Design and Building of A Portable Spirometer Based on Arduino Uno

Feri Yanto[1], Mohammad Rofi'i[2]

[1-2] Electromedical Engineering Study Program, Semarang College of Health Sciences

Correspondence Author: mohmdrofii@gmail.com

Article Info :	**ABSTRACT**
Article History : Received : 11-11-2022 Revised : 22-12-2022 Accepted : 29-12-2022 Available Online : 06-01-2023 **Keyword :** **Respiration, Spirometer, VC, FVC, FEV1**	*Spirometer is a medical instrument that functions to measure the capacity and volume of human lungs during expiration. This research is important because pulmonary function examination is an objective method in assessing changes in a person's lung function or suspected lung disorders, and assessing the type of treatment to be performed. In this study a portable spirometer instrument was designed, which is a tool to measure the strength of the breath used to measure the amount of air volume that can be exhaled after maximum inspiration or commonly called FVC (Forced Vital Capacity), VC (Vital Capacity), and the amount of air volume at the first second that can be expelled after maximum inspiration or commonly called FEV1 (Forced Expiratory Volume 1 second). This tool is designed using the MPX5500DP Air Pressure Sensor, which is an air pressure sensor to detect the pressure and airflow exhaled by the respondent through the mouthpiece pipe. There are 3 operating modes, namely, a test mode for measuring 3 parameters (VC,FVC,FEV1). Tool testing was carried out by comparing it with a standard tool that has been calibrated and measured using a calibration syringe. The results obtained were the percentage of accuracy or accuracy of measurement when measurements were made with a 3-liter Calibration Syringe of 98.1%, and for the percentage of errors or reading errors when compared with a tool in the hospital or in the market by 2.5%. The percentage error value is still within the tolerance limit of ±10%. From these results it can be concluded that this tool can work well and can be used in pulmonary function examination.*

1. INTRODUCTION

Respiration is a process starting from taking in oxygen, removing carbohydrates to using energy in the body. The lungs are one of the vital human organs, where the lungs are the place where gas exchange takes place to stabilize the supply of oxygen (O2) in the human bloodstream. This oxygen exchange process is carried out through the small circulatory system, namely when blood is pumped to the lungs to remove carbon dioxide (CO2) and transport oxygen to be distributed throughout the body as an energy source. When the blood experiences a lack of oxygen, the red color of the blood will disappear to become bluish as the lips, ears and body experience an imbalance. Even if the lungs do not receive oxygen for more than 4 minutes it can cause damage to the brain that is difficult to repair. Without breathing, humans would not live because oxygen is very important to carry out their functions (Andhi, 2019).

There are 2 phases during respiration, namely inspiration and expiration. Inspiration is when a human inhales, taking in air, the muscles between the ribs rise and are pushed upwards so that the chest cavity enlarges and the volume of the lungs increases (Ganong, 2008). Expiration is when a human exhales, the muscles between the ribs relax, causing the chest cavity to shrink and lung volume to decrease (Guyton, 2014). Lung volume is the amount of air obtained during

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respiration. Every human being has a different lung volume, this is caused by several internal factors such as gender, age, weight and height, while external factors such as a person's activities, smoking habits and the environment (Ratih, 2013).

Currently, technological developments in the medical world play a very important role in early diagnosis of lung function disorders. Pulmonary function examination is an objective method of assessing changes in a person's lung function or suspected lung disorders, and assessing the type of treatment that will be carried out. Pulmonary function examination is also called spirometry examination, which is an examination to measure a person's static and dynamic lung volume. Static volume is the volume of air in a static state that is not tied to the time dimension. Static volume consists of tidal volume (TV/Tidal Volume), inspiratory reserve volume (IRV/Inspiratory Reserve Volume), expiratory reserve volume (ERV/Expiratory Reserve Volume), residual volume (RV/Residual Volume), vital capacity (VC/Vital Capacity), and forced vital capacity (FVC/Forced Vital Capacity) where the volume value will later be measured. The tool used for spirometry examination is called a spirometer (Abdullah, 2015).

