Medical Spirometer for Diagnosing COPD Base On The Measurement of FVC and FEV₁

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Abstract. Lung is one of the vital respiratory organs in the human body. Where during respiration, there is a process of gas exchange in the lungs by taking oxygen (O₂) from the air and releasing carbon dioxide (CO₂) into the air. Because in the process of respiration involves air in the surrounding environment, the more contamination of air is inhaled, can cause various lung diseases. If the lung diagnosis is done early, then lung disease can get health care earlier. Chronic Obstructive Pulmonary Disease (COPD) is a type of disease that blocks the flow of air into the lungs due to swelling and mucus or phlegm, so that the sufferer has difficulty breathing. In making this research, we want to make a design tool to detect COPD and determine its severity using medical spirometer (spirometry). COPD can be diagnosed by measuring the value of Forced Expiratory Volume in One Second (FEV₁), Forced Vital Capacity (FVC) and comparing it with predictive values of FVC and FEV₁. The results obtained from the manufacture of spirometers have FVC measurement errors of 5.8950%, and FEV₁ measurement errors of 10.5030%.

Keywords: Chronic Obstructive Pulmonary Disease (COPD), Forced Expiratory Volume in One Second (FEV₁), Forced Vital Capacity (FVC), Spirometer.

1. Introduction

Lung is one of the vital respiratory organs in the human body. Where during respiration, there is a process of gas exchange in the lungs by taking oxygen (O₂) from the air and releasing carbon dioxide (CO₂) into the air. Because in the process of respiration involves air in the surrounding environment, the more contamination of air is inhaled, can cause the lungs to be unhealthy, maybe even can cause various lung diseases. If the lung diagnosis is done early, then lung disease can get health care earlier. Chronic Obstructive Pulmonary Disease (COPD) is a type of disease that blocks the flow of air into the lungs due to swelling and mucus or phlegm, so that the sufferer has difficulty breathing. In making this research, we want to make a design tool to detect COPD and determine its severity using medical spirometer (spirometry). COPD can be diagnosed by measuring the value of Forced Expiratory Volume in One Second (FEV₁), Forced Vital Capacity (FVC) and comparing it with predictive values of FVC and FEV₁. The results obtained from the manufacture of spirometers have FVC measurement errors of 5.8950%, and FEV₁ measurement errors of 10.5030%.

Keywords: Chronic Obstructive Pulmonary Disease (COPD), Forced Expiratory Volume in One Second (FEV₁), Forced Vital Capacity (FVC), Spirometer.
COPD can be diagnosed by using a spirometer to determine the condition or performance of the lungs by measuring the amount (volume) and speed of air flow that is inhaled and exhaled. These measurements include: Forced Expiratory Volume in One Second (FEV1) or the amount of air that can be forcibly exhaled in 1 second and Forced Vital Capacity (FVC) or total air in the lungs that can be blown in one full breath, this volume which is used as the main factor for diagnosing COPD.

The purpose of this research is to build a device to detect Chronic Obstructive Pulmonary Disease using a spirometer. Where users can input data such as name, gender, age, height, and weight. Then the results of the spirometer measurements will be displayed in a Graphic User Interface (GUI), so that it can be known the range of FEV values in diagnosing COPD and its severity. The next tool that will be made in this research is called Medspiro (Medical Spirometer).

2. COPD, FVC, FEV1, and Pressure Sensor

2.1. Chronic Obstructive Pulmonary Disease (COPD)

Chronic Obstructive Pulmonary Disease (COPD) is a type of disease that blocks the flow of air into the lungs due to swelling and mucus or phlegm, so that the sufferer has difficulty breathing. According to the World Health Organization (WHO) the main cause of COPD is cigarette smoke, in addition to long-term exposure to indoor air pollution (such as biomass fuel used for cooking and heating), outdoor air pollution, industrial dust and factory chemicals can also be a factor in this disease. [2]. COPD develops slowly, and can cause coughing which produces large amounts of phlegm, wheezing, shortness of breath, chest tightness, and other symptoms. Symptoms often worsen over time and can limit the ability to carry out routine activities. Even severe COPD can prevent someone from doing basic activities such as walking, cooking, or caring for themselves.

