A REVIEW AND COMPARATIVE ANALYSIS OF TECHNIQUES FOR DIAGNOSIS OF PULMONARY DISEASES

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Abstract: According to the statistics of world health organization (WHO) lung diseases are one of the major causes of deaths worldwide. To control these casualties due to pulmonary diseases, the preliminary diagnosis should be more effective and accurate. The common monitoring and diagnostic techniques for the pulmonary diseases are lung auscultation, spirometry, roentgenography and bronchoscopy. In this paper these techniques are discussed with their brief principle of operation indicating their advantages and limitations. Significant studies and research work for these techniques have been briefly reviewed so that they can be compared. Various papers and articles from national and international journals, conferences, books, and websites were used as the resource for this paper. A comparative analysis has been carried out based on this study to find out simple yet accurate diagnosis technique for pulmonary disease which will also be helpful in home and long term monitoring. The possibility of distant monitoring and diagnosis is also investigated. The result of this analysis shows that the lung auscultation technique in phonopulmonography configuration is a better option for the diagnosis of the pulmonary disease. This study will invite and encourage more research in the field of detection and diagnosis of pulmonary diseases.

Keywords: Pulmonary disease, lung auscultation, spirometry, roentgenography, bronchoscopy, phonopulmonography.

1. INTRODUCTION
World Health Organization has begun compiling and presenting the statistics known as ‘Burden of Diseases’ since 1990. From this data, it has been found that the human lung infections, which are responsible for lung diseases (pulmonary diseases), have continuously resulted in more burden than any other diseases [1, 2]. To detect the pulmonary diseases

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various techniques such as lung auscultation [3, 4, 5], spirometry [6], roentgenography [7], bronchoscopy [8] etc., are used. The purpose of this paper is to study the common techniques for the diagnosis of pulmonary diseases, their advantages and the limitations so that a conclusion can be drawn to find out a non-invasive, cost effective, simple to use and automated technique which can also be used for home monitoring, long term and distant monitoring. Therefore the common techniques for the diagnosis of pulmonary diseases with their advantages and the limitations are briefly discussed here. A comparative analysis amongst these techniques has been carried out to find out a suitable technique for the diagnosis of pulmonary diseases.

The paper is organized as follows. Next section gives the brief working principle and review of major research work carried out for the common techniques for the detection and diagnosis of the respiratory system [9] diseases with their advantages and limitations. A comparative analysis based on some vital parameters related to these techniques has been carried out and its result is summarized in section 3. Finally the conclusion from this analysis has been drawn in section 4 to signal out the best possible technique for the detection and diagnosis of the pulmonary diseases.

2. MONITORING AND DIAGNOSTIC TECHNIQUES

The common monitoring and diagnostic techniques for the pulmonary diseases are spirometry, roentgenography, bronchoscopy and lung auscultation. The brief working principle of these techniques has been explained in this section. Further these techniques are reviewed and their advantages and limitations are briefly explained here.

A. Spirometry

Spirometry is a medical screening trial that measures various features of breathing and lung function. It is performed by a spirometer. Spirogram is a tracing or recording of the information obtained from the test. There are two types of spirometers:

1. Volume spirometers that records the amount of air exhaled or inhaled within a certain time and
2. Flow spirometers that measures how fast the air flows in or out as the volume of air inhaled or exhaled increases. A typical example of a spirogram obtained from the spirometry test is shown in Figure. 1.

The general spirometric test requires that the subject exhale fully after taking in a full, deep breath. The subject’s effort is called the forced expiratory maneuver. The parameters recorded in the course of spirometry include forced vital capacity (FVC) and forced expiratory volume in one second (FEV1), from which the FEV1/FVC ratio is derived. These are key measures for diagnostic and treatment decisions. The indices derived from this forced exhaled maneuver have become the most accurate and reliable way of supporting a diagnosis of chronic obstructive pulmonary disease (COPD). When these values are compared with predicted normal values determined on the basis of age [10], height, sex, and ethnicity, a measure of the severity of airway obstruction can be determined [6].
Spirometry procedure using flow spirometers gives the graph between the air flows and the volume of air inhaled or exhaled. Typical graph obtained from spirometry test for normal case and for pathological case as compared to normal case is shown in Figure 2.