A spirometer is a measurement of the volume and flow of air that can be exhaled from the lungs from maximum inhalation, to assess the efficiency of the physical properties of the respiratory tract. A spirometer is an important part of the initial evaluation for patients with respiratory complaints. In particular, the spirometer plays an important role as a tool for non-invasively diagnosing the condition of the lungs, for example lung capacity.

Research on spirometers was previously carried out by Kemalasari, Paulus Susetyo Wardana, and Ratna Adil (2016), students of the Surabaya State Electronics Polytechnic (PENS), with the title Non-Invasive Spirometer with Piezoelectric Sensors for Lung Health Detection. Based on the research results, it can be concluded that this system is able to measure respiratory flow rate, vital lung capacity and condition automatically and the results will be displayed on a graphic LCD. In this research, the ATmega32 microcontroller IC is used as the controller and the sensor used is a piezoelectric sensor. The research design of this device is that the piezoelectric sensor is attached to the right side of the chest as an input to detect changes in pressure in the chest due to changes in chest movement when breathing and then strengthened by an amplifier, the noise in the respiration signal is filtered. These signals are processed in the microcontroller and converted from analog to digital. The results will be displayed on the graphic LCD. However, the drawback of this study is that measuring volume using a non-invasive method through the surface of the chest is less effective, because spirometers generally measure lung volume by exhaling through the mouth and nose when closed.

The second research refers to the final assignment of Mikki Fahrizi Maharrahman (2016), a student at the Health Polytechnic of the Ministry of Health in Surabaya who conducted research entitled Monitoring Respiratory Rate based on a Personal Computer (PC) equipped with Respiratory Volume. In this study it can be concluded that measuring the respiratory rate and respiratory volume per minute using techniques such as a spirometer then the results are displayed graphically in the form of respiratory frequency per minute and respiratory volume per minute on a Personal Computer (PC). This research uses the MPX5100 GP pressure sensor and ATmega32 microcontroller as controllers. The research design is that the MPX5100 GP pressure sensor is attached to the mouthpiece. The output from the sensor will be amplified by an amplifier and the signal is processed in the ATmega32 microcontroller and then converted from an analog signal to digital. The output results are in the form of numbers and volume graphs on the PC. In this study, lung volume was only measured using tidal volume parameters.

The third research is based on a thesis written by Syaeful Ilman, a student in the Master's Program in Electrical Engineering from the Faculty of Industrial Technology, Gunadarma University, Depok. This research was conducted in 2017. This research is entitled "Portable Spirometer Using Air Pressure Sensor MPX5500DP Based On Microcontroller Arduino Uno". The portable spirometer design consists of several electronic components which are given as follows. A power supply is required as a voltage source for all circuits. MPX5500DP is an air pressure sensor

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to detect the air pressure exhaled by the respondent through the mouthpiece pipe. A non-inverting amplifier is used to amplify the output voltage of the sensor. In addition, a push button is used to select the operating mode, namely either test mode or calibration mode. An Arduino Uno microcontroller is basically used to process data input from non-inverting and push button amplifiers. The results of the measurement process are displayed by an LCD connected to the output of the microcontroller. The method used in this research is to carry out portable spirometer calibration measurements carried out by testing an air balloon containing 1000 ml of air which will be injected from a syringe with a capacity of 100 ml and requires 10 injections for 1000 ml of air. Following this step, a 1000 ml air balloon is released through the mouthpiece. The result displayed by LCD shows 1073.72 ml instead of 1000 ml, indicating 7% error. The test mode is carried out in 2 stages. The first stage is to inhale a maximum of air for 1 second to measure FEV1 (Forced Expiratory Volume 1 second). Similar to the first stage, the test is carried out for 5 seconds to measure FVC (Forced Vital Capacity). The test results are displayed by LCD and a ratio is taken between FEV1 and FVC for each respondent. This shows that the ratio for the 6 respondents tested varies between 82.78% and 94.04%.

