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MobSpiro: Mobile Based Spirometry for Detecting COPD

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Abstract - Chronic respiratory diseases are diseases of the airways and other structures of the lung, usually resulting in difficulty in breathing and other symptoms. Chronic obstructive pulmonary disease (COPD) is considered to be one of the most common of respiratory diseases. Nowadays, spirometry remains the golden standard for diagnosing and staging COPD. By taking into consideration the possibility of this disease worsening over time and its negative impact on patient's life, sufferers should conduct regular spirometry checks at medical centers or buy expensive and portable devices to monitor and manage the disease. Therefore, COPD spirometry is costly in terms of both, money and time. In this work and due to the pervasiveness and advancement of smartphones, we attempt to make use of their built-in sensors and ever increasing computational capabilities to provide patients with a mobile based spirometer capable of diagnosing and managing COPD in a reliable and cost effective manner. We develop a model that allows the computation of the two critical parameters FVC and FEV1 by establishing a relationship between the frequency response of human exhalation recorded by mobile microphone and the actual flow rate. These two parameters are critical in diagnosing COPD. Preliminary results show that the mean percent error between FVC, FEV1, and FEV1/FVC ratio data as computed using MobSpiro application and the clinical spirometer is 4.6%, 3.1%, and 3.5% respectively. These results prove the effectiveness of the proposed system when compared to the clinical spirometer, and confirm that smartphones can play an important role in healthcare in the coming future.

I. INTRODUCTION

Lung diseases fall under two categories obstructive and restrictive diseases. Obstructive lung disease conditions make it hard to exhale all the air in the lungs due to the damage in the lungs or narrowing of the airways inside the lungs. Different factors could lead to lung diseases such as smoking, genetics and infections, which are considered the leading causes of lung diseases [1]. Among the most common lung diseases, COPD and Asthma are in the front with COPD as the third leading cause of death in the world [2], and some 235 million people suffer from asthma worldwide; which is considered also the most common non communicable disease among children [3].

Chronic obstructive pulmonary disease (COPD) is a progressive disease that makes breathing hard due to chronically poor airflow. Different factors lead to COPD with smoking in the lead. A COPD patient can suffer from one or more of the common symptoms like dyspnea, chronic cough, sputum production, wheezing and chest tightness. COPD is defined as a disorder characterized by abnormal tests of expiratory flow that don't change markedly over periods of several months' observation [4]. In order to diagnose COPD, patients should first notice symptoms and then conduct some tests to confirm the diagnosis of the disease. One of the most common pulmonary function tests is spirometry, which is used to measure lung functions especially the amount and speed of inhaled and exhaled air. In case of respiratory progressive diseases similar to COPD, patients should notice the progress and changes in the symptoms, and undergo regular checkups by performing the spirometry tests in order to catch the disease earlier and avoid exacerbations. Unfortunately these tests require physical visits to medical premises, and hence time and money.

Spirometry test is performed using a device called spirometer. During the test, the patient blows as hard as possible into a tube connected to a device. The device will measure how much air a patient breathes out and how fast he can blow air out. Most spirometers measure two parameters: (1) *Forced vital capacity* (FVC) which is the volume of air that can be expired after a maximum inspiration (2) *Forced expiratory volume in one second* (FEV1) which is the volume of air expelled in the first second of a forced expiration.

An alternative solution to the traditional clinical tests could be achieved by adopting an *mHealth* (mobile health) approach to diagnose and manage respiratory diseases. The work presented here focuses on the design and implementation of an Android-based application that assists in the diagnosis and management of COPD. The primary objective is to make use of the pervasiveness of smartphones and introduce clinic-equivalent tests at home or in rural areas where access to clinics is limited.

The rest of the paper is organized as follow: Section 2 discusses related work. An overview of the proposed approach is presented in Section 3. Section 4 presents and discusses the experimental work. Results are presented and discussed in Section 5. The paper is concluded in Section 6.

