Design of Ventilator with Gas Mixing, Tidal Volume, and Humidifier Parameters

Hanifah Rahmi Fajrin [1*], Edi Susanto [2], Pamela Sandi Agus Kristianto [3], Fery Ferizal Herdiyana [4], Susilo Ari Wibowo [5]
[1, 2, 3, 4,5] Department of Medical Electronics Technology, Universitas Muhammadiyah Yogyakarta, Yogyakarta, Indonesia
Email: [1] hanifah.fajrin@vokasi.umy.ac.id, [2] edi.susanto.vokasi18@mail.umy.ac.id, [3] pamela.sandi.vok18@mail.umy.ac.id
[4] fery.ferizal.vok18@mail.umy.ac.id
*Corresponding Author

***Abstract*—On the ventilator, there are several important parameters, including gas mixing, which functions to mix oxygen with free air, the tidal volume serves to supply mixed air to the patient, respiratory rate is the frequency of breath given to the patient, and the humidifier functions to regulate the temperature of the air given to the patient. In this research, the author intends to design a ventilator device that uses a working system to open and close the valve to distribute air to the patient. This tool uses several sensors: oxygen sensor KE-25F3, flow sensor yf-s201, pressure sensor MPX 5700, and temperature sensor DS 12B20. The tidal volume (VT) has 3 setting values: 700 ml, 500 ml, and 300 ml. The test is carried out by opening and closing the valve. The respiratory rate has 2 settings of 15 and 20 breaths/minute. In addition, the humidifier has 3 setting modes 32, 35, and 40º C. From the test results, the highest error was obtained in the 300 ml tidal volume test, which was 7.20%, and in the respiratory rate test, the highest error value was 0%. The test results with the oxygen concentration parameter obtained the largest error value of 0.1% at 100% oxygen concentration. In testing the temperature and humidity parameters, the largest average error was 2.40% at 40º C setting. So, it can be concluded that the tool is feasible to use because of the level of small error and is still within the standard calibration tolerance of 15%.**

Keywords—Gas mixing; tidal volume; humidity; ventilator.

I. Introduction

The ventilator has an important parameter, gas mixing, which functions to mix oxygen with free air according to patient needs [1]. Mixing oxygen gas with free air should get more attention because if it is not used properly, it can cause ventilation depression effects and oxygen poisoning [2]. Gas mixing equipment with a small human error is an automatic gas mixing tool because the system has set the value, so it is not easy to change [3]. On the ventilator, there is also a tidal volume parameter that functions to supply mixed air to the patient and respiratory rate [4], which is the frequency of breath given to the patient, and the humidifier functions to regulate the temperature of the air given to the patient [5]. A tidal volume or pressure that is too large can cause hyperventilation, barotrauma, and hemodynamic instability [6], [7]. Tidal volume is the maximum volume of the lungs or the amount of air that goes into and out of breath [8]–[11].

Respiratory rate or respiratory frequency is one of the parameters that must also be present on the ventilator in an effort to compensate for the small volume or volume of breath [12], [13], with units of breaths/minute [14]. If giving the breath or the respiratory rate value is too much, it will cause hyperventilation in the patient resulting in pneumonia [15], [16], [17].

The use of ventilators also often causes several effects in the form of respiratory tract infections, inflammation of the throat wall, or mucosa [18]. In a severe condition, it may cause respiratory failure due to narrowing of the respiratory tract due to swelling of the airways due to respiratory tract infections [19], [20]. This is because the air that enters the respiratory tract or lungs is still classified as dry air, which can trigger inflammation of the mucous layer or the outermost membrane of the throat [21]. Causes of respiratory tract infections are viruses and bacteria that enter through wounds due to inflammation of the respiratory tract, can even cause swelling and can even trigger respiratory failure in patients [22]. For this reason, it is necessary to maintain air and humidity [23], [24] so that there is no inflammation in the throat and lungs. With this, there must be a humidifier to regulate the temperature and humidity of the air given to the patient [25].