In terms of price, a spirometer can reach 10 million rupiah to 20 million rupiah, which means only a few people have this device. This tool is formed by pneumotacho meter sensors, processor and printer, with an alternative graphical data presentation, including: graphical measurement of volume-time curves, graphical flow-volume measurements (spirograms), VC (Vital Capacity), FVC (Forced Vital Capacity), FEV1 (Forced Expiratory Volume in the first second), and general information about the patient.

To overcome the feasibility of existing spirometers, the author tries to design a Portable Arduino Uno Spirometer that uses the Air Pressure Sensor MPX5500DP as a transducer, then the data from the pressure sensor will be processed by a microcontroller and displayed on the LCD in the form of 3 parameters for examining lung function, namely VC (Vital Capacity), FVC (Forced Vital Capacity), FEV1 (Forced Expiratory Volume1). In the tool that the author created, the reading results of the 3 parameters will be compared with standard tools or the values compared with the Calibration Syringe. In this research, an air pressure sensor using Silicon Stress Stain Gauge type MPX5500DP was chosen. This sensor was chosen because it is sensitive to low pressure, just a small blow can affect the resulting output voltage. The MPX5500DP sensor is a pressure sensor designed for a wide range of applications, especially working on microcontrollers or microprocessors with analog or digital input. From an economic perspective, this tool is relatively more affordable because it does not require many components to be purchased. So, on this basis, the author compiled a research regarding the discussion and manufacture of a portable spirometer entitled: "Design and Build a Portable Spirometer Based on Arduino Uno". From the research that the author will carry out, it is hoped that this tool can function to determine the volume and capacity values of the lungs by using the MPX5500DP pressure sensor to read the flow of exhaled air and the results are displayed on the LCD in the form of numbers in units of ml.

2. RESEARCH METHODS

In writing this research, the type of research writing method used by the author is applied research writing. Applied research writing is research writing that is carried out by applying the theories that have been obtained by the author into direct practice with the stages of literature study, field study, data analysis.

On every tool, whether it is a design or an existing tool, there must be a block diagram as a component reference for the basis of the tool. A block diagram is a part of a system, where the main parts or functions represented by the blocks are connected by lines that show the relationship of the blocks. Block diagrams are widely used in the world of engineering in hardware design, electronic design, software design, and process flow diagrams. The block diagram of the portable spirometer module is shown in Figure 1 below.

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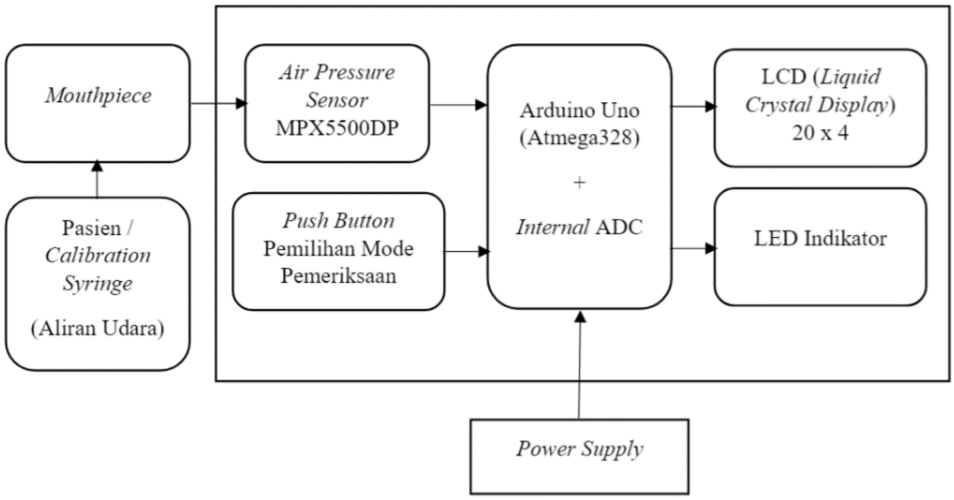

