Design and Testing of a Spirometer for Pulmonary Functional Analysis

M. Jagannath, C. Madan Mohan, Aswin Kumar, M.A. Aswathy, N. Nathiya

Abstract*: *Chronic Obstructive Pulmonary Disease (COPD) is considered as one of the greatest life-threatening syndromes worldwide, and it is estimated that over 600 million are afflicted with the disease. The objective of this study is to design and develop a spirometer which is functionally as well as cost effective. Authors have planned to keep the cost below 100$. The proposed spirometer has four main components – spirometer body, Circuitry, Computer and Software. The spirometer body includes a differential pressure sensor and a pilot tube through which the patient blows. The output is transmitted to the microcontroller. The analog to digital convertor within the microcontroller is employed for the conversion. Then the pressure difference output from the pressure sensor is converted into mass flow rate which is subsequently converted into volume. The microcontroller relays this data via a Universal Serial Bus (USB) connection to a computer which transmits this to the JavaScript based graphical user interface. This interface is used to display the flow and volume data in real-time. Then this experiment has proceeded further with this study by testing it on people. A spirometric test was conducted on 20 individuals of different ages, heights and gender. Their test results were tabulated and inferences on their breathing condition were drawn accordingly. The results show that lung capacity decreases with age. Although the current design is not able to meet clinical accuracy, with professional manufacturing, such a design could yield a device capable of meeting clinical accuracy without a significant increase in price.

Keywords: Chronic obstructive pulmonary disease; Microcontroller; Spirometer; Universal Serial Bus.

I. INTRODUCTION

In present scenario, Chronic Obstructive Pulmonary Disease (COPD) is becoming one of the greatest reasons of death, and it is estimated that over 600 million are afflicted with the disease. Spirometer is a device that used to airflow and air volume through respiratory tract. It is also useful for diagnosing and monitoring lung malfunctions like COPD [1]. Asthma is another disease that requires attention because the statistics already went above 300 million. Spirometer is also useful for detecting asthma. The low income and lower middle-income countries are mostly affecting by asthma that almost more than 80% people are dying [2]. But the disappointing thing is that most of the experts in this field are unable to afford a spirometer because of its cost that comes around USD 1000. Spirograms are the results or graphs that come from a spirometer device. Spirogram consists of a volume-time curve and a flow-volume loop [3]. The spirometery testing contains some procedures. Initially the patient is asked to take a long breath and then to exhale into the sensor very fast, and continue it for at least 6 seconds. If the doctors want to study about upper airway block, the patient is asked for rapid inhalation. Occasionally, the experiment procedure will be first carried out for tidal volume measurement or the forced inspiratory part that will be followed by the forced exhalation [3]. Soft clips are using while conducting spirometry testing for preventing air escape through nose. Certain mouthpieces are useful to block the entry of bacteria. Spirometry testing has limitations also. The main disadvantage is that it is highly dependent on the person who is undergoing the testing. It is highly incoherent also. So doctors need to repeat the testing 3 to 4 times for better accuracy. Forced Vital Capacity (FVC) cannot be underestimated because of patient. Moreover, this testing cannot be used for children under 6 years old and patients who have problem in understanding things. That means it is not useful for mentally impaired persons, sedated patients or people with similar conditions. This pulmonary function test is helpful for monitoring sudden decrease in FEV1, even if the total lung capacity is still normal [4].

In 1990, Gascoigne et al. suggested that a biphasic spirogram can be a hint to the bronchus narrowing problem. The authors conducted an experiment on two patients having narrowing bronchus problem [5]. Ferguson et al. put forward a spirometry device for daily care providers to detect COPD for patients who have severe smoking habit [6]. Lin et al. in 1998 designed a spirometer which is based on hot wire sensor principle. This device is efficient in performance but expensive. One of the advantages is that it can be connected to a computer for digital monitoring [7]. Today’s India is giving more attention in online treatments because data from worldwide can access from anywhere in the world with the help of new internet technology [8]. A Spirometer usually determines the air flow and volume during a breathing procedure that is proceeding in and out of the lungs [9].

II. METHODS AND MATERIALS

A. Design of Experiment

Figure 1 depicts the proposed design of experiment. Our spirometer has four main components – Spirometer body, Circuitry, Computer and Software. The spirometer body includes a differential pressure sensor and a pilot tube through which the patient blows. The output is transmitted to the microcontroller.

