR), Ratio I: E, Peak Inspiratory Flow (PIF), peak inspiratory pressure (PIP), and Positive end-expiratory pressure (PEEP) etc. . PIF is the peak inspiratory flow rate, PIF is the maximum flow given through the ventilator. Most modern ventilators can provide flow rates between 60 and 120 L/min. Flow flow should be titrated to meet the patient's inspiratory needs. If the PIF is too low for the patient, the patient may experience dyspnea, patient-ventilator asynchrony, and increased work of breathing. High PIF increases PIF pressure and lowers mean line pressure, this can lead to decreased oxygenation. In most patients, a peak flow rate of 60 L/min is sufficient. Higher flow rates are required in patients with higher ventilator requirements.

Higher PIF may also be required in patients with obstructive pulmonary disease to reduce inspiratory time[11][12][13], thereby increasing expiratory time and reducing the risk of auto-PEEP[14][15][16].

In the appearance of the PIF parameter there is a waveform to determine the timing of respiration on mechanical ventilation, in this waveform the timing of the patient's breathing will be known according to the settings given by the nurse, monitoring the waveform from PIF will be very useful to provide further treatment for patients, this has the potential to improve the results of the use of the ventilator[17][16], thus making the waveform an important parameter for monitoring in order to determine the accuracy of the waveform detected by the ventilator, in the last few studies discussing the ventilator tester module it provides information about the ventilator output but not the waveform which is output by the sensor, with these shortcomings the researcher wants to discuss the appearance of the PIF parameter waveform as a ventilator output validation[18][4][11]. In 2014, Fred Duprez et al., conducted a study on the accuracy of medical oxygen using flowmeters this study aims to determine the accuracy of medical flow to determine the error rate generated from medical flow meters, and obtain conclusion if the number of use of flow meters will affect the accuracy of the output[19]. Then, in 2020, Natsumi T. Hamahata et al., conducted a flow curve study when patients received assistance from mechanical ventilation. In this study, the researchers concluded that flow waveform shapes need to be considered when giving mechanical ventilation, giving attention to flow waveforms can To improve the outcome of therapy, researchers hope that further research on flow waveforms when providing mechanical ventilation to patients [10]. Then, in 2021, Tomy Abuzairi et al., conducted a study on the manufacture of an accessible ventilator tester so that ventilator checks can be carried out to maintain the accuracy of the device. Researchers expect further research on certain sensors so that the design of the Low Cost Ventilator Tester can be used accurately[20][21]. All previous studies analyzed the use of PIF on ventilator parameters. from previous studies, no one has used PIF as a validation of the accuracy of the ventilator device output.

PIF is the peak inspiratory flow rate. If the PIF is too low for the patient, the patient may experience dyspnea, patient-ventilator asynchronous, and increased work of breathing. High PIF increases PIF pressure and decreases mean airway pressure[22][23][24], this can lead to decreased oxygenation. the appearance of the PIF parameter has a waveform to determine the timing of respiration on mechanical ventilation, on this waveform the timing of the patient's breathing will be known according to the settings given by the nurse[25][26]. Based on the research that has been done previously, the author will make a study entitled "Design of a Ventalitor Tester With PIP and PIF Waveform Displays as Validation (PIF)" which is the development of research that has been made previously. This study aims to obtain the accuracy and precision of the sensor to display the waveform of the ventilator output so that the data obtained can be used as a support for making calibration tools with sensors that have been studied. pressure sensor to measure and display PIP and PIF waveforms.

This study aims to analyze the waveform generated from the flow sensor output as a flow sensor and the appearance of the waveform on the Ventilator Tester Design with PIP and PIF Waveform Displays as Validation (PIF).

II. METHOD

Data retrieval on the Ventilator Tester module was carried out using Ventilator 1 which was carried out at Lumajang Hospital. The research design used in making the module is Pre-experimental with the After Only Design type. In this design the researcher only uses one group of subjects and only sees the results without measuring and knowing the initial conditions, but there is already a comparison group. The independent variable in this study is the PIF module used. the dependent variable is the flow sensor used, namely P1031V. and the controlled variable is the microcontroller board used, namely arduino. This study uses a F1031V[27][28] flow sensor as a flow input, then the data flow will be processed using an Arduino microcontroller, and the flow results will be displayed on the LCD Display[29] . The block diagram in FIGURE 1 has 3 main parts, namely process input and output, the input consists of a flow sensor F1031V which is the source of input data on the microcontroller, the process section consists of a microcontroller which functions to receive data from the sensor, the microcontroller will process the output from the sensor into PIF, so that the sensor value can be displayed as PIF on the display, in the output process there is a display that serves to display data that has been processed by the microcontroller.