Figure 1. Block diagram of a portable spirometer

When measuring lung volume capacity, the process begins when the patient exhales through the mouthpiece tube where at the end of the tube there is a tube that is connected and enters the MPX5500DP pressure sensor. The air flow caused by the patient's exhalation will enter through the mouthpiece tube then into the plastic tube and towards port 1 of the Air Pressure Sensor, which will influence the pressure at port 1 of the Air Pressure Sensor. Then, the pressure at port 1 which is positive pressure will be compared with the pressure at port 2 which is vacuum pressure. The pressure that has been compared on port 1 will enter the analog pin of the Arduino Uno (A0) in the form of a voltage quantity, and will be converted into digital form by the internal ADC (Analog to Digital Converter) to then be processed by the Atmega328 microcontroller on the Arduino Uno.

Analog data in the form of electrical quantities that have been converted by the Arduino Uno's internal ADC will be converted into pressure values in kPa units (kilo Pascal) which have a range between 0 – 500 kPa which can change according to the air flow entering the sensor. Then, after obtaining the pressure in units of kPa, it will be converted back into the volume of air in units of milliliters. The conversion from pressure quantity to volume quantity is obtained through the Bernoulli equation, where the formula for this equation to obtain the desired volume quantity will be written in coding in the Arduino IDE. After obtaining the desired volume size according to the lung function examination parameters that we selected via the push button, the value of the volume measurement results will be displayed by the Arduino Uno via a 20x4 LCD device.

The working principle of this tool is basically to read the patient's exhaled breath pressure which has been carried out in accordance with medical procedures. After the initial initialization of the tool, a mode selection will appear that can be selected according to the desired examination, including the parameters VC (Vital Capacity), FVC (Forced Vital Capacity), and FEV1 (Forced Expiratory Volume 1). The following is a flow diagram of the working principle and design of a portable spirometer based on Arduino Uno which is shown in figure 2 and figure 3.

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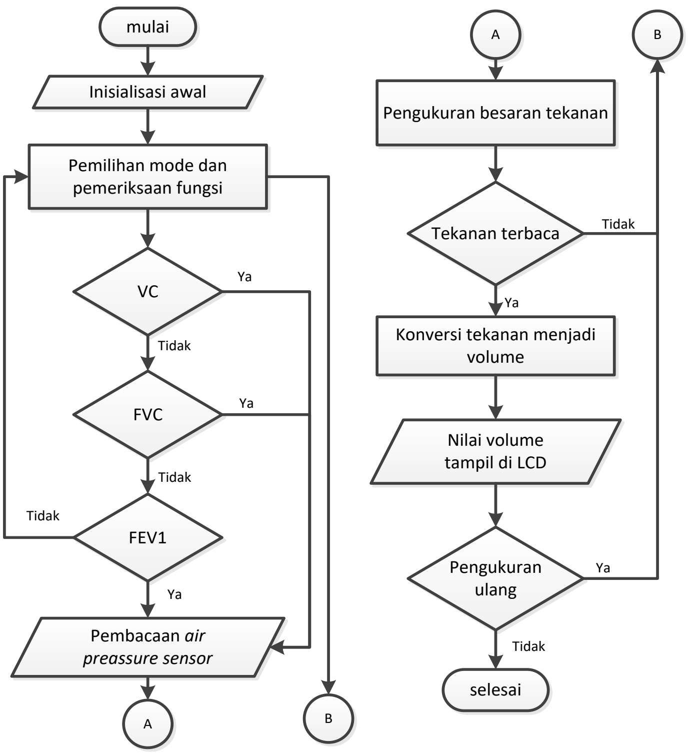

