Design, Development and Clinical Testing of Spirometer

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Abstract: **Spirometers are used to measure lung capacity and response of lungs and chest during physical therapy. Current spirometers available in the market are expensive and usually cost over $1,000. Due to this high cost, many physicians practicing in developing countries like India, cannot afford spirometry equipment. As a result, millions of people with chronic obstructive pulmonary disease, or COPD, are unable to be effectively monitored or treated for their disease. Thus, the development of a low cost reliable spirometer would allow these physicians to assess their patient's pulmonary health. All these factors led to the development of a product which addresses cost issues as well as technical accuracy[1] . A computer-based miniaturized spirometer system is Designed to be realized which would use a solid state pressure sensor. A proto-type of a Computer based Spirometer system has been realized which would employ a solid state single port pressure sensor. A dedicated analog signal acquisition and processing channel has been designed and tested along with the solid-state pressure sensor. Calibration of pressure sensor for known values of applied pressure has been performed for linearity tests. The MSP430 is employed in designing the micro-controller firmware program (using Code Composer Studio) for digitization and transmission of the signal to the computer. Dedicated computer software for data acquisition, display and analysis was developed in CVI LabWindows platform.**

Keywords – MSP430, Spirometer, Miniature

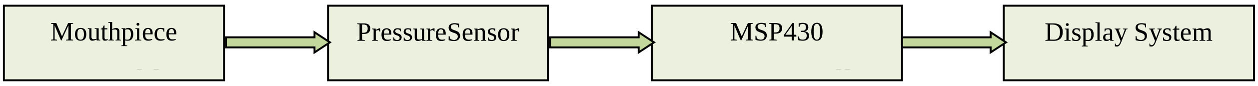
I. INTRODUCTION

Spirometry is the technique to measure the flow and volume of air entering and leaving the lungs. A spirometer is used to conduct a set of medical tests that help to identify and quantify defects and abnormalities of various lung conditions in human respiratory system.

These tests also help in monitoring the response of lungs to medical treatment. With the help of a spirometer, COPD can be detected well in advance. Monitoring cough and wheezing may not provide an accurate assessment of the severity of asthma in a patient. With the help of the breathing tests conducted using a spirometer, the response and improvement in an asthma patient's condition during the treatment can be monitored accurately. This helps in improving the quality of treatment by reducing the judgment errors. Pulmonary function tests (PFT's), or breathing tests, is used to identify and quantify defects and abnormalities in the function of respiratory system. These breathing tests can be classified into two types, depending on the lung characteristics that they measure. These are Gas Exchange Functions and Dynamic Lung Functions. The dynamic lung functions test the Forced Vital Capacity (FVC), Flow-Volume Curves, Maximum Voluntary Ventilation (MVV) and airway resistance and is the most common test and highly informative and useful in most of the case[2].

II. BLOCK DIAGRAM

An overview of the designed system is presented with the help of a block diagram shown in the following block diagram. The first block is the front-end of the system, in this case, the mouthpiece device. The second block is dedicated to the sensing device, here, a FREESCALE Semiconductors Inc. dual port, MEMS based pressure sensor (MPXV2010DP). The third block is reserved for the microcontroller which is MSP430FG4618. The fourth module is for the display of the output of the system which is a PC.



Block Diagram of Designed System

II.I Mouthpiece Assembly

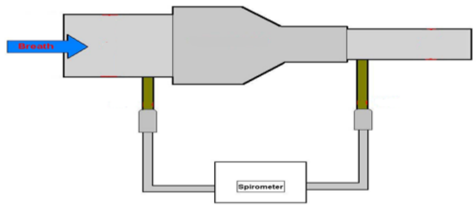
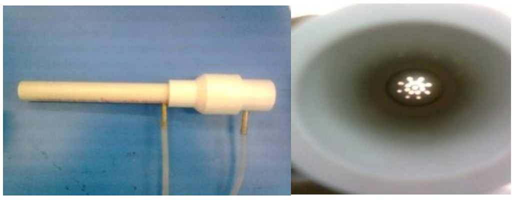


Illustration depicting the designed mouthpiece.

The mouthpiece will be designed for a 50% drop in pressure across its length. The design essentially consists of two PVC pipes connected via a coupling. The tube facing the patient would be of 1 inch diameter which is to be connected to a 1” to 0.5” reduction coupling. The latter end of this coupling will be connected to a 0.5” PVC pipe. An air resistance assembly is created to convert the turbulent flow input from the patient to laminar flow for better sensing accuracy and it is to be placed in the space between the sensing ports. The patient blows air from the left end resulting in a pressure difference between the ports which in-turn will be sensed by the silicon pressure sensor and converted to meaningful output by the system.