II. RELATED WORK

Several research attempts have been conducted to try and benefit from computers and smartphones in diagnosing and monitoring respiratory diseases. Researchers have used

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smartphones with health sensors to monitor and manage respiratory diseases at home [5-10]. Others tried to mimic spirometer by using an external microphone connected to a computer or mobile as Abushakra and Faezipour reported in their work [11]. They proposed a methodology of splitting the breathing acoustic signal captured using a microphone by applying voice activity detection (VAD) techniques and then computing the average time duration and energy of the breathing cycle. They used equations for both genders to estimate the lung capacity (FVC). The overall accuracy of their lung estimation methodology on the tested subjects was approximately 86.42%. However, they didn't use the built-in microphone in smartphone, but their results motivated other researchers to use the built-in microphone for lung capacity estimation. Other reported attempts tried to use the built in microphone in smartphone. Larson et al. [12] developed an iPhone mobile application that performs spirometry sensing using the smartphone's built-in microphone. The processing of the recorded signal is carried out on the cloud with FVC, FEV1 and PEF lung measurements eventually being reported to the user. They evaluated their app and the mean error when compared to a clinical spirometer was about 5.1% for common measures of lung functions.

Xu et al. [13] designed and developed an Android mobile phone application for lung function diagnosis called mCOPD. The app is designed to diagnose COPD disease. It uses the built in microphone to record subjects' exhalation, the processing on the resulted signal is done on mobile and the app provides users with FVC and FEV1 lung measurements. They evaluated mCOPD in controlled and uncontrolled environments with random subjects. The average deviation of the data FEV1/FVC when compared to the clinical spirometer was approximately 3.9%.

Stein [14] designed a smartphone app that uses the built in microphone and sound analysis algorithms to test lung functions and reports FEV1 and FEF25-75% lung measurements. The app is designed to work with a distance between the mouth and arm set manually to 30 centimeters. Unfortunately, the app was tested on two patients only; however, it showed promising results.

III. PROPOSED APPROACH

The proposed system utilizes the built in MEMS sensors in an Android-based smartphone to perform spirometry, diagnose if a patient suffers from COPD, and assess the severity of the disease. In spirometry, patient's exhalation is analyzed to extract lung measurements FVC and FEV1. According to the structure of the MEMS microphone, the built in MEMS microphone in the smartphone is capable of sensing direct airflow of human exhalation [13,15]. In order to calculate lung parameters FVC and FEV1, we need the volumetric flow rates of the exhalation. Practically, we cannot directly extract the air flow from the recorded exhalation signal. However, we can extract time and frequency responses of the audio signal using mathematical processing techniques. Accordingly, we developed a model to find the relation between the response of a human exhalation recorded by mobile microphone and the actual flow rate. We next designed an application that records the patient's exhalation and makes use of the model to analyze the signal, extracts the lung measurements FVC and FEV1, diagnoses the patient, and assesses the severity of the disease.

IV. EXPERIMENTAL WORK

The experimental set up used to derive the model is shown in Figure 1. We used a DYSON AM06 fan, which is a bladeless fan to provide a speed-stable airflow source. The fan allows adjusting the airflow speed and has an acceptable noise level. The AM-4201 anemometer is used to measure the actual flow rate, and a GALAXY S5 mobile to record the airflow. Initially, we tested the best orientation of smartphone to efficiently capture or sense the airflow, and found that microphone recording is clearer when the mobile's face is opposite to the source of airflow. Moreover, and as shown in Figure 1, we sound proofed the DYSON AM06 fan's lower part in order to reduce noise at higher fan levels. We next placed the GALAXY S5 mobile beside the anemometer fan 5 cm away from the DYSON AM06, with DYSON AM06 on a separate background to reduce the effect of DYSON AM06 noise on recordings.

In order to ensure the accuracy of the model, we recorded 34 *wav* files at different fan speed levels and by repeating the experiment at different day times morning, noon, afternoon, and evening since the environment nature such as air temperature and speed affect the flow rate of DYSOM AM06 fan air. While recording each wav file, we simultaneously recorded the corresponding flow rate value using the anemometer.

Figure 1. Experimental Setup.

