Mobile self-test unit for COPD-patients

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Abstract— Chronic Obstructive Pulmonary Disease is an illness that is characterized by airway inflammation, narrowing and destruction of lung tissue. It is possible to prevent further lung damage when a diagnosis can be done in an early stage. A common symptom of patients who are suffering from COPD is shortness of breath. These days the first step of determining the diagnose of COPD is by using a spirometer, the purpose of this paper is to develop a more compact yet still accurate device to replace these devices. Wireless devices are becoming more common in the field of biomedical engineering, hence the power consumption is kept to a bare minimum. Using an ultrasonic wireless manner to transfer data between devices will improve the power consumption and simplify the way of measurement. By modulating the data onto a higher frequency the sensor data is sent from one device to another. To receive the signal a smartphone is used, here the analysis of the data will also be done. By doing all this, patients will have the ability to use a medical-grade respiratory test by there self, while keeping the measurement accurate.

Index Terms*—*spirometer, ultrasonic, biomedical device, COPD

Introduction

CHRONIC OBSTRUCTIVE PULMONARY DISEASE (COPD) is a lung disease, characterized by a persistent blockage of airflow. It is a life-threatening disease that interferes with the normal breathing process. COPD is a common disease, affecting more than 680000 people[1] in Belgium, 320000 people in the Netherlands[2] and 800000 people in France[3] with an increasing trend. Furthermore there is an annual cost of 130 billion for this disease each year[4][5].

A paradigm shift in disease management is represented by mobile health practices. They give the possibility to each individual user to monitor and check their conditions in real-time. Chronic diseases, such as diabetes, are individually monitored through glucose meters whereas hypertension is registered through blood-pressure measurements. These are now properly controlled due to the existence of inexpensive and easy-to-use research devices.

The purpose of this paper is to provide a design for a smartphone-enabled spirometer, aiming to integrate detailed measurements of their particular disease into our device. The mobile spirometer aims to provide a continuous flow of information from patient to the physicians. This will result in a better treatment for that individual.

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Materials and Methods

Our goal is to plot the lung capacity of a person in function of the flow at which the person can ex- and inhale. This graph gives detailed information of the state of the lungs. Measuring the capacity of the lungs and plotting these values into a graph, an early indication of COPD can be determined.

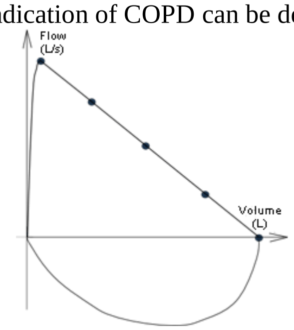

Figure 1: normal flow-volume plot

Different plots will give different diagnoses, the more basic diagnosis, which can be determined by looking at the plot, are shown in Figure 2[6].

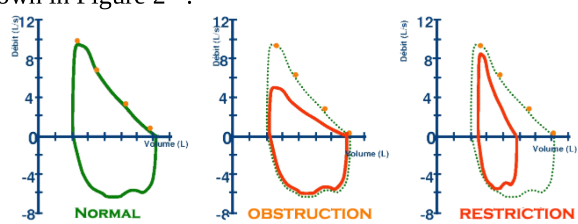

Figure 2: flow-volume comparison

A. Hardware

When rotating, the turbine in the spirometer blocks the light between an LDR and LED causing a change in resistance. This change can be measured with an ATMEGA microcontroller by using the resistor in a voltage divider.

Using the *tone()* function provided by the Arduino platform, the change in resistance could be transmitted through FM. To generate the sound wave, an ordinary speaker was used, salvaged from an old radio.

B. Signal processing

To test the previous mentioned hardware, Matlab is used. When we can confirm the hardware configuration sends out a correct signal it is possible to proceed to the next step and write an Android application. The reason for using Matlab first is because of the ease to analyze the audio signal coming from the hardware device. By applying a range of algorithms to this signal a correct function of the hardware can be established.

1) Discrete Fourier transform

The Discrete Fourier transform (DFT) gives us the frequency spectrum in which the audio signal is mapped. Having this we can conclude the hardware operates in the correct frequency range and we can proceed to analyzing the audio signal.

$$X(k) = X(\omega)\big|_{\omega=\frac{2\pi k}{N}} = \sum_{n=0}^{N-1} x(n)e^{-i\left(\frac{2\pi k}{N}\right)n}, k = 0, 1, \dots, N-1$$

As shown in Figure 3 the signal is located in the frequency range located between 16 kHz and 19 kHz. This is a frequency range that is difficult to distinguish for humans. So the transmission of data will hardly be noticeable for a human.

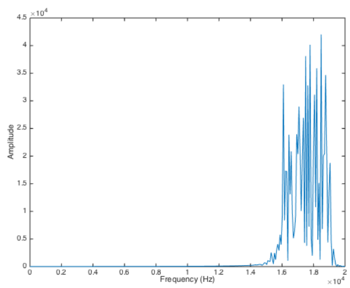

Figure 3: frequency spectrum plot ranges from 16 kHz to 19 kHz

2) Peak detection

When it is sure that the received signal is correct we can start by determining the *flow-volume loop*, by analyzing the peak interval the correct rotation speed can be determined.

Because the hardware is designed to send out a higher frequency for an increase in the rotation speed of the Spirometer's turbine, the peaks of the signal will be closer together. As a consequence of this, the distance between the peaks for lower rotation speed will be larger.

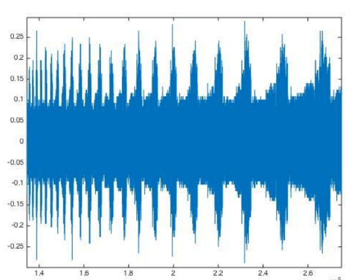

Figure 4: raw data received from the hardware

When a person exhales into the Spirometer the frequency will descend in function of time. A measurement that is done in this case can be seen in Figure 4.

