# Development of GUI for Spirometer and Calculation of different Spirometric Parameters

Isha G. Sodhi, Aparna Lakhe, Jyothi Warrier, Rajesh Kumar Jain, Vineet Sinha

**Abstract**— Spirometery is the fundamental of Pulmonary Function Test that is used to diagnose various respiratory diseases. The inference of the disease is based on various Spirometric parameters that are derived from Volume-Time and Flow-Volume Curves. The aim of this work is to develop a Graphical User Interface (GUI) displaying Spirometric graphs and calculate important Spirometric parameters that depend on the type of the pneumotachometer used. The paper also presents a comparison between the developed spirometer and a reference spirometer.

**Index Terms**— GUI, Forced Vital Capacity (FVC), Flow-Volume Loop, Pneumotachometer, Spirometer, Volume-Time Graph

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## 1 INTRODUCTION

SPIROMETER is a device that measures the volume and the flow rate of air that is inhaled and exhaled from the lungs. It measures the breath as a function of time. The importance of spirometry in Pulmonary Function Tests (PFTs) is gaining importance as it indicates the presence of a variety of pulmonary diseases like Chronic Obstructive Pulmonary Disorder (COPD), asthma, restrictive diseases etc.

Flow rate and volume are measured by connecting a spirometry sensor through a mouthpiece to the subject's mouth[1]. These are then used to calculate the spirometric parameters like Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second (FEV1), ratio of FEV1 to FVC (FEV1%), peak expiratory flow (PEF) and forced expiratory flow at 25–75% of FVC (FEF25–75). These spirometric parameters form the basis of the diagnosis and treatment of lung disorders. The basic output of the spirometer is represented in two graphical waveforms (Fig. 1); one being the graph of volume v/s time and other flow v/s volume.

As seen in fig. 1, graphical representation of the flow rates and volume is the most important requirement of a spirometer. Thus, a user interface must be designed to express the measured flow rates and volumes in a graphical form. This makes it easy for the practitioner/doctor to interpret the result of the test performed. In this work, importance is given to the development of software for spirometer. The software used in this work is a proven ANSI C integrated development environment (IDE). It provides a GUI builder with engineering components and in-built commands which aids the programmer to develop an easy to use graphical user-interface (GUI).
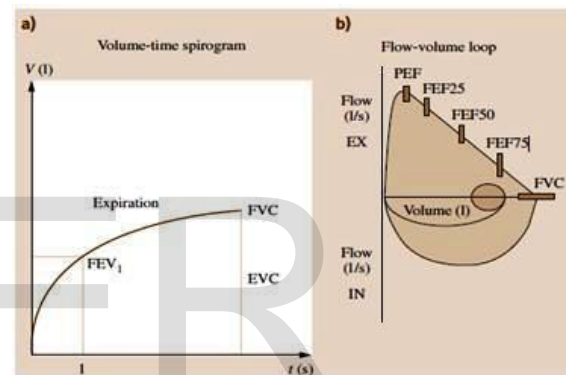


Fig. 1: Spirometry Curves, (a) Volume-Time Curve (b) Flow-Volume Loop

## 2 SYSTEM DESIGN

The hardware designed at Electronics Division of Bhabha Atomic Research Centre (BARC), Mumbai is based on a differential pressure approach. It uses a differential pressure sensor MPXV 2010DP, the output of which is fed to the ADC of the microcontroller. These ADC values are wirelessly transferred to the computer via Bluetooth. Indigenously designed PVC pipe is used as a mouthpiece for inhalation and exhalation of air. Lilly type pneumotachometer which is fitted in the pipe creates a differential pressure due to the mesh present between the two sensing points.
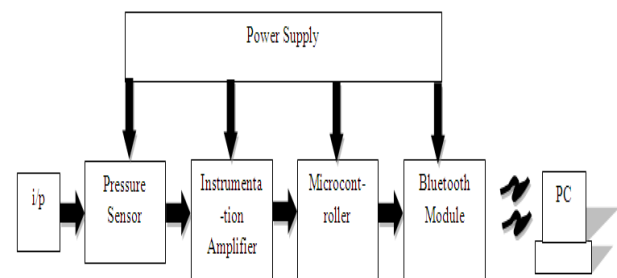
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Fig. 2: Block diagram of the Spirometer developed at BARC, Mumbai