Figure 2. Working principle of a portable spirometer

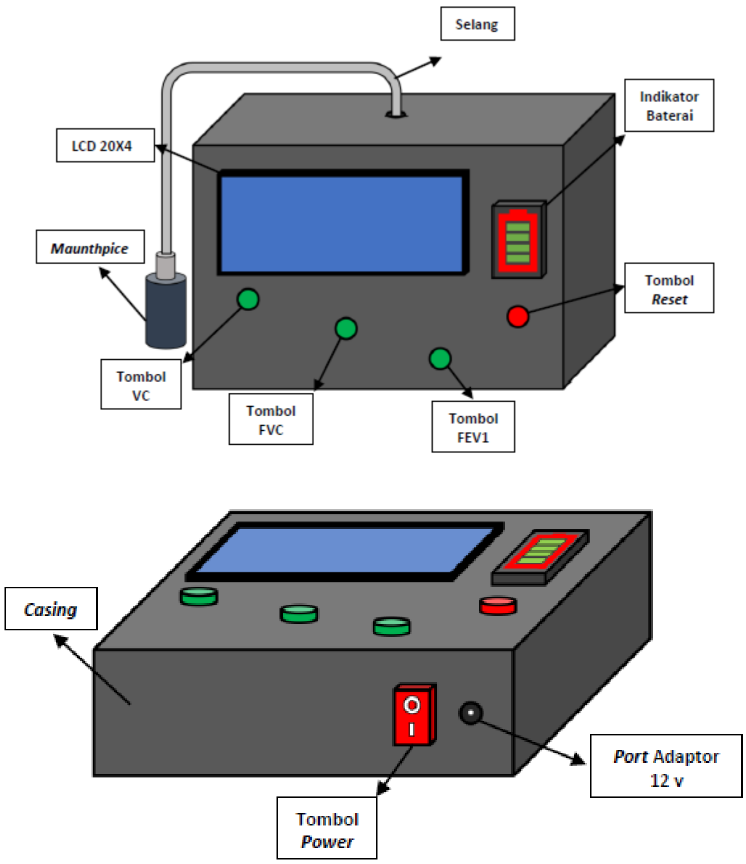

Figure 3. Design of a portable spirometer

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In planning and making this tool there are several stages, namely hardware design and software design. The following is a series of portable spirometer devices in Figure 4 and some of the main program codes for pressure readings are shown in Table 1.

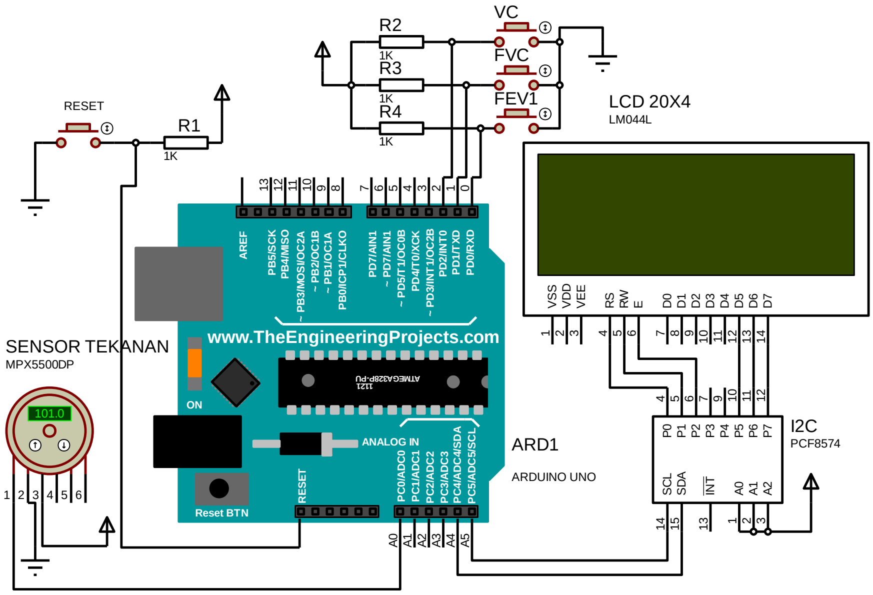

Figure 4. Wiring tool circuit

The software design for this tool uses the Arduino IDE and the following is the main program code for reading the pressure sensor on the portable spirometer that has been made.