The characteristic of COPD is the restriction of air flow that is not completely reversible into the air. Limitations of air flow are usually progressive and are associated with abnormal inflammatory response of the lungs to harmful particles or gases. Spirometer is the main tool for measuring lung function or airway obstruction, and spirometry tests are usually performed to determine respiratory disease. This test is an effective method to help health professionals diagnose COPD early [7].

There are two measurement values that are very important for diagnosing COPD, namely the value of Forced Vital Capacity (FVC) and Forced Expiratory Volume in One Second (FEV1).

2.2. Forced Vital Capacity (FVC) of Lung

Forced Vital Capacity (FVC) or total air in the lungs that can be exhaled in one full breath. In determining the predicted value of Forced Vital Capacity or FVC for men and women can use equations (1) and (2). FVC prediction value depends on age and height. In equations (1) and (2), "FVC Prediction" indicates the predictive value of FVC in liters, "A" indicates age in years, and "H" indicates height in centimeters. If the value of FVC measurement is more than 80% of the predicted value, the lungs are considered normal (healthy) [3].

\[
\text{Male: FVC Prediction} = 0.052 \times H - 0.022 \times A - 3.60
\]
\[
\text{Female: Prediction FVC} = 0.041 \times H - 0.018 \times A - 2.6
\]

Another value on the spirometry test results is the FEV1 / FVC ratio. Comparison of measured FEV1 and FVC (in liters), usually used to determine Forced Expiratory Ratios (FER), which is the ratio of clinical indices to measure airflow restriction. This value represents the volume of air in the lungs that can be exhaled in 1 second. FER values can be used to determine the condition of normal (healthy) lungs or potentially suffer from COPD disease. The percentage value of FER can be calculated using equation (3) [4].

\[
\text{FER} = \left( \frac{\text{FEV1}}{\text{FVC}} \right) \times 100
\]

The percentage value of FER shows the condition of the lungs, if the percentage value of FER is more than 70%, shows a normal (healthy) lung, and if the percentage value of FER is less than 70%, indicates air flow restriction or COPD disease.
2.3. Forced Expiratory Volume in One Second (FEV1)

Forced Expiration Volume in One Seconds (FEV1) is the amount of air that can be forcibly exhaled in 1 second. FEV1 takes a compilation of FVC measurements by taking the volume value of the air compilation process by exhaling using the first second. The severity of Chronic Obstructive Pulmonary Disease (COPD) can be determined based on the actual value of the value of Forced Respiratory Volume in One Second (FEV1), then compared with the calculated FEV1 value. FEV1 can determine COPD.

The classification of COPD severity includes four glasses, namely: motion sickness 1 - mild, intoxicated 2 - moderate; drunk 3 - Severe; and drunk 4 - Very Severe [5]. Prediction values of FEV1 can be calculated using predictive equations that depend on gender, height and age. One of the most commonly used equations in calculating FEV1 values is equation (4) for men, and equation (5) for women [4]. In equations (4), and (5), A denotes age (in years) and H denotes height (in centimeters).

Male: FEV1 Prediction = 0.04301 * H - 0.029 * A - 2,492  
Female: FEV1 Prediction = 0.0953 * H - 0.025 * A - 2,604

The classification of COPD severity can be determined using actual measurements of FEV1 with FEV1 prediction values as in equations (4) and (5). Based on the Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD) the classification of COPD severity is classified in table 1 [5].

| FEV1 Measuring | Severity            |
|----------------|---------------------|
| ≥ 80% FEV1 Prediction | Mild Obstruction  |
| 50% ≤ FEV1 Measuring < 80% FEV1 Prediction | Moderate Obstruction |
| 30% ≤ FEV1 Measuring < 50% FEV1 Prediction | Severe Obstruction |
| < 30% FEV1 Measuring < 30% FEV1 Prediction | Very Severe Obstruction |

2.4. Pressure Sensor MPX5100DP

The MPX5100DP is a Strain Gauge type of piezoresistif tranducer made from silicon which is integrated in a chip, works at a pressure of 0 kPa to 100 kPa (0 psi to 14.5 psi) or 15 kPa to 115 kPa (2.18 psi to 16.68 psi) with an output voltage of 0.2 volts to 4.7 volt.