Analysis of the signal developed by this spirometer required that the basic GUI should be developed first. Thus the initial step was to create a basic user interface (UI) as shown in Fig. 3. It incorporates the essential options that are listed as follows:

1. Button to establish connection with Bluetooth
2. Button to Start and Stop the acquisition
3. Button to Save and Load the acquired data
4. Save and Displays patient's demographics, current date & time
5. Graph to display the acquired signal
6. Graph scaling buttons

Once the basic UI is designed; the next step is to start the analysis of the signal by converting the measured pressure signal into desired flow rate and volume values.
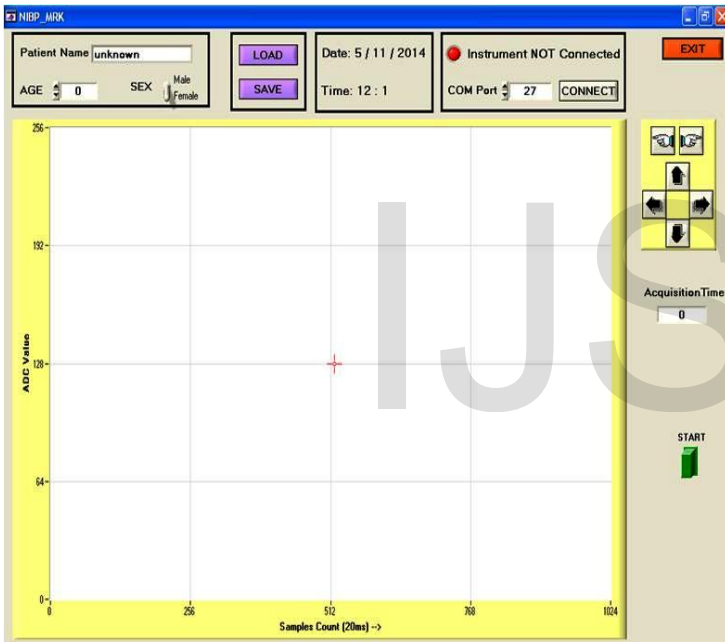


Fig. 3: Basic User Interface: Developed at initial stage to record the raw signal. Graph displays ADC values on Y-axis and Sample Count on X-axis

## 3 ANALYSIS OF SPIROMETER SIGNAL

### 3.1 Principle of Differential pressure based Spirometer

The dynamic pressure is dimensionally referred to as the change in kinetic energy per unit volume. Once the dynamic pressure is extracted from the sensor the Velocity of flow can be determined using (1) as given in [2].

$$P = \frac{1}{2} \rho v^2 \tag{1}$$

Where: $\rho$ = Density of Air at 300° K in kg/m3
  $v$ = Velocity of flow of the fluid in m/s

Flow rate is the product of the flow velocity and the cross-sectional area through which the fluid flows. From the calculated value of velocity, the flow-rate can be calculated by using (2) as given in [2].

$$F = A \times v \tag{2}$$

Where:  A = Area of cross-section of mesh used in m³.

Integral of the Flow-rate over the time of flow gives the total volume of the fluid. Thus volume can be calculated using (3) as given in [2].

$$V = \int_{t1}^{t2} F \cdot dt \tag{3}$$

### 3.2 Derivation of Pressure equation from ADC output

The differential pressure sensed by the sensor is converted to the corresponding voltage by the Instrumentation Amplifier. This voltage signal is given to the ADC input of the Microcontroller, which converts the analog input to digital values. The microcontroller sends the data to the PC in the form of these digital values which then needs to be calibrated in order to derive corresponding pressure.

The idea was to provide the sensor with known pressure

TABLE 1
PRESSURE & ADC VALUES US-
ING
SPHYGMOMANOMETER

| Measured Pressure (mmHg)- Y axis | ADC reading – X axis |
|---|---|
| -60 | 5 |
| -50 | 25 |
| -40 | 45 |
| -30 | 63 |
| -20 | 84 |
| -10 | 105 |
| 10 | 150 |
| 20 | 172 |
| 30 | 193 |
| 40 | 213 |
| 50 | 235 |
| 60 | 253 |

values and note down the corresponding ADC values. Twelve readings are recorded from sphygmomanometer, six in positive port of sensor and remaining in negative port of sensor. These readings are used to formulate an equation for pressure using MiniTab software. The readings and the corresponding