Table 1. Conversion of sensor readings

Listing Program	Information
ButtonVC = digitalRead(digitalButtonVC);	Check if the VC button is pressed
if (ButtonVC == LOW)	If you have entered the program
inputVolt = analogRead(analogInPin);	Voltage reading (0 to 1023)
vout = inputVolt * (vs / 1023.0);	The sensor voltage is divided by the analog value
pressure_kpa = ((vout / vs) - 0.04) / 0.0018;	Pressure in KPa (Transfer Function On Data Sheet)
if (pressure_kpa < 0)	If KPa is less than 0
pressure_kpa = 0;	Then the display will be 0
pressure_psi = psi * (pressure_kpa / kpa);	Pressure in psi
massFlow = k * sqrt (pressure_psi);	Air mass flow
volFlow = massFlow / rho;	Air volumetric flow
volumeVC = volFlow * dt;	Total volume (basically integrated over time)
dt = 0.025;	Delay time (the time it takes for the sensor to read the pressure)
delay(10);	Display time delay 10 ms

Check whether the button is pressed, if it has entered the program state. If the button has been pressed, the program will take a voltage reading. The voltage that has been read will then be divided by the analog value using the formula below :

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$$V_{out} = V_{in}\left(\frac{V_{sensor}}{1023}\right)$$

Then, to determine the pressure value in kpa, this is done by deriving the transfer function formula on the MPX5500DP sensor data sheet :

$$V_{out} = V_s(0.0018 * P * 0.04)$$

This equation is reduced to:

$$Preassure\ kpa = \left(\frac{(V_{out}/V_s) - 0.04}{0.0018}\right)$$

If the result of the conversion is that the volume pressure is less than zero, the number 0 will be displayed on the LCD display. Then if the conversion result is greater than or equal to zero, the result will be displayed on the LCD. The results of the pressure conversion are still in kpa units. To continue with the next program the units must be changed from kpa units to psi units :

$$Preassure\ psi = psi\left(\frac{preassure\ kpa}{kpa}\right)$$

To calculate the mass flow rate, it can be determined using the following formula:

$$V = k\sqrt{P}$$

V= mass flow rate (kg/s)
k = density (kg/m^3)
P = pressure (psi)

To calculate the volumetric air flow, it can be determined using the following formula:

$$Q = \frac{m}{\rho}$$

Q = air volumetric flow rate
m = mass flow rate (kg/s)
ρ = air density (kg/m^3)

After obtaining the volumetric air flow rate, then to find out the volume for each parameter, it is done by multiplying the volumetric flow rate by the delay time (the time required for the sensor to read the pressure). Each parameter has its own delay time. The VC (Vital Capacity) parameter has a dt of 0.025 seconds, FVC (Forced Vital Capacity) has a dt of 0.03 seconds, while for FEV1 (Forced Expiratory Volume in one second) it is 0.06 seconds.

3. RESULTS AND ANALYSIS

Instrument testing is carried out by taking measurements using a Calibration Syringe and comparing the measurement results with other spirometer devices on the market.

3.1. Measurement with a calibration syringe

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Measurements were carried out using a Calibration Syringe. This measurement aims to determine the percentage of error when the tool is calibrated. Data processing was carried out by carrying out examination tests of 3 lung function parameters using a portable spirometer module with a Calibration Syringe tool and taking 6 test data. Then, after going through the testing, retrieval and data collection process, the data results from this process will be processed so that the data held can be analyzed and conclusions drawn in table format. The measurement results can be seen in table 2 below.