Volume spirometers gives the graph between the amount of air exhaled or inhaled and time. Typical graph of volume spirometer for normal case and pathological case as compared to normal case is shown in Figure 3. Normal case is shown by dotted graph whereas abnormal case is shown by continues graph.
Figure 3: (a) Volume/Time Graph for Normal Case. (b) Volume/Time Graphs for Pathological Case (6).

Bellows or rolling seal spirometers are large and not very portable, and are used predominantly in lung function laboratories. Electronic desktop spirometers are compact, portable, and usually quick and easy to use. They have a real-time visual display and paper or computer printout. Small, inexpensive hand-held spirometers provide a numerical record of blows but no printout. It may be necessary to look up predicted values in tables, but some include these in their built-in software. Table 1 explains different stages of COPD and typical spirometric data associated with these stages.

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<th>TABLE 1</th>
<th>Typical Spirometric Criteria for COPD Severity [11]</th>
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| Mild COPD | • FEV1/FVC < 0.7  
• FEV1 ≥ 80% predicted | At this juncture, the patient may not be knowing that their lung function is abnormal. |
| Moderate COPD | • FEV1/FVC < 0.7  
• 50% ≤ FEV1 < 80% predicted | Indications usually develop at this stage, with shortness of breath typically on exertion. |
| Severe COPD | • FEV1/FVC < 0.7  
• 30% ≤ FEV1 < 50% predicted | Shortness of breath worsens at this stage and often restricts patient’s day to day activities. |
| Very severe COPD | • FEV1/FVC < 0.7  
• FEV1 < 30% predicted or FEV1 < 50% predicted plus chronic respiratory failure | At this stage, quality of life is appreciably impaired and exacerbations may be life threatening. |

Lot of efforts has been taken for improvement of spirometer and research work is going on over spirometry. Some significant works has been discussed here. Steltner H. et al, (2000), have suggested the use of multi-exponential models for describing the exhaled volume as a function of time in spirometry particularly for the patients with respiratory complaints and facing difficulties in completing the forced expiration maneuver [12]. P.L.
Enright et al., (2005), have observed that the office spirometry in primary care setting has the utility in the detection and supervision of asthma and chronic obstructive pulmonary disease (COPD). They also observed that the ratio FVC1/VC × 100% changes with age [13]. Kalicka, R. et al, (2007), have developed a new model of spirometry based on spirometry measurements to distinguish between healthy and diseased subjects [14]. In their paper, Carta R. et al, (2007), presented the design, implementation and measurements of a spirometer based on differential pressure sensing using the Venturi tube principle with data acquisition software and user interface [15]. Lay-Ekuakille A. et al, (2008), have developed a complete spirometric instrumentation to produce spirometric parameters of a probable pathologic curve and to predict pathology using a genetic algorithm [16]. Alejos-Palomares R. et al., (2008), have designed and developed a low cost, portable, easy to handle and computerized digital spirometer as a basic tool for evaluation of the respiratory capacity and to display the volume-time and flow-volume graphs [17]. In their work, Jafari S. et al, (2010) have designed a system for detecting normal and abnormal pulmonary system functions using spirometry data and multilayer perceptron neural networks [18]. D Cramer et al., (1984), has concluded that the body temperature pressure saturation (BTPS) conversion is valid and necessary for measurements made in routine spirometry [19]. Finkelstein, S.M. et al., (1993), used a paperless electronic spirometer system in a home monitoring program with distant monitoring facility for subjects who have undergone lung transplantation to compare the reliability of forced vital capacity (FVC) maneuvers recorded at home with similar measures recorded in the clinic pulmonary function laboratory and found that home spirometry can provide quality data for a home monitoring program after lung transplantation [20]. Finkelstein, S.M. et al, (1997) have suggested that home monitoring with the help of a paperless, electronic spirometer can provide early and consistent indication of pulmonary decline prior to chronic rejection in the patients with transplanted lungs, and should be considered as a future component of post-transplant follow-up care [21]. Jannett T.C. et al, (2002) have suggested an intelligent telemedicine system for remote monitoring of lung function using a home spirometer. In this system parameters useful in assessing lung function were transmitted over a telephone line to a database residing on an institutional computer system [22].