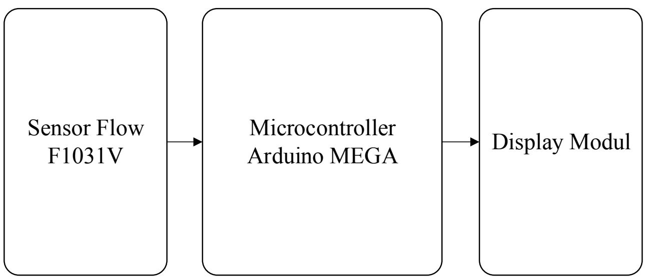

FIGURE 1. The diagram block of the system in research design of ventilator tester using F1031V sensor

This paragraph can explain FIGURE 2 turn on the ON button after the module is turned on then the process will initialize after the initialization process is complete it will continue in the next section, namely the selection of starting conditions, when the condition starts to value false then the process will return to initialization and if the condition starts to be true then the process will continue on sensor readings flow and continues on processing the flow sensor value to get PIF after data processing is complete, the process will continue on the appearance of data that has been processed by the microcontroller.

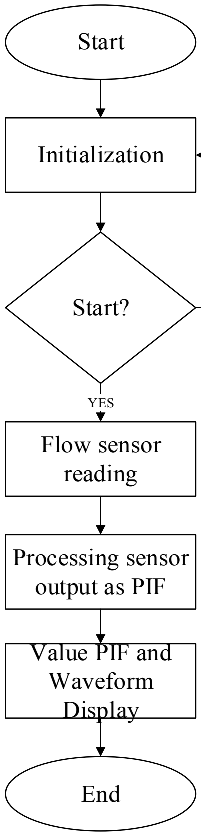

FIGURE 4. The flowcart system in research design of ventilator tester using F1031V sensor

A. DATA ANALYSIS

Measurements of each parameter, flow from 20 – 40 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 Eq (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 x denotes the mean (mean) for the n-measurements, x1 denotes the first measurement, x2 denotes the second measurement, and xn denotes n measurements. Standard deviation is a value that indicates the degree (degree) of variation in a data set or a measure of the standard deviation of the mean. The standard deviation (SD) formula can be shown in Eq (2):

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

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

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

where UA indicates the uncertainty value of the total measurement, SD indicates the resulting standard deviation, and n indicates the number of measurements. %error indicates a system error. The lower Error value is the average difference of each data. Errors can indicate deviations between the standard and the design or model. The error formula is shown in Eq (4).

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

where xn is the measured value of the machine calibrator. X is the measured value of the design.

III. RESULT

In this study, the module has been tested using a calibrator, namely the Ventilator. Designs featured in FIGURE 2.The digital part consists of the Arduino microcontroller[30] which is the main board of the device and the F1031V flow sensor like in the FIGURE 3.

FIGURE 2. Ventilator Tester Display Ventilation Tester display with two PIP and PIF waveforms for validation

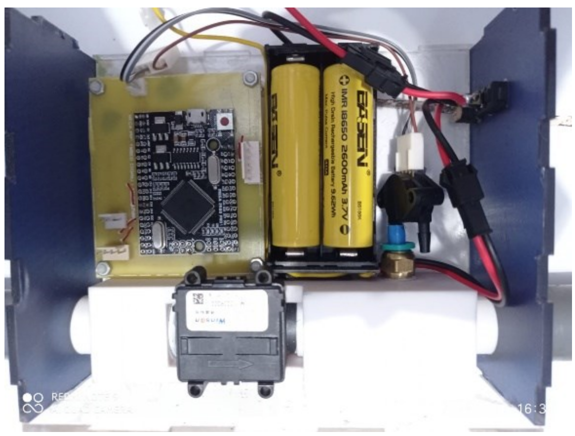

FIGURE 3. overall circuit ventilator tester using sensor F1031V

Data retrieval on the Ventilator Tester module was carried out using Ventilator 1 which was carried out at Lumajang Hospital. Error or error indicates the difference between the actual value coming out of the Ventilator and the measured value from the Ventilator Tester module, with the LPM pressure for PIF measurements. It can be seen in the table below that the smallest error value from the measurement of the Ventilator Tester module with Volume mode on Ventilator 1 is in the PIF 40 LPM setting, while the smallest error value for Ventilator 2 is in the PIF 20 LPM setting.