Based on the identification of the problem above, the author will design a ventilator with automatic gas mixing parameters, tidal volume, respiratory rate, and humidifier [25]. Automatic gas mixing to regulate the oxygen demand given to the patient, tidal volume to determine how much air will be given to the patient by using the yf-s201 airflow sensor and MPX5700DP sensor to detect the amount of air pressure to be given to the patient [26], [27], and also using the system Valve control as the entrance and exit of air to be given to the patient, while the respiratory rate is to find out how many breaths the patient takes in 1 minute [19]. Then there is a humidifier to regulate the temperature of the air that will be given to the patient [28]. The final result of this study displays the value of oxygen concentration, tidal volume, respiratory rate, and humidifier on the ventilator.

II. Method

A. Flowchart

The flowchart for the design of the ventilator is shown in Fig. 1. It can be explained that the process starts from the initialization of the program after the tool is turned on and continues with the process of setting the oxygen concentration [29]. After that, the valve will provide oxygen and free air input. The oxygen sensor and pressure sensor will work to detect the value of the oxygen concentration and the incoming air pressure [30], [31]. After that, oxygen is mixed with free air and supplied to the next process, setting the tidal volume value, setting the respiratory rate process, and entering the temperature setting process. The temperature sensor will work to detect the temperature and humidity of the air that will be given to the patient [32]–[34]. The process is complete when the tool is turned off by pressing the stop / off button.

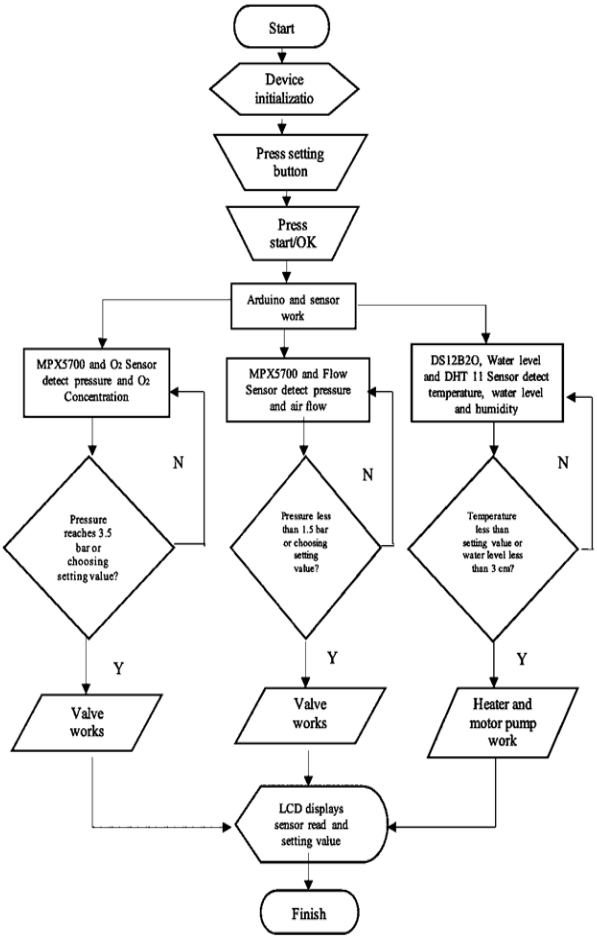

Fig. 1. Gas mixing circuit

B. *Hardware Implementation*

Here are some of the hardware used by the author in the research that has been done, including:

1) *Gas mixing circuit*

Fig. 2 shows gas mixing circuit processes and the overall schematic that the author uses in the study. There is an LM2596 module that is used to lower the 12V voltage from the power supply to 5V. The 5V voltage is used as power by the Arduino nano [35], LCD, and sensor signal conditioner. Then the 12V voltage is used as power by the IRF-520 Mosfet module and solenoid valve. The compressor gets AC voltage directly from the power source. Arduino nano has a role as a sensor output data processor and displays it into the LCD display [36], as well as processing input from the push button into a command to activate the IRF-520 Mosfet driver so that it can run the solenoid valve. LCD is used in this study to display the sensor value reading data and the amount of oxygen concentration to be used [37]. Then the sensor signal conditioning is used to condition the sensor output so that it can be processed by Arduino properly [38].

