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Using a differential pressure sensor as spirometer

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Abstract. For a doctor to determine the most accurate diagnosis of diseases of the respiratory tract, it must be as accurate as possible insight into the problem. Imaging technology allows to look into the body, unfortunately for example lung is an organ, where without contrast agent does not buy the picture. Furthermore, the methods that can be used are whole body plethysmography or, a better option, spirometry. A measurement of spirometry is performed by the pneumotachograph or the spirometry. Spirometer measures lung volumes and lung capacity. Pneumotachograph is the flow rate measuring device, but can also be used for indirect measurement of lung volumes and capacities. Spirogram is the result of spirometry measurements.

Keywords: Spirometry, lungs, function lungs parameters, digital communication, Matlab

1 Introduction

In the past it was possible to perform spirometer only in medical facilities. Older spirometers are voluminous, have high maintenance and their measurement capabilities are very limited. After each patient had to be the instrument properly disinfected to prevent transmission of bacteria. Over time, the dimensions of the device and thus diminished their demands for service and maintenance. The coup came with the advent of pneumotachograph. They also want to specify multiple parameters of lung and especially sharply reduced the size of the device itself. Now, using simple instruments, measurements can be made in domestic environments. Measurement results are displayed on the LCD display device or on a computer screen [5].

This paper describes how to create a demonstration and simple devices for spirometer. It can find usage in a professional environment or in an education area in an university. Modern digital sensor was used with excellent high sensitivity, low power consumption and preprocessing options. It was also used Matlab programming options.

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2 Methods

For spirometry is possible to use several different methods like water spirometer, dry-bellowed wedge spirometer or fully electronics spirometer, typically. Electronic spirometers have been developed that compute airflow rates in a channel without the need for fine meshes or moving parts. They operate by measuring the speed of the airflow with techniques such as ultrasonic transducers, or by measuring pressure difference in the tube [1]. These spirometers have greater accuracy by eliminating the momentum and resistance errors associated with moving parts such as windmills or flow valves for flow measurement. They also allow improved hygiene between patients by allowing fully disposable air flow channels.

3 Measuring set

Principle of measuring a spirometry was chosen differential manometer. Spirometer body is made up of a biological filter HEPA Light. Electronics device includes a digital component to communicate with a computer. This solution enables the processing of measured data using specialized software without having to perform other calculations.

The sensor is a product of Swiss company Sensirion (see Tab. 1). The sensor output is digital, the I2C bus. Temperature calibration is automatically done by the sensor and electronics output is already linearized. Influence of initial offset aging of the material is given less than 0.1 Pa per year. The default sensitivity resolution of 12 bits (can be 9 to 16 bits) is given $0,2\,Pa$. The sensor is recommended, inter alia, in health care. This sensor offers the best fit of desired parameters and especially its digital output, thus allowing easier processing in the computer.

The measurement is started by breathing into the spirometer. Non-electric value is converted to digital signals by sensor. [4]

Table 1. Sensor parameters.

Power supply	3 - 3,6 V for < 6 mA
Measurement range	-500 Pa ÷ 500 Pa
Response time	4.6 ms
Temp. calibration range	0 °C – 50 °C
I2C working frequency	100 kHz (max. 400 kHz)

The digital signal is converted into comprehensible forms for serial communication. The computer information is drawn from the serial line and the measurement is complete interpretation of the measured values. Result can be interpreted as a graph or directly calculated values of lung parameters. The measurement block diagram is displayed in Fig 1.

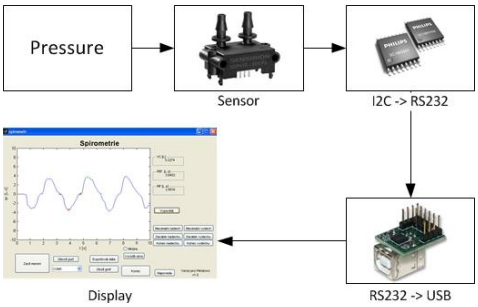

Fig. 1. Measuring set.

For easier interpretation of the results, the mathematical program Matlab is used. Matlab allows contact the programming elements and mathematical operations. Facilitates the work by omitting the definition of computing and thus automate the processing of values measured. Ideal measurement software should performs satisfy several following requirements:

- easy operation
- error – free functionality (clean code)
- the possibility to save results

The software (see Fig. 2) is developed as multiplatform for Windows and Mac OS X. For a smooth running program, you must have installed the virtual port driver and the Matlab version at least 2008 for Windows or for Mac OS X, Matlab 2009. For both operating systems, 32-bit and 64-bit architectures are supported.

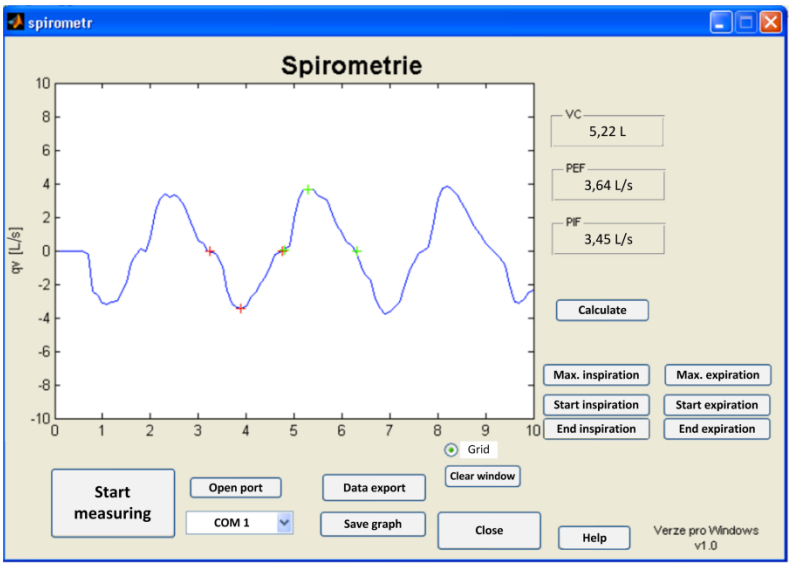

Fig. 2. Software window.

