To appear in IEEE ICEIC 2015

Diagnosing COPD Using Mobile Phones

Haya Hasan, Basel Safieh, Fadi Aloul, Assim Sagahyroon

American University of Sharjah, UAE

***Abstract*—Chronic Obstructive Pulmonary Disease (COPD) is common progressive lung disease that causes difficulty in breathing. The paper presents the design and implementation of a user-friendly mobile phone application developed on an Android platform that examines the lung functionality using the phone's built-in sensors. It allows the user to get a sense of whether they have COPD or not from home before visiting a specialized clinic and performing advanced medical tests. The proposed system will make use of the phone's microphone to record exhalations. By means of advanced signal processing techniques, the application will be able to mimic the medical spirometer and determine certain lung measurements that are used to assess the lungs' well-being and diagnose COPD. Furthermore, the application will allow the users to share test results with doctors who can directly assess the disease progression and give advice accordingly. The application was successfully tested among a number of users. Experimental data show promising results which can enhance the quality of life for COPD patients.**

I. Introduction

Chronic Obstructive Pulmonary Disease (COPD) is one of the most common lung diseases. It causes poor airflow in the lungs which leads to shortness of breath, coughing, wheezing, chest tightness, and sputum production. Although the disease can be manageable if diagnosed early, it is often left undiagnosed which could lead to the destruction of the lungs over time and hence increases the rates of motility and morbidity. A typical case would be reported only after losing 50% to 60% of normal lung functionality. Furthermore, unlike Asthma, the lung functionality in a COPD patient doesn't improve significantly with medication.

According to the World Health Organization [1], COPD was the 3rd leading cause of death worldwide affecting 329 million people or 5% of the world's population. More than 3 million people were killed in 2012 because of COPD, which suggests that one person was killed every 10 seconds by the disease.

Tobacco smoking is considered one of the main causes of COPD. Other causes include air pollution, inhalation of chemicals and dust as well as second hand smoke and genetics.

Patients with COPD suffer on a daily basis when performing routine activities. They cannot withstand simple physical activities such as going up the stairs or having a walk. A COPD patient would feel exactly as a person doing aerobics when doing simple life activities.

COPD is typically diagnosed by measuring the amount of air flow in the lungs using a traditional spirometer that is available in medical clinics. Affordable portable home spirometers are available today, but are limited in terms of measurement options, processing power and memory. Furthermore, they don't provide feedback from specialized doctors.

Recently, the utilization of hand held devices such as mobile phones in health-related applications have been on the rise. The rich features that today's mobile phones are equipped with provide industry and researchers with a valuable opportunity to continue improving human life by developing applications that address a wide spectrum of issues.

This paper presents the design and implementation of a mobile phone application that utilizes its built-in microphone to record the user's exhalation. The recording is then analysed on the phone using advanced algorithms to assess the lung's functionality and the possibility that a user might be suffering from COPD. The application is free as it doesn't require anything but the mobile phone and its built-in sensors. The application allows for the data to be shared with specialized doctors for feedback and advice.

The rest of the paper is organized as follows. Section II provides a background of COPD and discusses related work. Section III describes the proposed system hardware and software architecture. The testing and implementation results are reported in Section IV. Finally, the conclusion is presented in Section V.

II. Background & Related Work

Lung diseases are divided into two main parts: *obstructive* and *restrictive* pulmonary diseases. Both types of diseases make the patient suffer from shortness of breath specifically referred as Dyspnoea in medical terms. Dyspnoea is a medical condition which is considered as a common symptom between obstructive and restrictive lung diseases which varies in intensity based on the severity of the disease. Diseases that are considered under the obstructive category include COPD, Asthma, Cystic Fibrosis and Bronchiectasis. Obstructive diseases make exhalation of air difficult and slow. The air is exhaled slowly which may result in a large amount of air lingering in the lungs even after a full exhalation. However, restrictive diseases are related to causes that make the lungs stiff or hard. Therefore, the lungs cannot expand fully. This might be caused by obesity or Muscular Dystrophy.

Most people with COPD have a combination of chronic bronchitis and/or emphysema. *Chronic bronchitis* is a condition which causes the obstruction and inflammation of the air pipes and passages. This makes them narrower and unable to carry the regular amount of air to and from the lungs. Furthermore, it also leads to an increase in mucus production and coughing. On the other hand, *emphysema* is another condition which leads to the walls between the air sacks in the lungs known medically as alveoli to break down and get damaged. As a result, there is less space for air exchange and the oxygen intake becomes less which leaves the user in state of dyspnoea.

A user suffering from COPD needs to continuously monitor the progression of the disease to avoid the worsening of the symptoms and permanently damaging the lungs. COPD symptoms typically consists of the following: (1) Chronic Cough with a wheezing sound, (2) dyspnoea which progresses and becomes persistent, and (3) heavy mucus production and cough with sputum.