In the research of Yudhistira Suryanto et al., The MPX5100 sensor can be used as a sensor on a spirometer based on the results of sensor testing when given an inflantor gun input. Results were obtained in the range of 20 mmHg to 230 mmHg, while the maximum limit of human gusts was approximately 140 mmHg or 18 kPa [6].

3. Methods

The new system design of the Medical Spirometer uses an anti-static chamber in which there is a pressure sensor, the sensor output then enters the signal processing circuit and it is processed in order to measure air volume. Then, the signal from the microcontroller is refined using a digital filter in the GUI to produce the actual output signal. Data that has been taken at each check-up will be saved in the database. The following block diagram of the system:
The MPX5100 pressure sensor works based on the amount of pressure exhaled during the inhalation and exhalation process. The pressure output is then converted to air volume units using the principle equation pressure on the bernoulli law (6)[8]. Where $VF$ is flow volume, $T$ is the pressure in pascal, $\rho$ (rho) is the period of air type in kilograms per cubic meter, $A_1$ is area of section 1 while $A_2$ is area of section 2 in square meter. To get the value of the air volume value from the Flow Volume multiplied by 0.1

$$VF = \frac{1000 \times \frac{abs(T) \times 2 \times \rho}{\rho}}{\left(\frac{1}{A_1^2} - \frac{1}{A_2^2}\right)}$$

Equation (6)

The output signal is displayed in the Graphical User Interface (GUI) using Visual Studio 2012. The signals displayed are refined by using 8th order Finite Impulse Response (FIR) filters. Here are the general equations of FIR:

$$y[n] = \sum_{i=0}^{N} b_i x[n-i] = \sum_{k=0}^{M} b_k x[n-k]$$

Equation (7)

$$b_k = \frac{1}{M+1}$$

Equation (8)

Equations (7) and (8) are used in programs in Visual Studio where $M$ is the order of the FIR filter, $k$ is the index filter, and $bk$ is the filter coefficient.

The system workflow for determining COPD by using the Medical Spirometer is the first patient to input the name, gender, age, height, and weight in the column in the GUI. Then the method of retrieving data in patients is done by the following procedure:

1. The patient sits and is in a relaxed state, using the noseclip so that the breathing cycle is carried out by mouth.
2. the patient breathes normally 3 cycles, then take a deep breath as much as possible, exhale strongly until it runs out, last breathe normally again 3 times. The function of this measurement is to show manuver of FEV1 and FVC and determine the value of FEV1 and FVC.
3. Algorithms to determine whether the condition of a patient's lungs are healthy or obstructed are as follows:
   1. Calculate the predictive value of each FVC using equations (1) or (2) and FEV1 using the equation (4) or (5)
   2. Measurements are taken to determine the value of FVC and FEV1 from the patient. The FVC value is obtained from the amount of air volume released during the forced breathing cycle, while FEV1 is taken when measuring FVC by taking the air volume value when the process of exhaling forcibly in the first second.
   3. If FVC and / or FEV1 are low, then the presence of disease is highly likely and calculate percentage of Forced Expiratory Ratio (% FER) at equation (3). If % FER is equal or more than 70%, it is indicated a healthy lung or no airflow limitation, otherwise if % FER is lower than 70%, it is indicated chronic obstructive pulmanory diseases (COPD).
   4. Then look for the FEV1 Ratio by comparing the FEV1 measurement values with the FEV1 prediction. If a percentage of actual measurement of FEV1 is equal or more than 80% of the predicted value of FEV1, it is interpretted mild obstruction. If percentage of actual measurement of FEV1 is lower than 80% and equal or higher than 50%, it is interpreted moderate obstruction. If percentage of actual measurement of FEV1 lower than 50% and equal or higher than 30%, it
is interpretated severely obstruction. If it is a percentage of actual measurement of FEV1 is lower than 30%, it is interpreted very severe obstruction.