TABLE 1
Comparison Value of Module Measurement Error on Ventilator 1 and Ventilator 2

Setting Flow	Ventilator 1(%)	Ventilator 2(%)
20 LPM	1.01%	2.04%
30 LPM	0.64%	1.29%
40 LPM	0.47%	0.48%
Rata-rata ($\overline{X}$)	0.71%	0.09%

From the measurement results in TABLE 1, the overall error value obtained from the Ventilator Tester module can be said to be good with the highest error of ±1.01% on Ventilator 1, which is at 20 LPM setting, while on Ventilator 2 it is ±2.04% at 20 LPM setting. And for the smallest error value in the measurement of Ventilator 1, which is ±0.47% at 40 LPM settings, while in Ventilator 2 it is ±0.48% at 40 LPM settings as well. From the overall error value and the average error value on the two ventilators used, it can be seen if it does not exceed the tolerance range so that the Ventilator Tester module is fairly accurate for detecting the PIF value on the Ventilator.

TABLE 2
Comparison Value of Standard Deviation Measurement Module on Ventilator 1 and Ventilator 2

Setting Flow	Ventilator 1 (%)	Ventilator 2 (%)
20 LPM	0.707	1
30 LPM	1.517	1.34
40 LPM	0.894	0.894
Rata-rata ($\overline{X}$)	1.039	1.078

Based on TABLE 2, it can be said that the standard deviation value of the Ventilator Tester module measurement results is good, this is because the standard deviation value does not exceed the average value of the Ventilator Tester module measurement results. Thus, the average value of the Ventilator Tester module measurements can be used as a data representation of the entire measurement. The standard deviation value indicates that there is an oscillation or standard deviation in the measurement. From all measurements, the largest standard deviation value on Ventilator 1 is found in the 30 LPM setting, which is 1.517, while on the Ventilator 2 there is also the 30 LPM setting, which is 1.34. The standard deviation value is said to be quite good, which means that the data distribution or deviation is not too large, so it can still be said that the Ventilator Tester module measurement results are quite precise.

TABLE 3
Comparative Value of Uncertainty (UA) of Module Measurements on Ventilator 1 and Ventilator 2

Setting Flow	Ventilator 1	Ventilator 2
20 LPM	0.028	0.04
30 LPM	0.061	0.054
40 LPM	0.036	0.036
Rata-rata ($\overline{X}$)	0.041	0.043

Based on TABLE 3, we can see the uncertainty value of the measurement results of the Ventilator tester module which is used to see how close the measured value is to the actual value. This uncertainty is also used to see how much accuracy the Ventilator Tester module is, it can be stated that the smaller the uncertainty, the higher the accuracy. In this study, the greatest uncertainty value in the measurement of Ventilator 1 is found at the 30 LPM setting, which is 0.061, while in the Ventilator 2 there is a 30 LPM setting, which is 0.054. The results of this uncertainty can still be said to be good, so the accuracy of the Ventilator Tester module is also said to be good. Measurement results or readings that have random results are said to have no good stability. If it is associated with data reading, it does not change during the measurement, the graphic measurement does not change up or down and the values that appear do not change continuously.