2) *Control circuit for tidal volume and respiratory rate*

Fig. 3 is an image of the tidal volume and respiratory rate control circuit. Fig. 3 is a schematic in which there is a step-down circuit [39] that is used as a voltage drop from 12 VDC to 5VDC because to activate the Arduino nano circuit, sensors and LCDs require a voltage of 5VDC. In total, there are two Arduino Nanos with functions as the main control and mechanical control valve and equipped with an IRF-520 Mosfet driver circuit as a converter of the initial 5V voltage to 12V according to valve needs [40]. Then it is equipped with a series of indicators in each mode to make it easier when an error occurs on the device, and there is an LCD equipped with an I2C module [41].

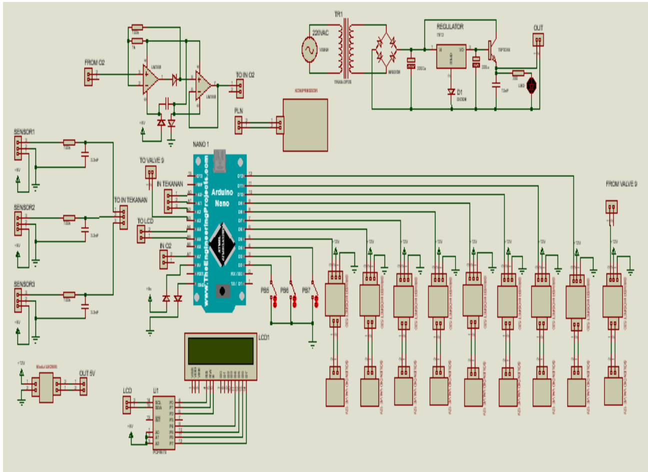

Fig. 2. Gas mixing circuit

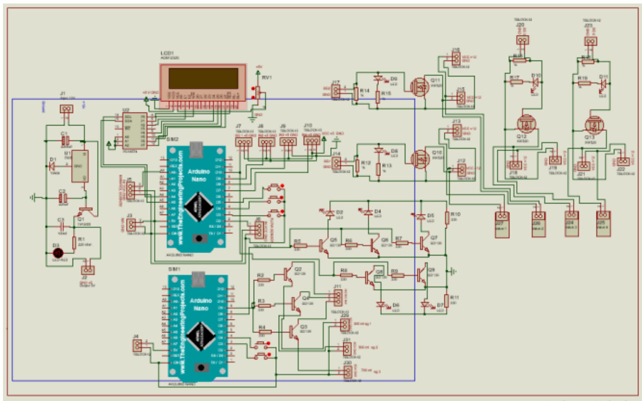

Fig. 3. Control circuit for tidal volume and respiratory rate.

3) *Humidifier Circuit*

Fig. 4 is a humidifier control circuit. It consists of a power supply as a voltage source to provide voltage to some of the circuit components of +12VDC, then lowered with a voltage-lowering circuit of +5VDC to provide voltage to all controls and sensors. The +5VDC voltage is used as the main voltage source, which will provide voltage to the entire circuit. The working principle of the whole circuit is that when the ON button is turned on, there will be a device initialization process so that the program will command the display on the start page, then the Start/Ok button is used to switch the initial LCD screen display to a mode choice, while the right button and left button is used to select the mode to use. Then when finished selecting the mode again, press the Start / Ok button, which means the tool is in a state of starting work. When the Start/Ok button is pressed on the LCD screen, it will start the process of reading all sensors by the Arduino Nano that has been installed, which are the DS12B20 sensor [42] for temperature parameters, DHT11 for humidity parameters [43], and Water Level Sensor [44] for water level parameters in the container. These parameters will be processed directly by the Arduino Nano mainboard. The sensor reading process lasts for a few seconds. Then, if it has been read completely, the Arduino Nano mainboard will process and display each of the parameters used. The temperature parameter is operated automatically. When the temperature is less than the setting value, the heater will turn on, and vice versa. When the temperature is more than the setting value, the heater will turn off. Furthermore, the water level parameter [45] is operated automatically. When the water level is less than the specified value, which is 1cm, the water pump will turn on, and vice versa. When the water level is more than 2 cm, the water pump will turn off.