COPD is typically diagnosed using spirometry which consists of measuring the volume of air exhaled after a maximum inhalation. The procedure is also used for diagnosing other pulmonary diseases such as Asthma. A patient performing spirometry is supposed to inhale the most amount of air they can and then forcefully exhale into a pipe or tube. The spirometry test is usually performed using a mouth piece that a person uses when exhaling and a nose clip. The nose clip is used to make sure that all the air is exhaled through the mouth. Furthermore, patients are usually given verbal instructions to exhale hard and as much as possible during the test. The test records two values: (1) FVC – *Forced Vital Capacity* which represents the total volume of air exhaled in one breath and (2) FEV1 – *Forced Expiratory Volume in One Second* which represents the volume of air exhaled in one second. A healthy user typically exhales 75-80% of the FVC in the first breath and has a FEV1/FVC ratio higher than 70% [2, 3]. According to the National Institute of Clinical Excellence, a COPD user would have an FEV1 value less than 80%

of the predicted value [4]. The *predicted* value is typically computed based on the age, sex, height, weight, and ethnic group of the user. Table 1 below shows the different lung measurements expected in order to diagnose COPD and its severity based on the GOLD standards [5].

TABLE I. GOLD Guidelines for Diagnosing COPD. The FEV1/FVC result is assumed to be below 70% in all cases below.

COPD Severity	**FEV1 Results**
Mild	FEV1 >= 80% predicted
Moderate	50% <= FEV1 < 80% predicted
Severe	30% <= FEV1 < 50% predicted
Very Severe	FEV1 < 30% predicted

Several studies have been conducted that experiment with the use of computers and mobile phones to diagnose COPD. Abushakra and Faezipour experimented with 20 users to inhale and exhale forcefully into a microphone connected to a computer [6]. Based on the energy of the signal, the volume of the lung (FVC) was calculated. The analysis was performed using Voice Activity Detection (VAD) which was done using MATLAB. The procedure was tested on 20 users at the same location to provide uniformity. Their procedure yielded an overall accuracy of 86.42% when compared to the clinical spirometer results.

Xu et al. [7] designed and developed a mobile phone application to diagnose COPD. The application, referred to as *mCOPD,* requires the user to blow into the phone's microphone and does the analysis on the phone. The procedure was tested on 40 users and yielded results that were within 3.9% - 6.5% from the clinical spirometer results.

Larson et al. [8] developed an iPhone mobile application, known as *SpiroSmart*. Unlike *mCOPD*, the application sends the recorded exhalation into an external server for analysis. The procedure was tested on 52 users and showed a mean error of 5.1% when compared to clinical spirometers.

Stein [9] proposed another Android mobile application to detect COPD. The phone is placed at a distance of 30 cm from the user and does the calculations on the phone. The application was tested on two patients and showed relatively good results. However, further testing is needed to confirm the effectiveness of the application.

III. System Architecture

The proposed solution consists of the development of an Android mobile phone application that uses voice recording software and the phone's built-in *microphone* to record the users' breathing patterns. One of the contributions of the proposed solution is the use of the *proximity sensor* in the phone to identify how close the phone should be placed to the user's face during the exhalation. The distance between the phone and the user varied from one user to another, and even among multiple trials for the same user, when performing the test in previous research implementations. Consequently, by utilizing the proximity sensor, the distance is fixed among all tests performed using the application which improves the accuracy and consistency of the system. A proximity sensor, unlike other sensors, is an interrupt based sensor, which gives only two values; 1 or 0. It responds to a change that is more than 5 cm away from the user's face. So if the mobile phone is placed at a distance less than or equal to 5 cm from the user's face, no readings will be taken. As the phone moves away from the user's face for more than 5 cm, the sensor gets triggered to indicate to the user to hold the phone at that distance from the face and start the exhaling process. Unlike previous approaches, no rulers or measurement items are needed to measure the distance between the phone and the user's face.

As shown in Figure 1, after the exhalation is recorded locally on the phone, it is analysed and the COPD diagnosis is assessed. The data is also securely sent to a remote server using Wi-Fi or 3G connection and stored in the server's database. The database is accessed via a web server by doctors, with privileged access to the users' records, to provide medical feedback and advice.

The Android mobile application is developed in JAVA using Eclipse IDE with the Android Development Tools (ADT) plugin. The phone used an SQLite database as a local database to store the records of the user. The local database allows the users to see their results offline. A website is implemented which allows both patients and doctors to access their records. The website has an authentication system and a database that stores the records posted by the users and doctors.