Using the MATLAB environment, we next analyzed the recorded files in the frequency domain, and found that the relation between the mean of frequency responses was in the range of 100 HZ to1200 HZ and the flow rate has the highest correlation factor of 0.8913 among other possible relations. We performed regression analysis on the collected data and chose the quadratic regression technique which resulted in the lowest Root Mean Square (RMSE) among other possible regressions. The relation between frequency response (X) and the flow rate m/s (Y) is shown in Figure 2 and expressed using the following equation:

$$Y = -0.000229 \times X^2 + 0.0442 \times X + 1.002 \qquad (1)$$

Where Y is the flow rate (meter/second) and X is the mean of frequency responses in the range [100-1200] HZ.

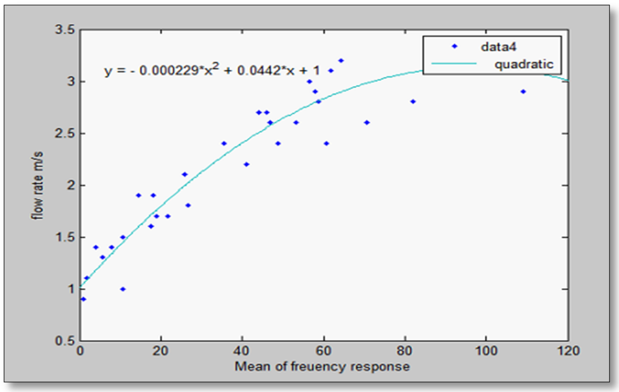


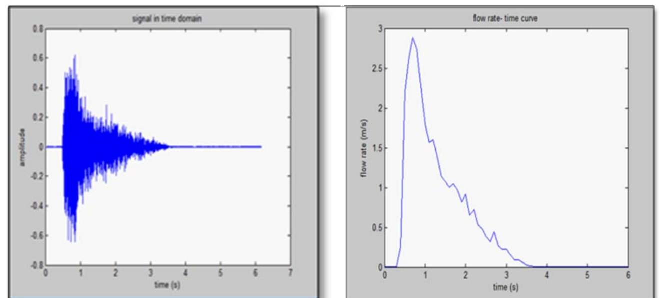
Figure 2. Quadratic Regression.

Based on the MATLAB analysis and computation, we next developed a corresponding Android application, known as MobSpiro, in JAVA using Eclipse IDE with the Android Development Tools (ADT) plugin.

In using the MobSpiro app, patients are required to undergo a Pretest Activity to estimate the probability of the disease. In the Pretest Activity, the patient answers few questions related to the disease symptoms and patient's lifestyle. The proximity sensor is used by the app to optimize the distance between the patient and the microphone. It then records the patient's strong exhalation three times. The recordings are saved in a wav format with size around 3 Mega Bytes on an SD card. The following algorithm is applied to analyze each saved wav file:

- Segment the file into 100 millisecond segments, so that the airflow of human exhalation is approximately stable within this interval.
- Convert each segment into frequency domain using Fast Fourier Transformation.
- Apply Butterworth filter on each segment to extract frequencies between 100 HZ and 1200 HZ.
- Calculate the mean of frequency responses between 100 HZ and 1200 HZ for each segment.
- Calculate the flow rate of each segment using equation (1).
- Convert flow rates into volumetric flow rate by multiplying it with cross sectional area that represents human mouth, and then convert unit into Liter/second.
- Integrate flow rate over the first second to obtain FEV1, and over the whole period of exhalation to compute FVC.

Figure 3 shows an example of a recorded exhalation and the resulting flow rate curve produced by the application. The app chooses the highest resulted FVC and FEV1 values among the three trials. Then, it calculates the ratio FEV1/FVC and FEV1%, which is the resulted FEV1% divided by the average FEV% in the population for any person of similar sex, age, and body composition. The final diagnosis is based on FEV1/FVC ratio and the Pretest probability. The classification of disease is based on FEV1% in case of COPD. The diagnosis and classification is based on golden standards used for diagnosing and classifying COPD.



(a) Recorded exhalation **(b) Flow rate vs Time**

Figure 3. Recorded exhalation (a) and its corresponding flow rate (b).