4. Result

The measurement result using the Medical Spirometer on normal clients with conditions breathing normally 3 times, forced breathing (take inhale deeply and forced exhale out completely), and then return to breathing normally 3 times again can be seen in figure 2 (a).

![Figure 2](image)

(a) Forced Vital Capacity (FVC)

(b) Force Expiratory Volume in One Second (FEV1)

**Figure 2.** (a) Results of FVC Measurements in Normal Patients (b) Results of FEV1 measurements in normal patients

This measurement show that the value of Forced Vital Capacity (FVC) is 3.6931 Liters, and from the FVC graph data is taken for Forced Expiratory Volume in One Second (FEV1) such as figure 2 (b) with the FEV1 measurement value is 2.7865 Liters. While the value of Forced Expiratory Ratio (%FER) is 75.4523% which indicates that the lung condition is healthy, and the value of FEV1 Ratio is 84.8385% which indicates no airflow limitation.

To determine the performance of Medical Spirometer, a comparison of Medical Spirometer data with BIOPAC Student Lab (BSL) Spirometer was conducted. BIOPAC Student Lab (BSL) system is an integrated life science teaching solution that includes hardware, software and curriculum materials that students use in undergraduate laboratories to record data from human’s body. It is the recognized leader in life science teaching systems and is in use in the top universities around the world [3]. Data from 8 clients with a range of ages 20 to 23 years were taken using BIOPAC and Medical Spirometer and data from each tool was taken 5 times for each person as follows:

![Figure 3](image)

(a) FVC Comparison chart of Medspiro and BIOPAC values

(b) FEV1 Comparison chart of Medspiro and BIOPAC values

In the comparison chart of FVC figure 3(a) and FEV1 measurements figure 3(b) above using BIOPAC and Medical Spirometer there is still an error. This error is caused by the mechanical shape of the mouthpiece in the two different devices which causes different ways of blowing the mouthpiece by the patient. In addition, successive data collection caused some patients to run out of breath to exhale forcefully. The error of Medical Spirometer against BIOPAC for measurement of FVC was 5.8950%, while for FEV1 was 10.5030%. A large FEV1 error was caused because BIOPAC determines the FEV1 manually by selecting the area on the FVC signal from the highest peak up to one second after with the I-Beam cursor. This causes the FEV1 measurement to be less accurate. While in Medical Spirometer, the determination of the FEV1 is automatically measured using a program in Visual Studio.
Measurement taken in COPD patient is shown in figure 4(a) for FVC signal and figure 4(b) for FEV1 signal. This test was performed on a 61-years-old male patient who had been diagnosed COPD by a doctor in RSU Haji Surabaya. Based on the value of height and age of the patient obtained FVC prediction value is 3,8660 Liters while FEV1 prediction value is 3,0507 Liters.

![Figure 4. (a) FVC chart produced by Medspiro in COPD patient (b) FEV1 chart produced by Medspiro in COPD patient.](image)

With the picture shown above, Forced Vital Capacity (FVC) value of COPD patient is only 1,0337 Liters, and Forced Expiratory Volume in One Second (FEV1) value is 0,6962 Liters. From these values obtained Forced Expiratory Ratio (% FER) is 67,3464 % which indicates obstruction, and the value of FEV1 Ratio is 22,8197 % which shows that the severity of COPD suffered by patients is very severe.

![Figure 5. Normal and Obstruction Comparison Charts](image)

As we can see in the graph figure 5, the difference between normal breath and obstruction. Although this data is taken from 2 people with different lung volumes, it can be seen that the exhaled air in the first second of patients with obstructive diagnoses tends to be long and obstructed to expel air from the lungs. This is due to limited air flow in the lungs. Whereas in normal people, within the first second of exhaling, the volume is almost close to the FVC value.

5. Conclusion

By using this Medical Spirometer, COPD can be detected by comparing the results of measurements of Forced Vital Capacity (FVC) and Forced Expiratory Volume in One Second (FEV1) which produce Forced Expiratory Ratio (% FER) value, whereas for COPD severity can be determined by comparing the FEV1 measurement value with FEV1 prediction value. The error produced with Medical Spirometer in this research is 5.8950% in FVC measurement, and 10.5030% error of FEV1 measurement.

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