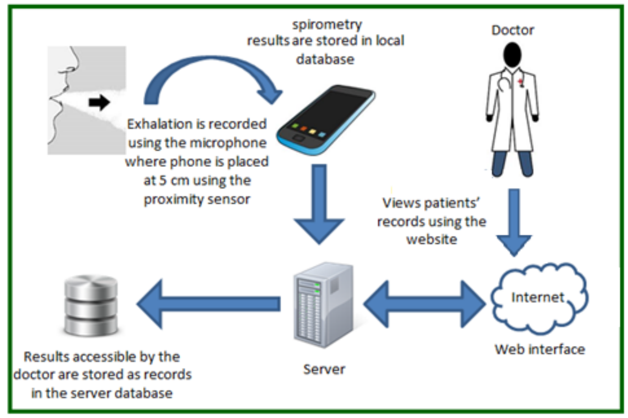

Figure 1. COPD Diagnosis System Overview.

In order to diagnose COPD from the user's exhalations, the loudest frequencies need to be computed. This is because the air blown to the microphone produces the loudest frequency. To assess the correctness of the mobile phone application, the spirometry algorithm was (1) written using MATLAB and tested on a computer and (2) written using JAVA and tested on a Samsung SIII mobile phone. The results from the computer and phone were compared for correctness. The algorithm performs as follows: the exhalations are recorded at a sampling rate of 44.1 kHz using the built in microphone of the phone and then analysed by dividing the signal into windows of size 0.1 seconds with a 50% overlap. Discrete Fourier Transform (DFT) is performed on each window to find the power density spectrum. The peak magnitude of each window is plotted which represents the flow of air exhaled in L/s. The recorded signal typically produces the shape as shown in Figure 2(a). The results of the air flow obtained are shown in Figure 2(b).

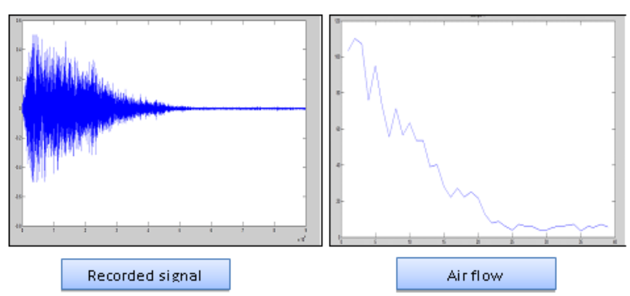

Figure 2. (a) Recorded signal of the exhalation and (b) its corresponding air flow result.

A clinical spirometer is used to obtain a typical breathing signal of a user. The clinical spirometer plays a major role in evaluating the accuracy of the mobile phone's spirometry algorithm. The signal in Figure 3 is obtained after the person is instructed to breath in and out normally and then forcefully inhale and exhale followed by breathing normally again. The Y-axis is the air volume and the X-axis is N (array indices). The positive Y-axis values represent inhaling, therefore, the lungs has air in it, whereas the negative values represent the exhalation, therefore, it is negative.

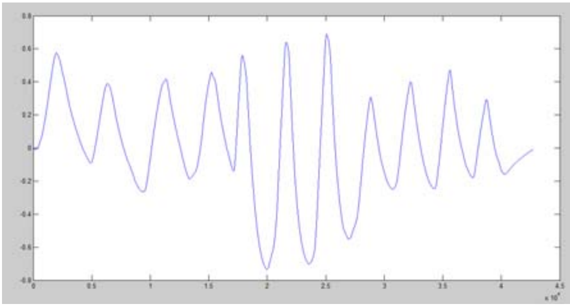

Figure 3. Sample spirometry signal.

Since the mobile application is only concerned with the forceful exhalation, the signal that is imported will consist of the forceful breath only. The signal will then be inverted and all the exhalations will be extracted. The inversion of the signal is necessary in order to make the exhalations as positive values rather than negative values which ease the analysis process. The exhalations are extracted by finding the peaks and troughs of the inverted original breath signal. Each exhalation will be from one trough to the next peak and so on. The ratio of FEV1/FVC is then calculated for each exhalation by finding the volume of air exhaled at one second to the total volume exhaled.

IV. System Testing And Implementation Results

Several experiments were conducted to evaluate the proposed application. The first experiment evaluated the *precision* of the application, since precision plays an important role in the spirometry test. Therefore, it was decided to know how close the values are from each other in the same controlled environment. In order to perform the test, two users, a male and a female, took the test in a quiet room individually. Each user performed the spirometry test 100 times. The standard deviation was computed for each volunteer's results. The standard deviation results for the female and male users were 0.0462 and 0.0301, respectively.