4 Calibration

The value of the pressure difference Δp is linearly dependent on the volume q_v and size of air flow resistance R (see (1)).

$$\Delta p = p_2 - p_1 = R \cdot q_v \tag{1}$$

To calculate the correct flow of gas was needed to determine the value of air resistance. The gas flow is expressed first by equation (1) and from already adjusted equation (2) is calculated the gas flow value q_v .

$$q_v = \frac{\Delta p}{q_v} \tag{2}$$

The value of pressure difference and flow rate were known during the calibration. Therefore equation (2) was modified into (3).

$$R = \frac{\Delta p}{q_v} \tag{3}$$

The gas rate was simulated using a phantom of an air, in the range of $0,3 L \cdot s^{-1}$ to $0,85 L \cdot s^{-1}$. Phantom of air was connected to the spirometer input and the differential pressure was sensed by a computer with a period of 10 s. Readout pressure was calculated by averaging the readings over one minute.

Next table (see Tab. 2) shows results from calibration. The average air resistance R was calculated as the mean of the measured resistance and is equal to $0,2029 Pa \cdot s \cdot L^{-1}$. This value was set as the resistance to air flow. Then it is easy to compute unknown air flow by (2) because Δp is measured and R is known from previous computation.

Table 2. Computed resistance R.

$q_v \left[L \cdot s^{-1} \right]$	$\Delta p \left[Pa \right]$	$R \left[Pa \cdot s \cdot L^{-1} \right]$
0,30	0,0325	0,14
0,35	0,0490	0,1083
0,40	0,0653	0,1632
0,45	0,0817	0,1816
0,50	0,0980	0,1960
0,55	0,1143	0,2078
0,60	0,1307	0,2178
0,65	0,1470	0,2262
0,70	0,2251	0,3216

5 Testing

Test was made for all functions of the device and measurement software. Readings from the program were compared with values measured on the spirometer made by ZAN. The spirometer ZAN100 (the principle of differential pressure) was used for testing. There have been several controlled test measurements. The next table (see Table 3) shows results from testing.

The difference of the reference level and minimum inspiration values is equal to the peak of inspiration flow (PIF) in liters per second. By integrating the volumetric flow across the interval of maximum inspiration is received a value of vital lung capacity in liters. See (4) where $t_{1,2}$ is start and end of inspiration, q_v is volume flow and V is vital lung capacity.[6][7]

$$V = \int_{t_1}^{t_2} q_v \, dt \tag{4}$$

Table 3. Compare between SDP610 and ZAN100.

Parameters	SDP610	ZAN100
PEF	3,6 $L \cdot s^{-1}$	3,8 $L \cdot s^{-1}$
PIF	3,4 $L \cdot s^{-1}$	3,6 $L \cdot s^{-1}$
VC	5,2 L	5,5 L

Next figure (see Fig. 3.) shows the record along breath made from one inspiration and expiration, and an intensive inspiration and expiration.

6 Conclusions

Method of measurement using differential manometer was chosen. Durability and reliability of the spirometer are improving by no moving parts are needed during the measurement. For compiling of the devices were used materials from health care, or materials wholesome. HEPA filter Light is used as the air resistance to the spirometer. It also serves as a barrier to the spread of bacteria. Spirometer is designed for easy using with the hygienic mouthpiece.

Electronic part of the device was selected for processing of signal on the computer. As differential sensor, the digital sensor SDP610 from the company Sensirion has been selected. With the compensation capabilities of this sensor is not necessary to further modify the signal. The signals from the sensor are transferred via serial communication line and then sent to a computer. In the computer was created software for processing.

Sensor SDP610 proved to be very suitable sensor with potential for use in medical applications.

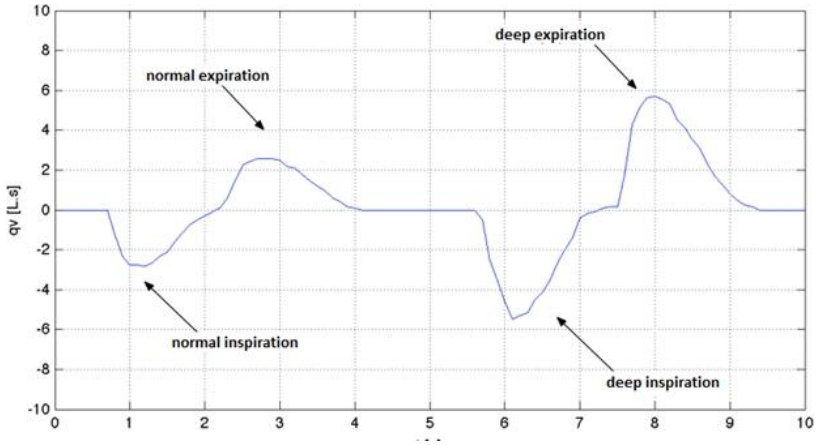

Fig. 3. Air flow along breath and intensive breath.

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