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Analysis of the Accuracy of Differential Pressure Sensor in a Portable Spirometry with FVC, FEV1 and PEF Parameters

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ABSTRACT Accurate measurement of lung function is essential for diagnosing and monitoring respiratory diseases such as chronic obstructive pulmonary disease (COPD), asthma, and cystic fibrosis. Traditional spirometry methods often face challenges related to accuracy and sensitivity, which can lead to misdiagnosis and inappropriate treatment. This study aims to evaluate the performance of the DF-Robot differential pressure sensor as a portable spirometry tool, focusing on key parameters including Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second (FEV1), and Peak Expiratory Flow (PEF). The research was conducted at the Surabaya Electromedical Engineering Department, utilizing a pre-experimental design with a single group. The DF-Robot sensor's output was compared against a Hans Rudolph 5530 Syringe Calibrator to determine its accuracy. Data collection involved three different tube sizes, with ten repetitions for each size using the calibrator, and five repetitions with human subjects to assess real-world applicability. Results indicated that the DF-Robot sensor demonstrated high accuracy, with the smallest tube size yielding a minimal error of 0.9%. In contrast, larger tube sizes resulted in significantly higher error rates, with the largest tube showing an error of 33%. The study concluded that the DF-Robot differential pressure sensor is a promising alternative for portable spirometry applications, providing reliable measurements of lung function parameters. The findings underscore the importance of sensor selection in spirometry, as the accuracy of measurements directly impacts patient diagnosis and treatment. This research contributes valuable insights into the development of portable spirometry devices, potentially enhancing the diagnostic capabilities for respiratory diseases and improving patient outcomes in clinical practice. Future studies should explore further refinements in sensor technology and methodologies to optimize spirometry accuracy and reliability.

INDEX TERMS Spirometry, Differential Pressure, FVC, FEV1, PEF

I. INTRODUCTION

Measurement of lung function is an important aspect in diagnosing and monitoring respiratory diseases such as chronic obstructive pulmonary disease (COPD) [1] , [2] , asthma, and cystic fibrosis [2] [3] [4] . Spirometry is a widely used diagnostic tool that involves measuring the volume of air a person can inhale and exhale, as well as the speed with which they can exhale [4] , [5] . The accuracy of spirometry equipment is very important because inaccurate spirometry results can lead to misdiagnosis and mistreatment, this can be dangerous for patients, especially in patients with certain lung diseases , [1] [3] . So the accuracy of the sensor that will be used for spirometry must be known [3] . There are several types of sensors used for spirometry tools, one of which is differential pressure, this sensor reads the pressure difference produced by the air flow flowing through the tube, one sensor that is easy to get is the differential pressure sensor from DF-robot [6] .

DF-Robot differential pressure is a sensor that can be obtained easily so this tool can be used as an option for developing a portable spirometry tool. The DF-Robot sensor offers several advantages, including high accuracy and precision, simple and durable design, and is suitable for measuring gases with varying pressures and temperatures.

However, it is necessary to evaluate the performance of this sensor to measure spirometry parameters such as forced vital capacity (VDC), forced expiratory volume in one second (VEP1), and peak expiratory flow (PEF) [7] [8] . Therefore, this research paper aims to analyze the performance of the DF-Robot differential pressure sensor for use in portable spirometry devices. The results of this study will provide valuable information for the development of accurate and reliable portable spirometry devices that can improve the diagnosis and monitoring of respiratory diseases.

There are several previous studies that discuss spirometry, including in 2018 conducted by Jeffrey M [3] , with the title "Basic spirometry testing and interpretation for the primary care provider". This research discusses standard spirometry examinations for reviewing health services, in In this study, the researchers concluded that examination using spirometry has an important role in diagnosing and classifying patients with lung disease, so the accuracy of spirometry is very important to have, but this study did not discuss sensors. Further research in 2019 was carried out by Andriani L [9] . with the title "Portable Spirometer for Measuring Lung Function Health (FVC and FEV1)" this research discusses the development of a portable spirometer with FVC and FEV1 parameters. In this research the researcher concluded that the use of a more accurate sensor is needed to get better results, in 2020 there was research conducted by Maulidil Li Kharis L [10] , this research discussed the use of the MPXV700DP sensor as a spirometry sensor, in this research the researcher concluded that the sensor that had been used was less sensitive so it was necessary to use another sensor to make the readings more accurate and sensitive .

Based on the problems and research that has been carried out, the author will create research entitled " Improving the Accuracy and Sensitivity of Spirometry Using the Differential Pressure Method (500 Pa) and Venturi Tube with Parameters (FVC, FEV1 and PEF) " This research is aimed at analyzing DF-robot differential pressure sensor as a sensor in the spirometry tool.