TABLE 4
Comparative Value of Module Measurement Correction on Ventilator 1 and Ventilator 2

Setting Flow	Ventilator 1	Ventilator 2
20 LPM	0.2	0.4
30 LPM	0.2	0.4
40 LPM	0.2	0.2
Rata-rata ($\overline{X}$)	0.2	0.067

The correction value is an additional value given to compensate for the addition of errors systematically. The correction value in this study proves that there are still errors or inequalities between the setting value and the average. From the table above, it can be seen that the correction value indicates an error in the system from the module. If the correction value is smaller, the better the performance of the module will be. Based on TABLE 4, it can be seen if the correction value in the measurement results of the Ventilator Tester [31][7] [16], module on Ventilator 1 is the same, namely 0.2. Meanwhile, in the Ventilator 2 measurement, the largest correction value is found in the settings of 20 LPM and 30 LPM, namely 0.4. If it is seen from the largest correction value and the average correction value of the module, it can be said that the error caused by the module is relatively small. Therefore, the system module performance is considered good. Measuring instrument can be said to be good if it has high accuracy and precision. Not all measuring instruments that have good precision also have good accuracy. In addition, the measurement also requires good sensitivity or good response to small changes in the input signal.

IV. DISCUSSION

After testing the Ventilator Tester module, data collection and analysis of the results are carried out to determine the performance of the module manufacture. This research also aims to obtain the accuracy and precision of the sensor to display the waveform of the ventilator output. Then the results obtained on the ventilator are as follows: In reading the PIF value on the Ventilator Tester module in volume mode, the error value obtained from the Ventilator Tester module can be said to be good with the highest error of ±1.01% on Ventilator 1, which is at 20 LPM setting, while on Ventilator 2 it is ±2.04% at 20 setting. LPM. And for the smallest error value in the measurement of Ventilator 1, which is ±0.47% at 40 LPM settings, while in Ventilator 2 it is ±0.48% at 40 LPM settings as well. The largest standard deviation value on Ventilator 1 is found at the 30 LPM setting, which is 1.517, while on the Ventilator 2 it is also found at the 30 LPM setting, which is 1.34. The standard deviation value is said to be quite good, which means that the data distribution or deviation is not too large, so it can still be said that the Ventilator Tester module measurement results are quite precise. Meanwhile, the greatest uncertainty value in the Ventilator 1 measurement is in the 30 LPM setting, which is 0.061, while in the Ventilator 2 it is at the 30 LPM setting, which is 0.054. The results of this uncertainty can still be said to be good, so the accuracy of the Ventilator Tester module is also said to be good. All previous studies analyzed the use of PIF on ventilator parameters. from previous studies, no one has used PIF as a validation of the accuracy of the ventilator device output. then there is a weakness from this research, the value of the tool's output cannot be saved. then the battery capacity tends to be small so it takes several charging times. then a display that is not equipped with graphics. For the correction value in the measurement results of the Ventilator Tester module on Ventilator 1, the value is the same, namely 0.2. Meanwhile, in the Ventilator 2 measurement, the largest correction value is found in the settings of 20 LPM and 30 LPM, namely 0.4. When viewed from the largest correction value and the average correction value of the module, it can be said that the error caused by the module is relatively small. Therefore, the system module performance is considered good. The implications of this research are used to test and prove the accuracy and precision of the sensor to display the waveform of the ventilator output. Due to various factors, the module made by the author is still far from perfect, both in terms of planning, manufacturing, and how the module works. So that there are several shortcomings that have been analyzed from the tool that the author made. The first is that the display on the hardware can use other applications or interfaces so that it can be clearer and the value of the results from the module can be stored. Then it is necessary to discuss the MPX5010 sensor and its effect using 1 input or 2 inputs to identify the suitability of the conversion value.

IV. CONCLUSION

The purpose of this research is to test and prove the accuracy and precision of the sensor to display the waveform of the ventilator output. The measurement accuracy and precision of the F1031V sensor to detect PIF and generate waveform graphs is said to be good. This is because the highest error value is ±2.04% at the 20 LPM setting. While the value of the largest standard deviation at the 30 LPM setting is 1.517 and the greatest uncertainty value at the 30 LPM setting is 0.061. Then, the largest correction value is found in the setting of 20 LPM and 30 LPM, namely 0.4. Furthermore, the F1031V sensor reading program and conversion to PIF values are designed using the Arduino IDE Application, as well as delivery to the TFT LCD to display graphs and read PIF values. Based on the testing of the ventilator tester module that has been carried out by comparing the measurement results with a calibrated ventilator device and the results obtained are said to be good and can carry out their work functions. The development of research that can be done in the future will be found adding an SD Card for storing values and waveforms. then the addition of a battery so that the tool can be used longer and also the addition of a web display to display so that the results obtained are more accurate.

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