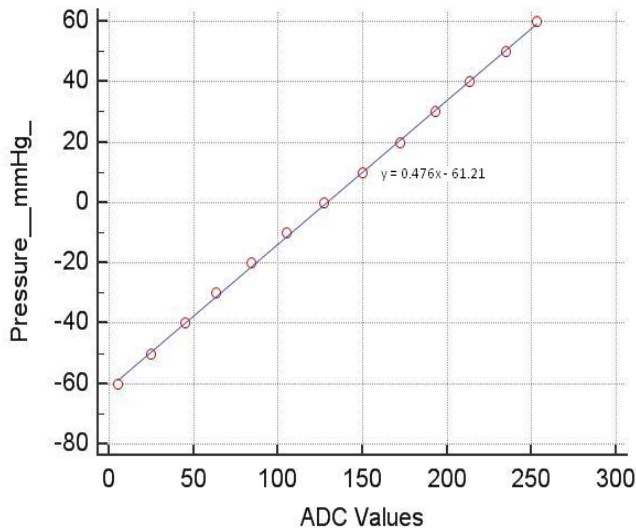equations are as shown in Table 1 and in fig. 4 respectively.



Fig. 4: Plot of ADC values v/s Pressure in mmHg

minium mesh was placed between two straight pipes. The diameter of each hole in the mesh is kept at 3.5mm with a cross sectional area of around $0.67 \times 10^{-4}$ m². Resistance offered by this pneumotachometer was approximately 10Pa/L/s.

a)          b)



Fig. 5: a) Pneumotachometer with change in tube diameter
b) Pneumotachometer without change in tube diameter

The differential pressure w.r.t atmospheric pressure is sensed by the sensor. The ADC values are plotted on the X-axis and the Pressure values are plotted on the Y-axis. Regression equation (4) achieved is used to calculate pressure:

$$y = 0.476x - 61.21, \tag{4}$$

where, y= pressure in mmHg and x= ADC values

The value of Pressure obtained in (4) is substituted in (1). After adjusting the units in standard form, the velocity was obtained in m/s. Subsequently value of velocity is substituted in (2) and is used to calculate the flow rate. The area considered is the cross sectional area of the mesh inserted in the pneumotachometer. Finally the volume is calculated by integrating the flow rate with time.

### 3.3 Pneumotachometer

Type, size and shape of the pneumotachometer being used are of great importance. In this work three different pneumotachometers, of two different shapes, are tested. The first two had a change in diameter (as shown in fig. 5.a) of the tube as well as the mesh, while the third was a tube with uniform diameter with a mesh inserted at the center of the tube (as shown in fig. 5.b). Initially a mesh was fabricated with the hole of 1mm diameter and cross sectional area of $0.1021 \times 10^{-4}$ m². This resulted in a high airway resistance of about 2kPa/L/s which is beyond the limits set by ATS of 150 Pa/L/s. Another mesh of the same shape, was fabricated with 2mm diameter and a cross sectional area of around $0.6 \times 10^{-4}$ m². This resulted in much lower resistance but a common problem was observed in both these mouthpieces and it was observed that the shape of these pneumotachometers was creating a turbulent flow. Thus, third pneumotachometer was designed with no change in the tube diameters and an allu-

### 3.4 Spirometric parameters

Commercial spirometers provide different options for the type of tests to be performed, like forced spirometry test, slow spirometery test, maximum ventilation test etc. In this work the focus is to develop a spirometer that conducts forced spirometry test. It involves the test in which the patient is advised to inhale to its full capacity and then forcefully exhale to its full capacity. Total 17 parameters are calculated based on their definitions. These parameters are calculated from the volume and flow values obtained in the analysis part. List of calculated parameters:

1. Forced Vital Capacity (FVC)
2. Forced Expiratory Volume in 1 sec (FEV1)
3. Forced Expiratory Volume in 1 sec (FEV3)
4. Forced Expiratory Volume in 1 sec (FEV6)
5. FEV1/FVC
6. FEV1/FEV6
7. FEV3/FVC
8. Peak Expiraotry Flow (PEF)
9. Full expiratory Time (FET)
10. Full Inspiratory Capacity (FIVC)
11. Full Inspiratory Capacity in 1 sec (FIVC1)
12. FIVC1/FIVC
13. Peak Inspiratory Flow (PIF)
14. Forced Expired Flow at 25% of FVC (FEF25)
15. Forced Expired Flow at 50% of FVC (FEF50)
16. Forced Expired Flow at 75% of FVC (FEF75)
17. Forced Expired Flow between 25%-75% of FVC (FEF25-75)