II. METHODHOLOGY

This research was conducted at the Surabaya Electromedical Engineering Department Campus with the Hans Rudolph 5530 Syringe Calibrator [11] as a reference and comparison in determining the accuracy value of the differential pressure sensor [12] [13] [6] [14] and the module error value for portable spirometry with parameters (FVC, FEV1, and PEF). 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 looks at the results without measuring and knowing the initial conditions, but there is already a comparison group.

This research uses the df ROBOT Differential Pressure sensor. This differential pressure sensor with I2C communication is used to measure the pressure difference at two points on the device. Inter Integrated Circuit or often called I2C is a two-channel serial communication standard specifically designed for sending and receiving data. The I2C system consists of SCL (Serial Clock) and SDA (Serial Data) channels which carry data information between I2C and the controller.

The data output is in the form of digital data and has high resolution. The application of this sensor is medical care equipment, portable medical equipment, medical monitoring, industrial control and central ventilation systems.

A. DATA ANALYSIS

Data collection was carried out using 3 different tube sizes with 10 repetitions using a syringe calibrator and using human patients with 5 repetitions of data collection. The average measurement value is obtained using the mean or average by applying equation (1). The average is a number obtained by dividing the number of values by the amount of data in the set.:

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

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

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

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

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

where UA shows the uncertainty value of the total measurement, SD shows the resulting standard deviation, and n shows the size of the measurement. %error indicates a system error. The lower error value is the difference in the mean of each data. Errors can indicate deviations between standards and designs or models. The error formula is shown in equation (4).

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

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

III. RESULT

In this research, the module was tested using a calibrator, namely the Hans Rudolph 5530 Syringe Calibrator as a reference and comparison in determining the accuracy value of the differential pressure sensor and the module error value for portable spirometry [15] [4] with parameters (FVC, FEV1, and PEF). The tourniquet module design is shown in FIGURE 1.

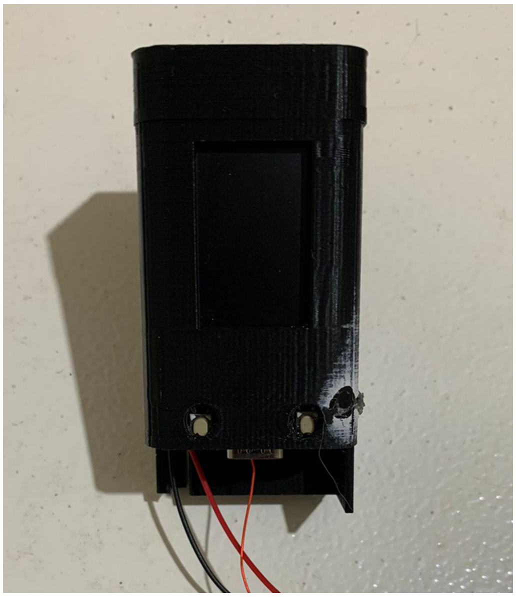

FIGURE 1 . Module and Circuit Design

This differential pressure sensor with I2C communication is used to measure the pressure difference at two points on the device. Inter Integrated Circuit or often called I2C is a two-channel serial communication standard specifically designed for sending and receiving data. The I2C system consists of SCL (Serial Clock) and SDA (Serial Data) channels which carry data information between I2C and the controller.

The data output is in the form of digital data and has high resolution. The application of this sensor is medical care equipment, portable medical equipment, medical monitoring, industrial control and central ventilation systems.

The SEN0343 flow sensor [16] is first connected to a voltage source, namely the VIN pin and GND pin to the ESP32 microcontroller, then the sensor output will be connected to the ESP32 digital communication serial pin [17] namely the SDA pin (21) and SCL pin (22) . Then from the ESP32 microcontroller the data from the SEN0343 sensor will be processed and will be displayed on the TFT screen. as shown in FIGURE 2.

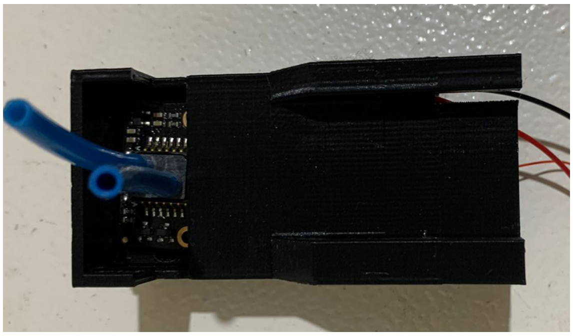

FIGURE 2 . MPX5050DP Pressure Sensor

The module measurements will be compared with the Hans Rudolph 5530 Syringe Calibrator as a reference and comparison in determining the accuracy value of the differential pressure sensor and the module error value for portable spirometry with parameters (FVC, FEV1, and PEF) [8] [7] [18] . Data collection was carried out using 3 different tube sizes with 10 repetitions using a syringe calibrator and using human patients with 5 repetitions of data collection.