The analog to digital convertor within the microcontroller is employed for the conversion. Then the pressure difference output from the pressure sensor is converted into mass flow rate which is subsequently converted into volume. The microcontroller relays this data via a Universal Serial Bus (USB) connection to a computer which transmits

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this to the JavaScript based graphical user interface. This interface is used to display the flow and volume data in real-time. The experimental setup is shown in Figure 2. During first phase, the age group is divided into two groups: 18-30 and 30-45. Then the proposed spirometer had experimented on both males and females in these age groups during phase 2. Then collected the forced vital capacity (FVC) and forced expiratory volume first second (FEV1) values of the subjects and compared with standard values to draw a conclusion whether the subject has any kind of disorder. FEV1 and FVC are the two important values that indicates normal lung functioning.

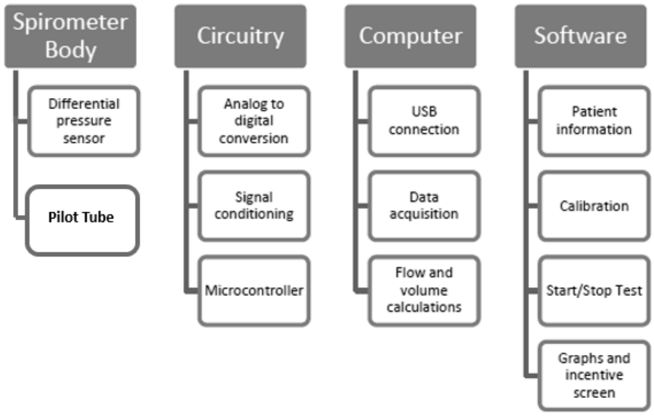

Figure 1. Block diagram of proposed system.

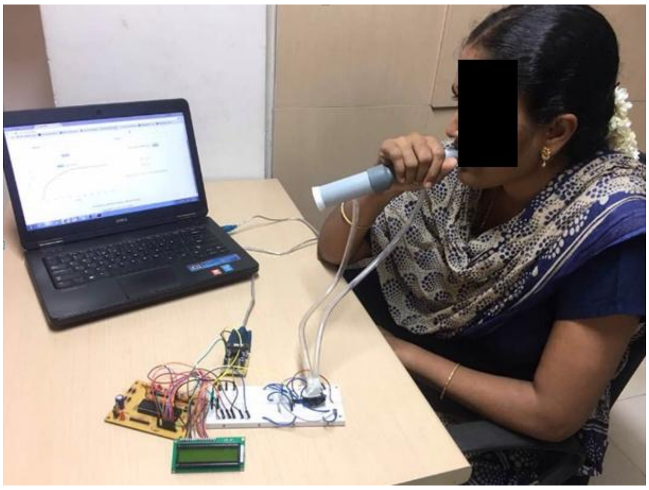

Figure 2. Experiment setup includes hardware and software interface modules.

B. Hardware Interface

The kind of tube used to blow into the sensor is called a pilot tube. The fluid flow velocity can be measured using a pilot tube by transforming kinetic energy in to potential energy. The two pressures are connected to a differential pressure sensor which converts the difference between them into voltage. The differential pressure sensor used is MPX10DP. Authors decided to use differential pressure sensor because it is less affected by temperature, smaller in size, less expensive and durable for long periods of duration. This sensor measures the difference between two pressures, one connected to each side of the sensor.

The microcontroller used for the experiment is PIC16F877A. The PIC16F877A has 8 channels 10-bit Analog-to-Digital converter and EEPROM data memory with 256 bytes. Here PIC was chosen because its performance is superior due to RISC architecture, power consumption is less and interfacing with analog devices is easier. This data from the microcontroller is relayed to computer via serial communication from where the data is transmitted to the website we created. Figure 3 shows the entire hardware setup.

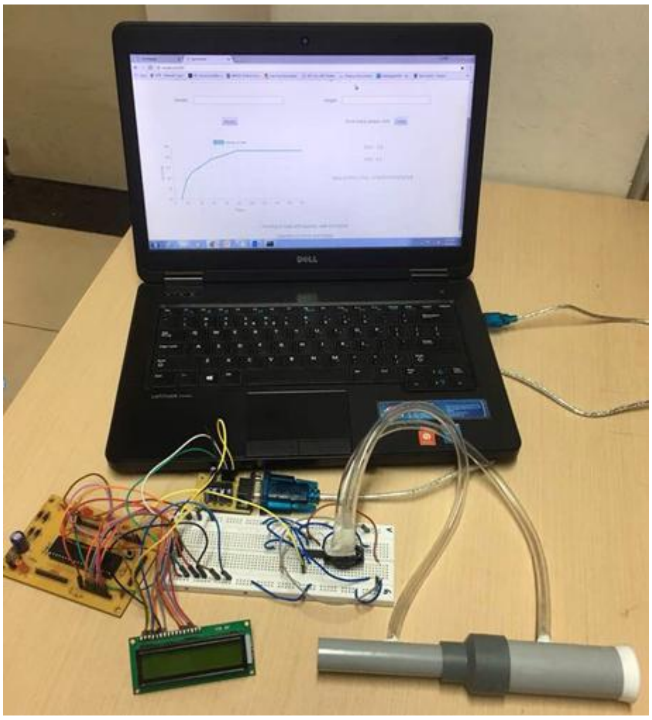

Figure 3. Hardware setup of proposed low cost spirometer.