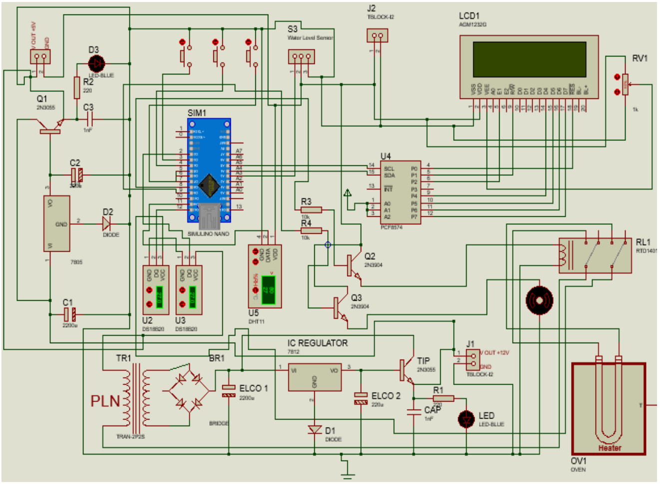

Fig. 4. Humidifier control circuit

III. Result and Discussion

Testing on the sensor of the tool is carried out to determine the success of the performance of the tool in conducting a feasibility test of the sensor on this ventilator. The test is done by starting the ventilator and testing the tidal volume, flow rate, and respiratory rate.

A. Mechanical Design

The following is an approximate design of the shape and arrangement of the components to be made. The image can be seen in Fig. 5.

Description:

1. The box for the gas mixing process.
2. LCD 4x16 display of oxygen concentration results.
3. Drain chamber in the humidifier
4. Air temperature controlling humidifier section.
5. The connecting hose between tidal volume and supply to the humidifier
6. LCD display for flow rate, chamber pressure, tidal volume
7. The part that controls the tidal volume, respiratory rate, and flow rate.
8. Output connector that will go to the patient.
9. LCD for temperature control results display.

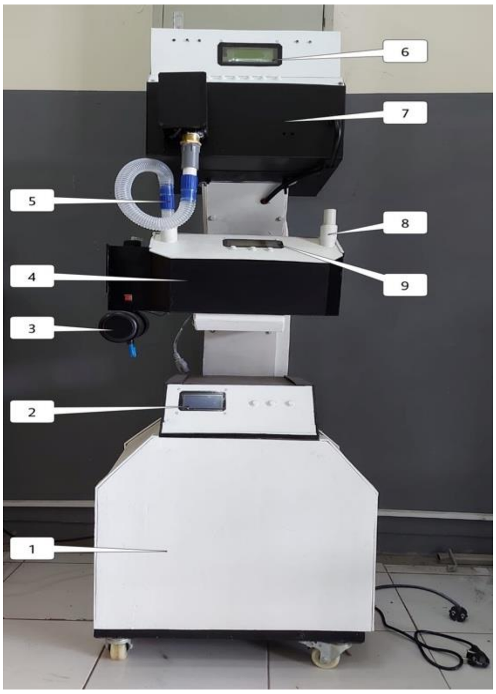

Fig. 5. The mechanic of the Tool

B. Tidal Volume Test

Tidal volume is the volume of air that enters and leaves the lungs during the respiratory process [46], [47], while the unit of tidal volume is in milliliter (ml). This tidal volume test uses settings of 300, 500, and 700ml. The test was carried out using a gas analyzer calibration tool VT502 with data collection for each set 5 times.

Table 1 is the result of testing the tidal volume parameter using the VT502 gas analyzer calibrator 5 times with 3 setting modes: 300, 500, and 700ml. In the measurement with the 300ml setting, the average result is 321.6, with an error rate of 7.20%. With the 500ml setting mode, the average result is 490.2 with an error value of 1.96%. Meanwhile, with the 700ml setting, the average result is 700.8, with an error value of 0.11%.

TABLE 1. TIDAL VOLUME TESTING

No	Tidal Volume (ml)	Average (ml)	Error (%)
1	300	321,6	7,20
2	500	490,2	1,96
3	700	700,8	0,11

C. Flow rate test

Flow rate is a measure of the volume of fluid that moves in a certain amount of time, the unit of flow rate is liters per minute (m^3/minute). In this test, the settings are 18, 30, and 42 liters/minute (m^3/minute).