Error is the difference between the actual value compared to the measured value of the module that will be converted into a parameter (Fvc, Fev1, Pef). It can be seen in table 4.12 below that the largest error value from measuring the module is when using tube 3 at 33%, then the smallest error is obtained when the module uses tube size number 1 with an error of 0.9% as shown in **TABLE 1.**

TABLE 1
Error Value for Each Tube Using the Hans Rudolph 5530 Syringe Calibrator Comparison Tool

Tube Size	Errors (%)
1	0.9
2	-13
3	33

If we look at the error value for each tube size used by the module, it can be concluded that the more the tube size matches the module, the smaller the error obtained will be. The larger the tube size used with the module, the greater the error obtained, and if you use a tube size that is smaller than the module, the error value will be minus/negative.

TABLE 1 is the error value obtained from the actual value compared with the value of the Hans Rudolph 5530 Syringe Calibrator. TABLE 2 is the standard deviation value obtained from measurements with the spirometry module. The spirometry module is said to be good, because the standard deviation value does not exceed the average value of the spirometry module measurements. TABLE 3 Uncertainty values (UA) are used to see how big the deviation (accuracy) of the spirometry module is in reading pressure values. TABLE 4 Corrected values in this study prove that there are still errors or insecurities between determining the value and the average.

TABLE 2
Comparison Value of Standard Deviation for Each Tube Using the Hans Rudolph 5530 Syringe Calibrator Comparator

Tube Size	Standard Deviation		
	FVC	FEV1	PEF
1	0.4	0.22	0.84
2	0.52	0.55	1.14
3	0.36	0.48	0.55

It can be seen from TABLE 2 above that the standard deviation obtained from measurements with the spirometry module is said to be good, because the results of the standard deviation value do not exceed the average value from the spirometry module measurements. This shows that the average value from the spirometry module measurements can be used as a measurement representation of the entire data.

TABLE 3
Uncertainty Comparison Value (UA) for Each Tube Using the Hans Rudolph 5530 Syringe Calibrator Comparator

Tube Size	Uncertainty (UA)		
	FVC	FEV1	PEF
1	0.17	0.09	0.36
2	0.22	0.23	0.48
3	0.15	0.20	0.23

It can be seen from TABLE 3 above, the uncertainty value (UA) is used to see how big the deviation (accuracy) of the spirometry module is in reading parameter values (Fvc, Fev1, Pef). Relative uncertainty is closely related to measurement accuracy, that is, it can be stated that the smaller the uncertainty, the higher the accuracy. In this study, the largest deviation value was obtained in the PEF parameter using tube 3, which was 0.48, while the smallest deviation value was in the FEV1 parameter using tube 2 with a value of 0.09.

TABLE 4
Comparison of Correction Values for Each Tube Using the Hans Rudolph 5530 Syringe Calibrator Comparator

Tube Size	Correct
1	0.03
2	0.42
3	1.12

From **TABLE 4** above, it can be seen that the correction value indicates an error in the system. So, the closer the correction value is to 0, the better the tool works.

Based on the data above, the largest correction value in this study was found when using tube 3 with an error of 1.12. For the smallest correction value, use tube 1 with an error of 0.03 in the spirometry module.

A module that has output values using a differential pressure sensor can be said to be good if it has high accuracy and precision values. Not all modules that have output in the form of values from a sensor have good precision and also have good accuracy. Apart from that, a module also requires good sensitivity or good response to small changes from each of the many data collection attempts at any time.

FIGURE 4. **System Block Diagram**

The block system in **FIGURE 4** has 3 main parts, namely the sensor section, the microcontroller section and the output section. In the sensor section there is a differential pressure sensor which functions as a data source for the microcontroller, then in the microcontroller section it will receive data via the input/output (I/O) pin, the data received via the I/O pin in the form of digital values will be processed and converted into Next, the pressure value data that has been processed by the microcontroller will be sent to the output section which consists of an Oled display.

FIGURE 5 is a flow diagram of the microcontroller program in this research. Turn on the ON button after the module is on, the process will carry out program initialization. After initialization is complete, it will continue in the next section, namely reading sensor values, then it will continue to the process of processing sensor values and converting sensor values in the form The spirometry value continues in the process of sending data to the Oled output and then continues in sending data to Excel.