**Advantages of Spirometry**

Pulmonary function tests can be performed most accurately by the spirometry. Following are the advantages of spirometry test.

- It is a safe diagnostic technique for pulmonary disease.
- Spirometry is a non-invasive technique except a mouth piece for blowing air.
- Electronic desktop spirometers and hand-held spirometers are compact, portable and easy to handle.
- Home and distant monitoring and diagnosis are possible by spirometry.
- It is a very good confirmation test for chronic obstructive pulmonary disease after its initial diagnosis.
Limitations of Spirometry

Although spirometry can provide useful diagnostic and screening information for the diagnosis of pulmonary diseases, it has a few limitations which are listed here.

- Initial setup is required to conduct spirometry.
- The spirometry setup has nasal clip to airtight the nasal path of air and a mouthpiece to blow air. Hence the procedure of spirometry test is neither comfortable nor convenient for the patient.
- Long term monitoring is not possible with spirometer.
- Spirometry requires a clinical environment or the supervision of the experienced physician for interpreting the results.
- Spirometry cannot be the sole screening tool of a respiratory disease.
- Spirometry test results can show restrictive or obstructive disease patterns, but they are not disease-specific. For example, a person’s spirogram may show a low FEV$_1$, but a physician may not be able to determine whether the cause is from asthma, emphysema, or some other obstructive disease. Additional information, such as a physical examination, chest x-rays, and health and occupational histories, are needed to make a diagnosis.
- Spirometry often can detect obstructive diseases in their early stages, but for some of the restrictive diseases, it may not be sensitive enough to show abnormalities before extensive, and in some cases, irreversible damage has been done. For example, signs of silicosis and coal worker’s pneumoconiosis may be found on chest x-rays while spirometry results are still normal.
- The skill of the operator which results in human error factor plays an important role in spirometry and is an important limitation of it.
- The measurement of inhaled and exhaled air should be accurate during sprometry for correct diagnosis. Paul L Enright, (2003), has explained some factors responsible for error and guidelines to minimize them [23].
- Air leak from mouth while blowing during spirometry introduces an error in the measurement.
- In case of children, elders where the occurrence of Chronic obstructive pulmonary disease (COPD) in subjects aged over 65 years is 6–15% in women and 7–34% in men, and the occurrence of asthma is 7% and 3% respectively [24] and in case of mentally challenged people, this test can be difficult to perform. In a study by Licia Pezzoli et al., (2003), around 18.2% old age people were unable to perform spirometry test properly [25].
- The American Thoracic Society recommends that spirometry should not be performed if the patient has experienced a myocardial infarction in the last four weeks. Test should be avoided in patients with recent abdominal surgery [26].
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- Enthusiastic training for correct breathing maneuvers for spirometry test remains vital to reduce the risk of false diagnosis and it is significant in the primary care setting.
- In spirometry there is always a possibility of error in obtained data if ambient temperature is different from body temperature [19].
- The reference values of the spirometry test for normal and pathological case depends highly on the age of the patient [11, 25, 27].

B. Roentgenography

The roentgenograph is named after German physicist Wilhelm Conrad Rontgen, who discovered X-ray in 1895. Roentgenograph is the photograph of internal organs of the body. It is obtained by passing a small dose of ionizing radiation through the body to create a shaded image on specifically sensitized film. It is a non-invasive checkup test that helps physicians in diagnosing. In the diagnosis and treatment of lung related diseases, the roentgenogram is generally used to see actual physical situation of the lung. It is predominantly valuable in emergency diagnosis and treatment [28].