VI. RESULTS AND DISCUSSION

We tested the MobSpiro application on 25 subjects, 10 of which are patients already diagnosed with COPD or Asthma diseases, 5 are smokers, and 10 are healthy subjects. The results showed that FVC, FEV1 and FEV1/FVC values obtained using the application are close to the values obtained using the clinical spirometer as shown in Figures 4, 5, and 6. The mean percent error between FVC, FEV1, and FEV1/FVC ratio data computed using the application, and that obtained using the clinical spirometer was 4.6%, 3.1%, and 3.5% respectively. The final diagnosis reported by the application depends on the Pretest possibility of the disease and the resulted parameters FVC and FEV1. Healthy and smokers subjects had negative diagnosis of COPD by both MobSpiro app and the clinical spirometer. 96% of patients' samples are correctly diagnosed and staged by MobSpiro app.

By comparing MobSpiro to the previous proposed systems, MobSpiro is considered an independent system that utilizes the built-in sensors and the computational capabilities of smartphone to help COPD patients in the diagnosis and management of their disease. MobSpiro depends on the built-in proximity sensor in the adjustment of the distance between patient and the smartphone. Moreover, it does the processing of the recorded physiological signals locally and indicates the patient condition in near real time.

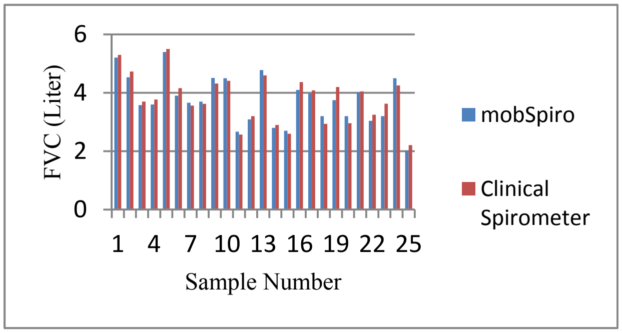


Figure 4. FVC differences between clinical spirometer result and MobSpiro result.

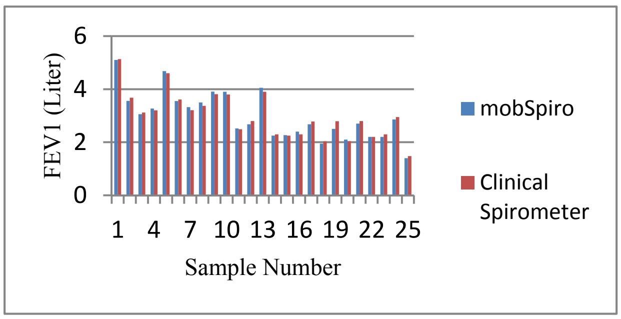


Figure 5. FEV1 differences between clinical spirometer result and MobSpiro result.

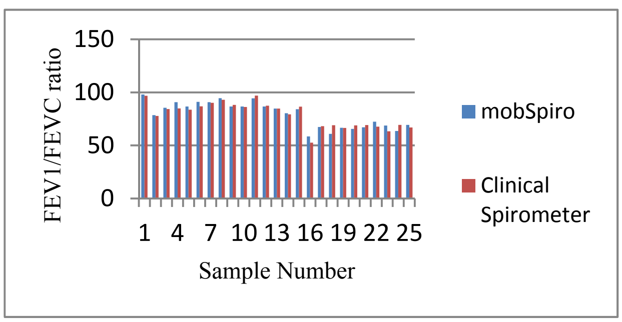


Figure 6. FEV1/FVC ratio differences between clinical spirometer result and MobSpiro result.

Chronic obstructive pulmonary disease (COPD) is a chronic lung disease that makes it hard to breath. The traditional method of diagnosing and classifying the disease is considered costly in terms of time and money, since it requires the regular performance of a popular lung function test called 'Spirometry', using a device called spirometer. Due to the pervasiveness of smartphones and their powerful computational capabilities, we propose a design that takes advantage of the built-in sensors in the smartphone to extract and analyze physiological signals in order to diagnose, stage, and monitor the COPD. Our methodology combines the results of a Pretest probability and the analysis results for the physiological signal to diagnose and classify the disease. We tested the application on 25 subjects. The results showed that all test samples were correctly diagnosed, and the mean percent error between FVC, FEV1, and FEV1/FVC ratio data resulted by our MobSpiro application and the clinical spirometer is 4.6%, 3.1%, and 3.5% respectively. These results emphasize the concept of the proposed system and show the importance of smartphones in healthcare field in the coming future.

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