The second experiment evaluated the *accuracy* of the application. This was achieved by comparing the mobile phone application results with the clinical spirometer results. 27 users took the accuracy test on both the clinical spirometer and the phone application. The users were required to take the test at least three times on each device. They were also encouraged to try to take the test as much as they possibly can. The users were instructed on how to use the clinical spirometer and mobile application. All users had to use the mouthpiece and the nose clip when doing the test. The test required the users to start by breathing normally for three times and then forcefully. Since the users could possibly feel dizzy after the test, they were instructed to inform the person supervising the test of any mishaps and to stay seated till feeling normal again.

After the user has completed the test on the clinical spirometer device, the testing on the mobile phone takes place. Since the users provided various number of samples, the highest three samples from both the clinical spirometer and the mobile phone were chosen for analysis. The mean of the highest three FEV1/FVC ratios from the exhalations were computed for the clinical spirometer and the mobile phone. The percentage difference between both readings was calculated for each user. The mean difference was found out to be 5.56% among all samples.

The third experiment evaluated the *correctness* of the approach and if the clinical spirometer and mobile phone application were diagnosing the COPD patients correctly. In order to evaluate that, several samples representing healthy users were tested. The ratio of FVC/FEV1 was computed for each sample. Out of the 134 healthy samples, the mobile phone application identified 18.66% samples as possible COPD patients. While for the clinical spirometer, out of 271 healthy samples, 16.97% samples were identified as possible COPD patients.

False positive diagnosis is expected in both the smartphone application as well as the clinical spirometer device if the test is not performed correctly. Both tests require training first before taking the readings. The user is usually instructed verbally on how to perform the test. However, it was noticed that users needed to at least try the spirometry test on the application twice to perform the test correctly. It was also observed that if the test was first practised in front of the user, there is a better chance that the user will perform the test correctly. Finally, exhaling into a phone microphone is safer as opposed to blowing into a clinical spirometer tube due to hygiene reasons.

Finally, a user suffering from asthma was also used to test the system. The user provided 31 samples using the mobile phone, out of which 90.32% indicated that the user suffers from COPD. The user also provided 29 samples using the clinical spirometer, out of which 69.23% indicated that the user suffers from COPD.

V. Conclusion

A new efficient, user-friendly approach for diagnosing COPD using mobile phones is proposed. The approach takes advantage of the built-in microphone and proximity sensor in correctly recording the user's exhalation. The processing is done on the phone and doesn't require external servers. The data is also securely shared with an external server to be checked by specialized doctors. The spirometry results on the phone are compared to the clinical spirometer results. The results suggest that about 95% of the time the results of the phone matched the clinical spirometer results. The developed application is not intended to replace clinical spirometers, but can replace portable home spirometers. The application is expected to enhance the lives of COPD patients and to help diagnose patients at an earlier stage.

References

[1] "The 10 leading causes of death in the world, 2000 and 2011," *World Health Organization*, July 2013.

[2] A. Qaseem, T. Wilt, S. Weinberger, N. Hanania, G. Criner, T. van der Molen, D. Marciniuk, T. Denberg, H. Schünemann, W. Wedzicha, R. MacDonald, and P. Shekelle, "Diagnosis and management of stable chronic obstructive pulmonary disease: a clinical practice guideline update from the American College of Physicians, American College of Chest Physicians, American Thoracic Society, and European Respiratory Society," in *Annals of Internal Medicine*, 155 (3), 179–91, August 2011.

[3] V. Young, "Blueprints Medicine", 5th ed. Philadelphia: Wolters Kluwer Health/Lippincott William & Wilkins. 69, 2010.

[4] "Clinical guideline 101: Chronic Obstructive Pulmonary Disease," *National Institute for Health and Clinical Excellence*, London, June 2010.

[5] J. Vestbo, "Diagnosis and Assessment in Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Pulmonary Disease" in *Global Initiative for Chronic Obstructive Lung Disease*, 9–17, 2013.

[6] A. Abushakra and M. Faezipour, "Lung capacity estimation through acoustic signal of breath," in Proc. of the *IEEE Int'l Conference on Bioinformatics & Bioengineering* (BIBE), 386-391, 2012.

[7] W. Xu, M. Huang, J. Liu, F. Ren, X. Shen, X. Liu, and M. Sarrafzadeh, "mCOPD: mobile phone based lung function diagnosis and exercise system for COPD," in Proc. of the *Int'l Conference on Pervasive Technologies Related to Assistive Environments* (PETRA), no. 45, 2013.

[8] E. Larson, M. Goel, G. Boriello, S. Heltshe, M. Rosenfeld, and S. Patel, "SpiroSmart: using a microphone to measure lung function on a mobile phone," in Proc. of the *ACM Conference on Ubiquitous Computing*, 280-289, 2012.

[9] B. Stein, "A Mobile Smart Care Platform Home spirometry by using the smart phone microphone," *Master's Thesis*, Leiden Institute of Advanced Computer Science, Leiden University, The Netherlands, August 2013.