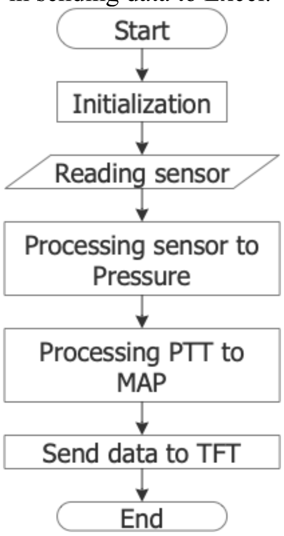

FIGURE 5. **Flow diagram**

IV. DISCUSSION

After testing the spirometry tool which was compared using a calibrator, data collection and analysis of the results were carried out to determine the accuracy and stability of the value of the differential pressure sensor output.

Module measurements will be compared with the Hans Rudolph 5530 Syringe Calibrator as a reference and comparison in determining the accuracy value of the differential pressure sensor and the module error value for portable spirometry with parameters (FVC, FEV1, and PEF. Data collection is carried out using 3 different tube sizes with 10x repetition using a syringe calibrator and using human patients with 5x repetition of data collection.

After conducting research experiments to obtain parameter values (FVC, FEV1, and PEF) using the Hans Rudolph 5530 Syringe Calibrator, the results obtained in the module are as follows:

On the module and also on the Hans Rudolph 5530 Syringe calibrator, volume results were obtained that were in accordance with the calibrator settings and had a small difference in output if using a tube that matched the module size. The smallest module output volume error value was obtained when using tube size number 1 with an error of 0.9%, then the largest error value was obtained when using tube number 3 with an error of 33%. Furthermore, there is also a negative error value due to the tube size being smaller than the original tube, an error value of -13% is obtained if using tube size number 2.

The best data distribution is when using tube number 2 for the FEV parameter with a standard deviation value of 0.09 which also produces an uncertainty close to 0. An uncertainty value of 0 can be interpreted as if the stability of the results is good because there is no change in each measurement. The uncertainty value (UA) is used to see how big the deviation (accuracy) of the spirometry module is in reading parameter values (Fvc, Fev1, Pef). Relative uncertainty is closely related to measurement accuracy, that is, it can be stated that the smaller the uncertainty, the higher the accuracy. In this study, the largest deviation value was obtained in the PEF parameter using tube 3, which was 0.48, while the smallest deviation value was in the FEV1 parameter [9] [10] [15] using tube 2 with a value of 0.09 .

While the correction value is still said to be good, it can be seen that the correction value indicates an error in the system. So, the closer the correction value is to 0, the better the tool works.

Based on the data above, the largest correction value in this study was found when using tube 3 with an error of 1.12. For the smallest correction value, use tube 1 with an error of 0.03 in the spirometry module.

A module that has output values using a differential pressure sensor can be said to be good if it has high accuracy and precision values. Not all modules that have output in the form of values from a sensor have good precision and also have good accuracy. Apart from that, a module also requires good sensitivity or good response to small changes from each of the many data collection attempts at any time.

There are several shortcomings in the module that has been created, including the need for further research to find out which tube is most suitable for use in this spirometry module. Then the sensors used are still not standard medical grade. Then the data storage in this module is not yet equipped. So the value that has been obtained must be recorded first.

IV. CONCLUSION

Overall, this research can be concluded that the tool for increasing the accuracy and sensitivity of spirometry uses the differential pressure method (500 Pa) and Venturi Tube [19] [14] with parameters (FVC, FEV1 and PEF). Based on the research that has been carried out, the following conclusions can be drawn.

A tool can be made to increase the accuracy and sensitivity of spirometry using the differential pressure method (500 Pa) and a venturi tube with parameters (FVC, FEV1 and PEF). A connecting circuit can be made between the pressure sensor and the microcontroller. Coding (programming language) can be created to convert sensor output results into spirometry parameters. You can make a 3D design tube with 3 different sizes as a place for the sensor and as a mouth piece. The smallest module output volume error value was obtained when using tube size number 1 with an error of 0.9%, then the largest error value was obtained when using tube number 3 with an error of 33%. Furthermore, there is also a negative error value due to the tube size being smaller than the original tube. The error value is -13% if you use tube size number 2. The best data distribution is when using tube number 2 for the FEV parameter with a standard deviation value of 0 .09 which also produces an uncertainty close to 0. The largest deviation value in the PEF parameter using tube 3 is 0.48, while the smallest deviation value is in the FEV1 parameter using tube 2 with a value of 0.09. The largest correction value in this study was found when using tube 3 with an error of 1.12. For the smallest correction value, use tube 1 with an error of 0.03 in the spirometry module.

There are several developments that can be developed in this research. First, for the tubes used, further research can be carried out regarding the dimensions of the modules used so that the results obtained have good precision and are stable in accordance with the values of the calibrator tool. Sensors that already have medical grade can be used because they collect data on human patients. Can be equipped with storage using SD-card. So the data that has been obtained is immediately stored in the memory of the module.

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