C. Software Interface

Then a JavaScript based graphical user interface which can display the flow and volume data in real-time was build. The software will allow for input of various patient demographic data such as age, height and sex which are necessary to establish expected pulmonary function indices. The back end of the software performs data acquisition from the microcontroller and calculation of flow and volume.

Knowledge on fluid mechanics allows authors to convert pressure difference into mass flow rate using the (1).

$$dp = \left(\frac{W^2}{2\rho}\right)\left(\frac{1}{A2^2} - \frac{1}{A1^2}\right) \qquad (1)$$

where dP is the change in pressure across the tube in Pa, W is the mass flow rate in kg/s, ρ is the air density in kg/m^3, and $A1$ and $A2$ are the U-tube cross sectional areas in m^2. Now volume flow rate is given by (2) as,

$$volFlow = \frac{massFlow}{\rho} \qquad (2)$$

Since volumetric flow rate is simply volume over time, *volume* can be written as in (3),

$$volume = volFlow \times time \qquad (3)$$

To adequately perform lung function assessment, various pulmonary function indices should be measured including FVC and FEV1 [10, 11]. These are calculated from the Volume – Time graph generated. Figure 5 shows the volume time graph and the resultant FEV1, FVC and the ratio between these 2 parameters.

III. RESULTS AND DISCUSSION

Table 1 and Table 2 show the measured FEV1 and FVC values of females and males under the age group of 18-30 respectively. According to our experiment, females are more prone to lung disorder than males under this age group. Table 3 and Table 4 show the measured FEV1 and FVC values of females and males under the age group of 30-45 respectively. Without doubt, scientists says gender and height are the most valuable prognosticators of lung functioning. Height and the size of lung are linearly correlated [12]. Another fact is FEV1 and FVC are highly related to chromosomes 4, 6 and 18. Literature review on previous studies reveals a complicated relationship between lung functioning and the various factors affecting these functions [13]. Other than gender, age and height, there are lot of factors influencing lung functioning. Because of these complexities, it is very difficult to predict standard values for FEV1 and FVC [14].

Table. 1. Test results of females in the age group of 18-30 years.

Subject No.	Gender	Age (Year)	Height (cm)	FVC (Litres)	FEV1 (Litres)	Measured FVC & FEV1 with respect to standard values (%)	Condition
1	Female	18	165	3.21	2.68	85.1 & 81.4	Normal
2	Female	19	155	2.5	1.97	75.07 & 67.9	Mild Disorder
3	Female	21	170	3.1	2.57	77.6 & 73.6	Mild Disorder
4	Female	23	175	4.01	3.48	95.24 & 94	Normal
5	Female	27	172	2.4	2.01	58.3 & 55.9	Severe Disorder

Table. 2. Test Results of Males in the age group of 18-30 years.

Subject No.	Gender	Age (Year)	Height (cm)	FVC (Litres)	FEV1 (Litres)	Measured FVC & FEV1 with respect to standard values (%)	Condition
1	Male	19	171	4.32	3.64	90 & 88.7	Normal
2	Male	19	168	3.9	3.22	81.2 & 78.5	Normal
3	Male	21	173	4.1	3.42	85 & 83	Normal
4	Male	22	182	3.1	2.42	57.4 & 53	Severe Disorder
5	Male	29	172	3.4	2.66	72.3 & 66.8	Mild Disorder

Table. 3. Test Results of Females in the age group of 30-45 years.

Subject No.	Gender	Age (Year)	Height (cm)	FVC (Litres)	FEV1 (Litres)	Measured FVC & FEV1 with respect to standard values (%)	Condition
1	Female	35	164	2.1	1.67	67 & 61.8	Mild Disorder
2	Female	37	159	2.3	1.87	74.1 & 69	Mild Disorder
3	Female	37	165	2.62	2.19	84.5 & 81.1	Normal
4	Female	40	155	1.72	1.29	55 & 47.7	Severe Disorder
5	Female	44	169	2.63	2.24	73.05 & 72.2	Mild Disorder

Table 4. Test Results of Males in the age group of 30-45 years.