Table 2 is the result of testing the Flow Rate parameter using the VT502 gas analyzer calibrator 5 times with 3 setting modes: 18, 30, and 42 L/min. In the measurement with setting 18, the average result is 18.2, with an error rate of 1.11%. With mode setting 30, the average result is 30.88 with an error value of 2.9%. Meanwhile, with setting 42, the average result is 40.42 with an error value of 1.05%.

TABLE 2. FLOW RATE TEST

No	Flow Rate (L/ Minutes)	Average (L/ Minutes)	Error (%)
1	18	18.2	1.11
2	30	30.88	2.9
3	42	40.42	1.05

D. Respiratory Rate (RR) Testing

Respiratory rate (RR) is the number of breaths taken from each person in each minute, the unit of respiratory rate in minutes. The tests are carried out at settings of 15 and 20 per minute. Each set is done 5 times using a stopwatch calibrator.

Based on Table 3, the Respiratory Rate test using a Stopwatch for each setting was carried out 5 times. In the setting of 15 times/minutes, the average value is 15 with an error value of 0%. While setting 20 times/minute, it obtained an average of 20 with an error value of 0%.

TABLE 3. RESPIRATORY RATE TEST DATA

No	RR (times/ Minutes)	Average (times/ Minutes)	Error (%)
1	15	15	0
2	20	20	0

E. Humidifier Results

Data retrieval with settings 32.35 and 40° C for 5 times. Data collection was obtained by using a Thermohygrometer [48].

Based on Table 4, the temperature test using a stopwatch at a setting of 32ºC obtained an average value of 32.59 with an error of 1.84%. In the 35ºC setting, an average value of 35.15 was obtained with an error value of 0.44%, while the 40ºC setting obtained an average value of 40.98 with an error value of 2.40%.

TABLE 4. TEMPERATURE TEST RESULTS

No	Temperature (°C)	Average (°C)	Error (%)
1	32	32.59	1.84
2	35	35.15	0.44
3	40	40.98	2.40

F. Result of oxygen concentration

Oxygen concentration is the amount of oxygen given to the patient in units (%) in this test using the Gas Analyzer [49] VT502 calibration tool. Each set is tested 5 times.

Based on Table 5, the results of testing the oxygen concentration using a gas analyzer VT502 in each set were carried out 5 times. In the 21% setting, the average is 21.76, with an error value of 0.026%. In the 30% setting, the error value is 30.74, with an error value of 0.017%. For setting 40%, it obtained an average value of 40.64 with an error value of 0.018%. Setting 50% obtained an average of 50.64 with an error value of 0.017%, and setting 60% obtained an average value of 60.84 with an error of 0.02%. For the 80% setting, the average value is 80.12 with an error value of 0.039%, and for the 100% setting, the average value is 90.4 with an error value of 0.1%.

TABLE 5. OXYGEN CONCENTRATION TEST RESULTS.

No	Oxygen (%)	Average (%)	Error (%)
1	21	21.76	0.026
2	30	30.74	0.017
3	40	40.64	0.018
4	50	50.64	0.017
5	60	60.84	0.02
6	80	80.12	0.039
7	100	90.4	0.1

IV. CONCLUSION

It can be concluded that a ventilator has been made with automatic gas mixing parameters, respiratory rate, and tidal volume, and a humidifier using yf-s201 airflow sensor [27], MPX5700 pressure sensor [50], KE-25 oxygen sensor [51], and DS12B20 temperature sensor [52]. Temperature and humidity sensors can work well in the temperature range between 32-35 ºC. The greater the temperature setting value, the humidity produced every minute increases and approaches stability. The water level sensor is only used for monitoring and control to maintain the stability of the water in the container, i.e., when the water level in the main container shows a height of less than 3 cm, the pump will turn on and fill the water in the main container to control humidity value, while when the water level in the main container shows a height of more than 3 cm, then the pump will automatically turn off. The work of the compressor affects the readings of the oxygen sensor due to the presence of an electric field when the compressor is working. The higher the oxygen concentration value, the greater the error value.

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