3) Band pass filter

When transmitting data through ultrasound, the sound wave will interfere with surrounding noise from the environment. To eliminate this a band pass filter is used in the interval of [16000 19000] Hz. By applying this filter to the signal the noise will be removed and only the data transmitted by the hardware device will come through.

4) Moving average filter

After determining the average value of series of peaks we need to filter out the random noise, this can be done by using a moving average filter, where $2n + 1$ is a representation for the length of the filter.

$$y'_i = \frac{1}{2n+1} \sum_{j=-n}^{n} y_{i+j}$$

In Figure 5 the signal is plotted of the average peak interval after using a moving average filter.

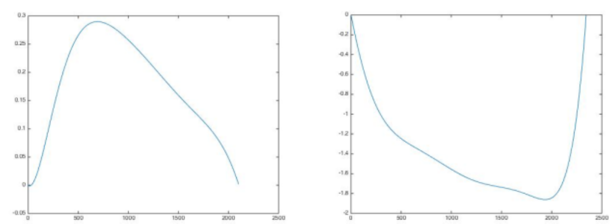

Figure 5: time differences plot from the exhale and inhale phase

By recalculating these values, based on a calibration of the FlowMir, the correct values of the rotation speed of the Spirometer can be determined.

When plotting these results into a graph, the following result is shown in Figure 6.

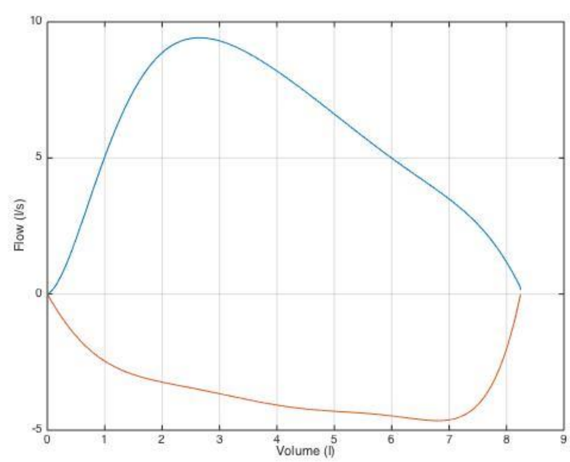

Figure 6: volume-flow plot measured by our device

Results

A small demo module was made out of MDF to test the idea. While measuring the airflow, the unit emits an FM signal between 16-19 kHz. This signal is picked up by a smartphone running the application that processes the data stream. The data is then transformed into understandable information to display to the user.

Figure 7: mobile device

To compare the results, a standard flow-volume graph was used[7]. The signal measurement starts in the zero-position and rises to the Peak Expiratory Flow (PEF). The line then descends till all the air is exhaled, constructing a straight or convex line ending in the Forced Vital Capacity (FVC). Forced expiratory flow (FEF) gives an indication of the exhaled amount of FVC. This proved the constructed figure had a normal flow to volume pathology.

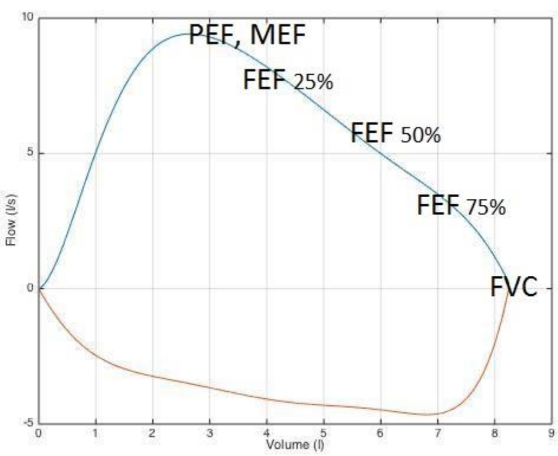

Figure 8: volume-flow plot with critical points

Conclusions and Discussion

A smart-phone enabled mobile spirometer gives COPD-patients the means to self-monitor their condition. This already became obvious in the early stages of the project. By using easily obtainable electronic components combined with the existing FlowMir disposable turbine, it proved easy to produce a portable product.

The goal of this project is to provide medical experts with a continuous and in depth source of information about each individual patient. This could not be possible without a portable solution. By providing a means to gather a larger amount of measurements of the attack themselves, it will be easier for medical staff to make a correct diagnosis and to treat accordingly.

This research proves it's possible to use a smartphone as a means to receive and process data from mobile medical devices giving companies an easily accessible platform to connect their products to. This may lead to a wide range of mobile spirometers.

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References

[1] http://www.gsk.be/luchtwegaandoeningen.html

[2] http://www.gezondheidsplein.nl/aandoeningen/copd/

[3] http://sante.lefigaro.fr/sante/maladie/broncho-pneumopathie-chronique-obstructive/quest-ce-que-cest

[4] American Lung Association. (2014) Chronic obstructive pulmonary disease (COPD) fact sheet. [Online]. Available: http://www.lung.org/lung-disease/copd/resources/facts-figures/COPD-Fact-Sheet.html

[5] The New York Times. (2014, October) The soaring cost of a simple breath. [Online]. Available: http://www.nytimes.com/2013/10/13/us/the-soaring-cost-of-a-simple-breath.html?pagewanted=all& r=0

[6] http://www.spirometrie.fr

[7] Adelaide Hospital. (1991, May) Flow Volume Loops in Patients With Goiters. [Online]. Available: http://www.researchgate.net/profile/Matthew_Kiernan/publication/21423441_Flow_volume_loops_in_patients_with_goiters/links/02e7e520ea67074cba000000.pdf