Photograph of the fabricated mouthpiece (left) and cross-section showing the laminar flow resistor (right).

Ii.Ii Pressure Sensor

The MEMS based single port pressure sensor MPXV2010GS [5] has been used. It is a silicon piezoresistive pressure sensor which provides a very accurate and linear voltage output directly proportional to the applied pressure. The sensor has a precise offset calibration and temperature compensation. Prior to making any measurement, the pressure sensor needs to be calibrated for its performance. A FLUKE Inc. blood pressure simulator (BP-PUMP2) will be employed for applying a fixed quantum of static pressure on the sensor ports. The sensor is calibrated by connecting to the simulator. The applied pressure has been varied and the voltage at the output of the analog circuit is measured. This output voltage is normalized by subtracting the mid-point potential of 5V (Maximum input swing for ADC) with the output value. This results in a range of voltage values from 0 to 5 V with 2.5V as centre value. The pressure to voltage conversion factor (+ve & -ve ports) has been calculated. This factor is crucial in deducing the pressure value from the output of the ADC. Alternately, the applied pressure has been calibrated using a sphygmomanometer in parallel with the fluke BP simulator and the deviation of pressure values have been found out between the mercury readings and our system.

The analog circuit for the spirometry system consists of instrumentation amplifier (AD624) in conjunction with an OPAMP. The output of the IA will be then coupled as input to a general purpose OPAMP (AD713) for further amplification to give a signal large enough to drive the input to an ADC in the digital micro-controller module. Gain can be tuned depending on the value of the output signal from the pressure sensor and the ADC input range. Additionally, level-shifting block is added at the output to prevent the negative drift of output voltage from the negative pressure port of the sensor. This level shifter is designed with a single low power, low leakage current Quad OPAMP (LMC 6044) in a summation configuration. The input reference voltage is fixed at the mid-gap of the ADC range of 5V. The reference voltage of 2V is supplied by a potential divider arrangement consisting of two 1MΩ resistors. The mid-point of the divider is connected to a buffer for voltage stability and the output of the buffer is connected to the non-inverting terminal of the level shifter OPAMP. A digital module is consisting of the analog to digital converter, RS-232 interface & microcontroller (MSP430FG4618) is employed to convert the analog signal to a digital output and send data in digital form to the computer via the RS-232 port. The digital module will send data to the computer, which will then be interpreted and plotted.

II.III Principles of Fluid Dynamics

Total Pressure of a fluid flowing through a tube is the sum of the static and dynamic components. Static component of pressure is essentially the pressure exerted on the walls of the tube when the fluid is at rest (velocity = 0 m/s) whereas the dynamic component gives the pressure exerted by fluid when in motion. The dynamic pressure is dimensionally referred to as the change in kinetic energy per unit volume. The Designed spirometer system is designed to work on the principle of measurement of dynamic pressure of a fluid when it traverses a tube.

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Dynamic Pressure: $P = \frac{1}{2}\rho v^2$ …..Equation (i)

Where: ρ = Density of Air at 300ºK

ν = Velocity of flow of fluid

Once the dynamic pressure is extracted from the sensor, the velocity of flow can be determined using equation 1.

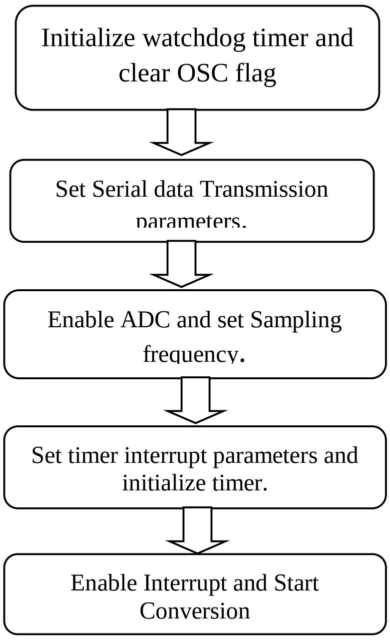
Flow Rate: F = A × Velocity ....Equation (ii)

Where: A = Area of cross-section of tube.