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Subject No.	Gender	Age (Year)	Height (cm)	FVC (Litres)	FEV1 (Litres)	Measured FVC & FEV1 with respect to standard values (%)	Condition
1	Male	33	175	4.32	3.51	86.4 & 87.7	Normal
2	Male	41	167	3.3	2.57	75 & 71.3	Normal
3	Male	41	171	3.62	2.89	82.3 & 80.2	Severe Disorder
4	Male	43	165	2.33	1.6	52.9 & 44.4	Mild Disorder
5	Male	44	168	3.01	2.28	68.4 & 63.3	Mild Disorder

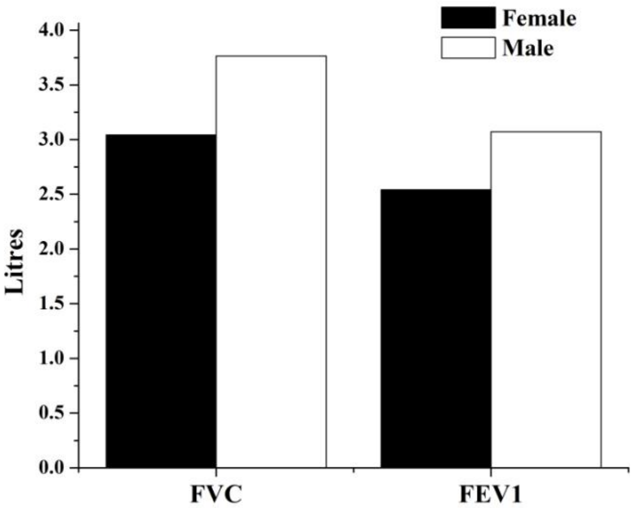

Figure 4. Average FVC and FEV1 values of female and male in the age group of 18-30 years.

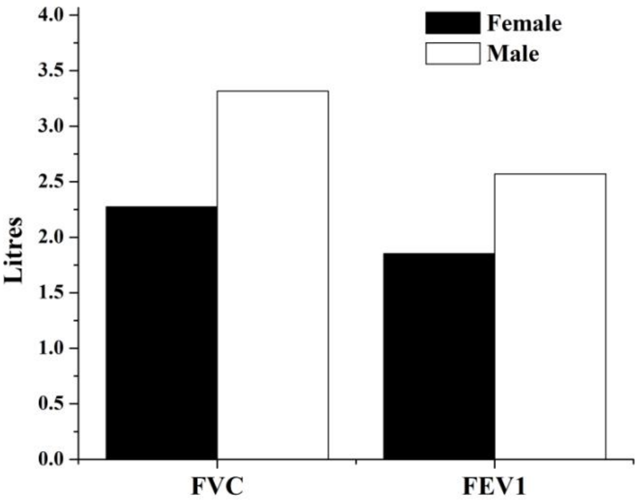

Figure 5. Average FVC and FEV1 values of female and male in the age group of 30-45 years.

The data collected from the 20 people are summarized using average values and presented in the form of graphs for easier understanding. If the measured FVC and FEV1 are at least 80% of the predicted normal values then the patient is fit without any breathing disorder. He or she suffers from a mild condition if the measured value is between 70% and 80% of the normal values. A severe case is when the measured value is less than 60% of the normal values [15]. The average FVC and FEV1 decreases with increasing age as lung capacity decreases gradually. Also the lung measurements of males are comparatively higher than females owing to physiological differences between the two genders. In our opinion, best suitable age range to collect spirometric indices is 20 to 40 or we can split it into 20, 30 and 40. Then these measured values can be taken as a reference in that particular subject's life for individual changes in his/her lung functioning.

IV. CONCLUSION

The low-cost, open-source spirometer described above fulfills its intended purpose of measuring respiratory air flow and volume data and providing a graphical user interface to display the data and calculate pulmonary function test parameters. The low-cost spirometer measures lung flows and volumes to a sufficient accuracy to serve as a preliminary screening for respiratory disease. Furthermore, the ability to visualize the shape of the flow and volume data allows a trained respiratory technician to make an informed, qualitative assessment of the patient's lung function. Although the current design is not able to meet clinical accuracy, with professional manufacturing, such a design could yield a device capable of meeting clinical accuracy without a significant increase in price.

The experiment conducted gives insights on the breathing patterns of different age groups and genders. Average FVC and FEV1 decrease with increase in age. Also, the lung measurements of males are comparatively higher than females owing to physiological differences between the two genders.

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