Table 2. Measurements with Calibration Syringe

No.	Check Up Result	Measurement Results (mL)						average (mL)
		1	2	3	4	5	6	
1	*VC (Vital Capacity)*	3.068	3.073	3.077	3.061	3.053	3.047	3.063
2	*FVC (Forced Vital Capacity)*	3.065	3.070	3.073	3.066	3.067	3.069	3.068
3	*FEV1 (Forced Expiratory Volume 1)*	2.437	2.443	2.435	2.447	2.453	2.458	2.445

The results of data collection in Table 2 show that the percentage of error in the VC (Vital Capacity) parameter is 2.1%. Then the percentage error in the FVC (Forced Vital Capacity) parameter is 2.2%. Meanwhile, the percentage error in the FEV1 (Forced Expiratory Volume in One Second) parameter is 1.5%. In the measurement parameters of the Forced Expiratory Volume (FEV1) lung function examination. In the first second a normal person can expel breathing air of 80% of the VC value, so that the normal value or setting point using a 3 Liter Calibration Syringe becomes 2400 mL or 2.4 Liters. In measurements using the Calibration Syringe, it can be concluded that the error value or percentage error in the measurement of the Portable Spirometer Module using the Calibration Syringe is still within the tolerance limit, namely ±10%. The measurement results showed that the average error percentage was 1.9%. So this portable spirometer module has an average percentage of measurement accuracy and accuracy reaching 98.1%.

3.2. Comparing with standard tools

This measurement was carried out by comparing the measurement results between spirometers on the market and the portable spirometer module that the author made. Comparisons were made by taking direct measurements with the patient object, namely the author himself. Comparisons were made 3 times on the portable spirometer module that the author made and on the PC-based spirometer at the Roemani Muhammadiyah Hospital, Semarang. The comparison results can be seen in Table 3 below:

Table 3. Comparison of portable spirometers with standard devices

Tool	Inspection Parameters	Measurement results (mL)			Average(mL)
		1	2	3	
P	*VC (Vital Capacity)*	3.126	3.129	3.130	3.128
M		3.201	3.206	3.198	3.201
P	*FVC (Forced Vital Capacity)*	3.134	3.137	3.129	3.133
M		3.213	3.208	3.211	3.210
P	*FEV1 (Forced Expiratory Volume 1)*	2.429	2.434	2.430	2.431
M		2.503	2.504	2.499	2.502

Information : P = Comparator (Spirometer in the Hospital)
M = Module (Portable Spirometer Design Module)

From the results of data analysis in Table 3, the percentage error in the VC (Vital Capacity) parameter is 2.3%. Then the percentage error in the FVC (Forced Vital Capacity) parameter is 2.4%. Meanwhile, the percentage error in the FEV1 (Forced Expiratory Volume in One Second) parameter is 2.9%. From the comparison of these measurements, the average percentage error in

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results with spirometers available on the market/in hospitals is 2.5%. This error percentage was obtained because there are differences between the portable spirometer module that the author made and the spirometer devices available on the market/in hospitals. These differences include the mountpiece, the hose in the module, the amplifier circuit, and the data processing application.

4. CONCLUSION

Based on the results of design, testing, data analysis and discussions that have been carried out in this research, namely regarding the design and construction of a portable spirometer based on Arduino Uno, a tool for measuring lung volume and capacity was produced using the MPX5500DP gas pressure sensor, piezoresistive transducer type. And the following conclusions can be obtained:

1. This portable spirometer using the MPX5500DP Air Pressure Sensor is fully functional and can be used to measure three lung function examination parameters, namely VC (Vital Capacity), FVC (Forced Vital Capacity), FEV1 (Forced Expiratory Volume) according to what the author designed.
2. The instrument for measuring lung volume and capacity has an average percentage of measurement accuracy or accuracy when measuring with a Calibration Syringe of 98.1%, and shows an average percentage of error or reading error when compared with existing instruments in hospitals of 2 .5%.

5. DECLARATION OF COMPETING INTEREST

We declare that we have no conflict of interest.

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