Volume of air: $V = \int_{t1}^{t2} F.dt$ ...Equation (iii)

III IMPLEMENTATION

III.I Implementation of Software

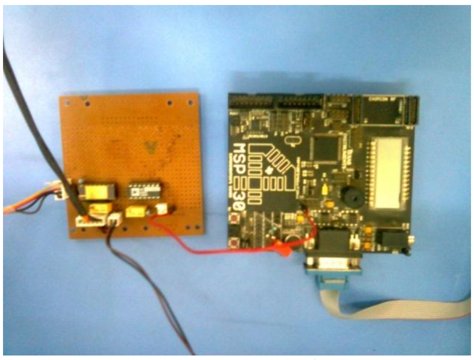


Flowchart of implemented MSP430 program

III.II Design of micro-controller firmware

RS-232 interface & microcontroller (MSP430FG4618) is employed to convert the analog signal to a digital output and send data in digital form to the computer via the RS-232 port. The sampling frequency of the ADC was set at 500 Hz for digitizing the input signal. Since the input signal is of very low frequency (<10Hz), a sampling frequency of 500Hz is enough to give good real time performance. The flow of the implemented micro-controller firmware program has been illustrated in figure. To begin with, the read, write & interrupt pins of the ADC were assigned to the micro-controller. The next step was to initialize watchdog timer to clear OSC flag. Then, serial transmission parameters were set and ADC was enabled by setting its sampling frequency at 500 Hz. By enabling timer, interrupt conversion was started (baud rate – 115200).

III.II Implementation of Hardware



Photograph of complete setup

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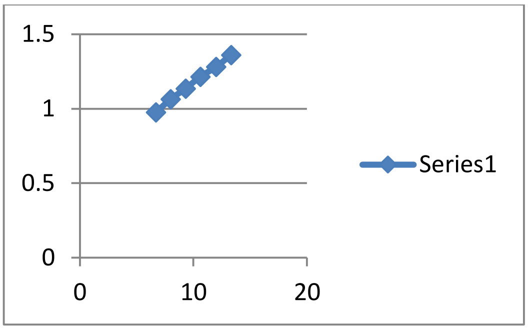
IV. EXPERIMENTAL RESULTS

IV.I Linearity and Calibration of Sensor

MSP430 board was interfaced with USB debugger & AD624 experimental board. On the bp pump, by using T, pressure is given to the sensor as well as mercury manometer. The experiment was started by 50mm Hg up to 100mm Hg with an interval of 10mm Hg. Then, pressure was measured on the BP pump as well as on the mercury manometer. Sensor is connected to instrumentation amplifier AD624 & its output is given to MSP430 to drive its ADC. The driving voltage of ADC is 3.3V. Using multimeter, output of ADC was measured. On the real terminal, using RS-232, hex value was checked for each input pressure & voltage was calculated by using following formula: $V = (V_{ref}/2^n-1)$*decimal value. (MSP has 12-bit ADC but real terminal works on 8-bit only so 12-bit ADC program was converted to 8-bit by shifting 4 LSB. Now, "n = 8" & V_{ref} is 3.3).

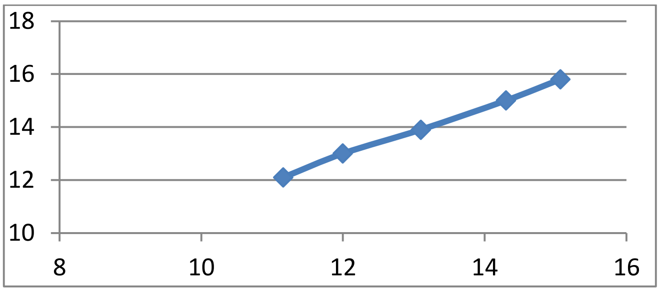
Applied Pressure	Measured Pressure	Measured Voltage	NORMALIZED	M.p. / normalized
6.7	11.25	2.826	0.976	11.5266
8	12.55	2.945	1.095	11.4611
9.3	12.8	2.964	1.114	11.4901
10.6	13.95	3.064	1.214	11.4909
12	15.45	3.2	1.35	11.4444
13.3	16.2	3.26	1.41	11.4893
			Average =	11.4837