## 4 RESULTS & DISCUSSION

The basic GUI was eventually modified to an advanced GUI as shown in fig. 6. It includes options for printing with a provision of recording total 10 efforts for each patient. All the 10 efforts or only the selected efforts could be displayed for comparison. Waveforms of each effort are color coded to avoid any confusion. All the parameter values are displayed in a single table.
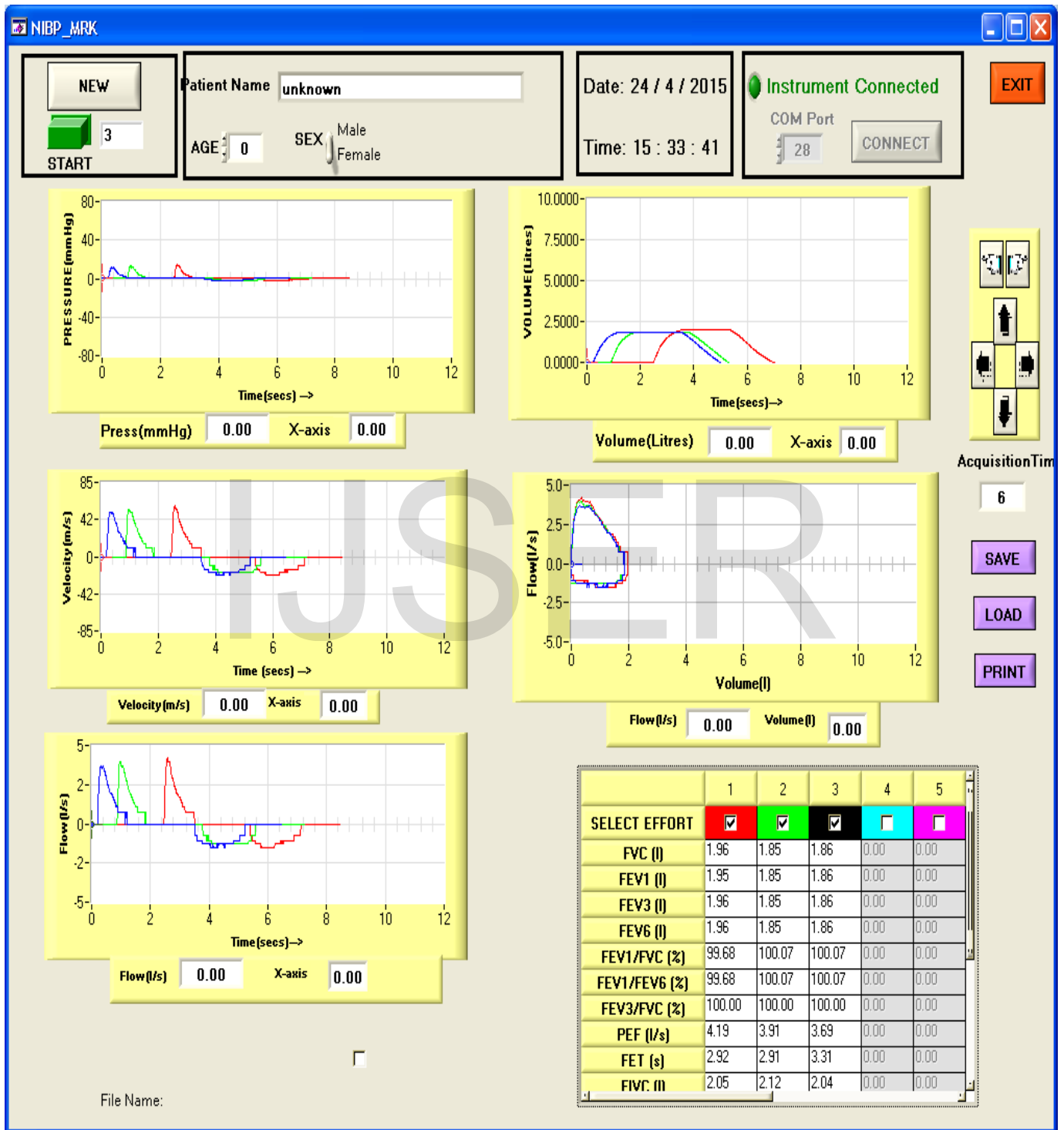