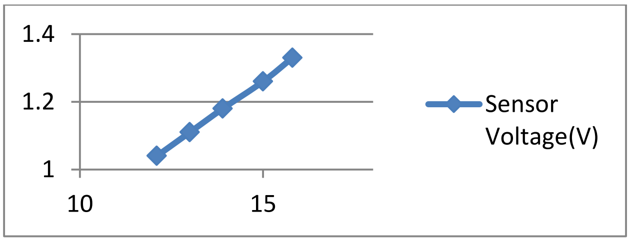
Graph of sensor calibration

IV.II Calculated values of implemented Spirometer

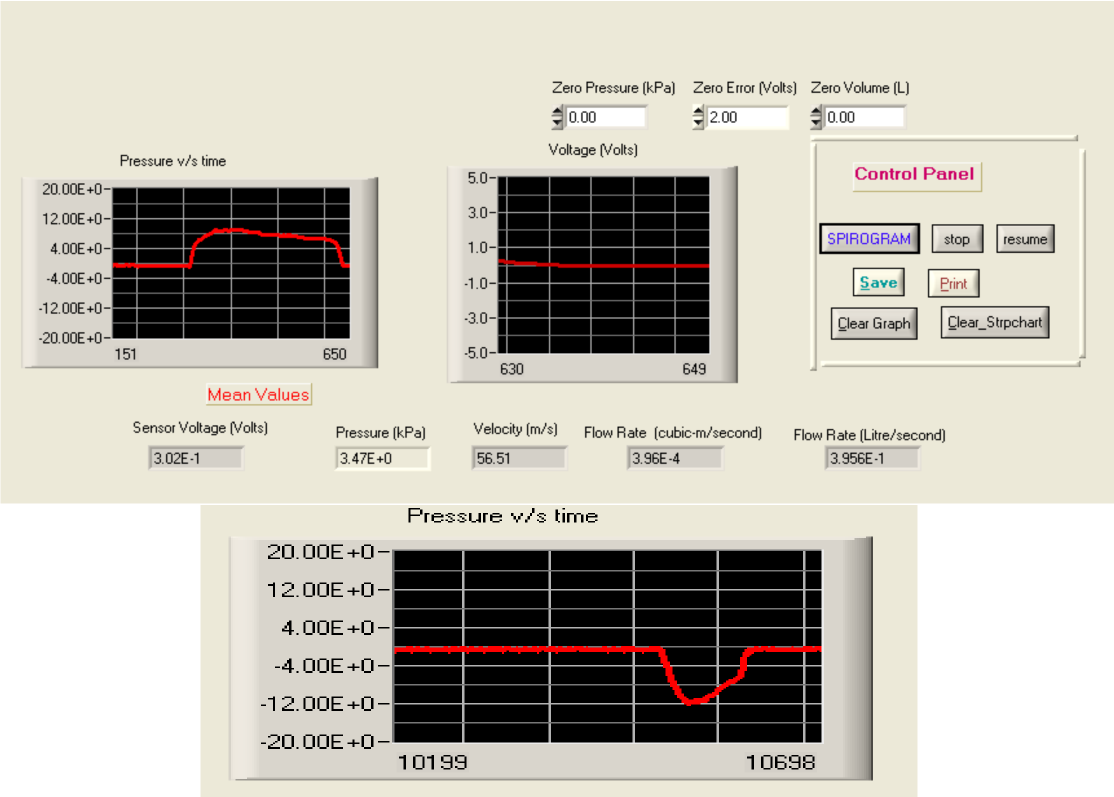
Set Point(kPa)	Measured Pressure(kPa)	Observed Pressure from graph(kPa)	Sensor Voltage(V)	Velocity(m/sec)
6.7	11.16	12.1	1.04	143
8	12	13	1.11	147.3
9.3	13.1	13.9	1.18	152.53
10.6	14.3	15	1.26	159.93
12	15.07	15.8	1.33	165.2



Measured vs. Observed Pressure



Observed Pressure vs. Voltage



Snapshot of the GUI program for spirometer system showing a sample taken for a human subject

V. CONCLUSION

A portable, cost effective, reliable spirometer is designed to be designed by using MSP430FG4618. At this stage, all the MSP basic programs have been performed. These programs are implemented on Code Composer Studio (CCStudio) Integrated Development Environment (IDE) v5. Linearity of time and ADC has been checked. Calibration of pressure sensor is to be done by pressure to voltage conversion. The user interface is to be done on NI Lab Windows™/CVI. A 3-Liter calibration syringe was used to test the accuracy and precision of our prototype.. Our current prototype has successfully met our target accuracy and precision goals for the project at this point. With further optimization, we are confident that we will be able to fulfill all required American Thoracic Society performance specifications. To fully explore the potential of our spirometer in developed and developing markets.

A need for spirometry within the developing world certainly exists, as respiratory diseases like COPD are an ever-growing concern due to factors such as smoking and the use of biomass fuels. In the developed world, there is significant potential for an inexpensive spirometer to improve our ability to diagnose respiratory diseases.

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