Fig. 6: Final GUI: Showing 5 graphs, Spirometric parameter values displayed in table. Three different colours of waveforms denotes three different efforts

TABLE 2

COMPARISON TABLE BETWEEN RESULTS OF SPIROMETER DEVELOPED BY BARC AND RESULTS OF SPIROMETER DEVELOPED BY WELCH ALLYN (CARDIOPERFECT) SHOWING SNAPSHOTS OF GUI

|  | BARC | CardioPerfect |
|---|---|---|
| Flow-Volume Curve |  |  |
| Volume-Time Curve |  |  |
| Readings |  |  |

BARC Readings:

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| SELECT EFFORT | ☑ | ☑ | ☑ | ☐ | ☐ |
| FVC (l) | 1.96 | 1.85 | 1.86 | 0.00 | 0.00 |
| FEV1 (l) | 1.95 | 1.85 | 1.86 | 0.00 | 0.00 |
| FEV3 (l) | 1.96 | 1.85 | 1.86 | 0.00 | 0.00 |
| FEV6 (l) | 1.96 | 1.85 | 1.86 | 0.00 | 0.00 |
| FEV1/FVC (%) | 99.68 | 100.07 | 100.07 | 0.00 | 0.00 |
| FEV1/FEV6 (%) | 99.68 | 100.07 | 100.07 | 0.00 | 0.00 |
| FEV3/FVC (%) | 100.00 | 100.00 | 100.00 | 0.00 | 0.00 |
| PEF (l/s) | 4.19 | 3.91 | 3.69 | 0.00 | 0.00 |
| FET (s) | 2.92 | 2.91 | 3.31 | 0.00 | 0.00 |
| FIVC (l) | 2.05 | 2.12 | 2.04 | 0.00 | 0.00 |

CardioPerfect Readings:

| Efforts | Units | NHANESIII 1999 | Pre 3. | Pre 2. | Pre 1. |
|---|---|---|---|---|---|
| Selected |  |  | ☑ | ☑ | ☑ |
| FVC | L | 3.31 | 1.75 | 1.79 | 1.81 |
| FEV1 | L | 2.87 | 1.54 | 1.58 | 1.62 |
| FEV1/FVC | % | 85 % | 88 % | 88 % | 90 % |
| FEV6 | L | 3.52 | 1.75 | 1.79 | 1.81 |
| PEF | L/s | 6.60 | 3.47 | 4.02 | 3.65 |
| FEF25-75 | L/s | 3.49 | 2.20 | 2.05 | 2.07 |

First row of Table 2 shows the flow-volume curves of the same subject from both, the test as well as reference spirometer. It is evident that the shape of the curves in both the spirometers is almost similar with negligible difference. Also, the maximum peak expiratory flow obtained is around 4.19 l/s in the test spirometer and 4.02 l/s in the reference spirometer. Maximum FEF25-75 obtained is around 2.78 l/s in test spirometer and 2.20 l/s in reference spirometer. Second row shows the volume-time curves of the same subject from both the spirometers. In the test spirometer, both, the Inspiratory and expiratory, cycles are shown while in the reference spirometer only expiratory cycle is shown. Repeatability is seen in both the spirometers. The maximum FVC in test spirometer is 1.96 L while in reference spirometer is 1.81 L. Third row shows the readings of Spirometric parameters of the same subject from

both the spirometers. It is observed that FVC shows highest correlation between the two spirometers.

## 5 CONCLUSION

Graphical representation of the complete breath cycle forms the basis of diagnosis in spirometry. An easy to use GUI has been developed successfully comprising of the Pressure Flow, Velocity and volume graphs w.r.t to time, Flow-volume curve, facilitates to acquire and save ten different efforts for each patient with printing facility of the report. Seventeen different Spirometric parameters are calculated based on their definitions and displayed in tabular form in the GUI. FVC values show high correlations with those achieved by the reference spirometer. Further, more regressive validation process will make the spirometer ready to be commercially available.

## ACKNOWLEDGMENT

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