Important research work in roentgenography is reviewed here as follows. Chien Y.P. et al, (1974) used a class of pictures of medical importance, namely, chest X-ray images, to test the proposed pre-processing and feature-extraction technique. The classification results presented in this paper show the feasibility of the proposed pictorial pattern recognition system in effectively screening out the abnormal pictures without human intervention [29]. In their work, Devan K.S. et al, (2005), have developed a rule-based expert system with an embedded imaging module to help physicians for early detection of pulmonary diseases from chest x-ray [30]. A fast piecewise heuristic follower of the boundaries of difficult-to-notice non overlapping blobs in digitized X-ray images is described by Sankar P.V. et al, (1982), to detect the boundaries of lung nodules with good fidelity of the detected boundaries [31]. M Bombino et al., (1991), have concluded that as compared to computed tomography consistent reading of portable chest roentgenograms by proposed scoring tables is an important tool in approximating the level of pulmonary edema in a patient with adult respiratory distress syndrome [32]. Patil S.A. et al., (2009), have presented a computer algorithm for nodule detection in chest radiographs for lung cancer and TB [33]. Peichun Yu et al., (2009) have suggested a texture analysis method on digital chest radiograph to distinguish pneumoconiosis chest from normal chest [34]. An automatic system was implemented by Lampotang S. et al., (1998), for synchronizing beam exposure with peak lung inflation during chest radiography to enhance clinical diagnostic data in a chest radiograph [35]. The spectral property of singular value decomposition is used by Wei-ChunLin et al., (2010), for enhanced interpretability of information in low contrast images for human viewers while the noise and blurring were reduced [36]. Seunghwan Kim et al., (2000), have suggested the nonlinear warping to eliminate the image of rib from chest x-ray images [37]. It is very important to locate and recognize the lung region accurately in chest X-ray images in clinical application and research. Different methods for the segmentation of lung in X ray images have been suggested by many researchers [38-40]. Iakovidis
D.K.(2008), proposed a innovative methodology that copes with lung field detection in both stationary and portable chest radiographs by combining statistical grey-level intensity information and directional edge maps particularly for patients with lung consolidation [41]. In their work Jeanne V. et al., (2009), have proposed X-ray image classification and retrieval [42]. The compact X-ray tube design utilizing carbon nanotubes cold cathodes with brazing technique developed by Dae-Jun Kim et al., (2010), may be a significant advance in X-ray technology development and could lead to portable and miniature X-ray sources for medical and industrial applications [43]. Some roentgenographs are given here for illustration. The typical roentgenographs for normal and diseased cases are shown in Figure 4.

![Figure 4: (a) Frontal Chest Roentgenograph of a Normal Male Patient. (b) Posteroanterior Chest Roentgenograph with Pneumonia.](image)

**Advantages of Roentgenography**

The advantages of the roentgenography are as follows.

- It gives directly the internal image of the chest.
- Actual image of the lung states the physical condition of it.
- It is very handy in emergency diagnosis and treatment.

**Limitations of Roentgenography**

The roentgenography has many drawbacks and limitations.

- It is a complex diagnostic technique.
- Initial setup is required for roentgenography.
- Roentgenography is a non-invasive technique but X-ray radiations passes through the body during the process. Frequent exposure to this radiation during roentgenography is harmful for the body. There is always a probability of cancer from intense exposure to radiation.
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- This exposure is very harmful for the children and particularly for the foetus. Therefore pregnant women should avoid roentgenography.
- Instrument for the roentgenography is neither compact nor portable.
- The diagnostic value of a chest radiograph is improved if chest movement is minimal and X-ray is taken at or near peak lung inflation.
- Image of rib cage hides some portion of lung which cannot be seen in roentgenograph.
- Roentgenogram is mostly used during emergency for the diagnosis to see the actual physical condition like liquid deposition in lung, shrinking of lung, foreign body in lung etc.
- Home monitoring, long term monitoring and distant monitoring and diagnosis cannot be done by roentgenography.
- The level of human error factor during roentgenography depends upon the skill of the operator who is performing it.
- It requires a clinical environment and the supervision of the experienced physician for interpreting the results.
- There is a possibility of error in the interpretation of chest roentgenograms by a physician and it depends on his or her knowledge and experience. Moreover it has been demonstrated that physicians are likely to disagree with each other over the interpretation of roentgenogram [44].
- In case of children and mentally challenged people, this test can be difficult to perform.

Roentgenography gives the image of the lung. Thus there is lot of scope for image processing and synthesis techniques to minimize the limitations of this technique.

C. Bronchoscopy

Bronchoscopy is a process that enables the physician to inspect the major air passages of the respiratory system and allows him to evaluate the lungs. Small samples of tissue or fluid can also be taken from respiratory system if required. It is an invasive process and is used to view the nasal passages, pharynx, larynx, vocal cords, and bronchial tree of respiratory system. In addition to the diagnosis, it is used for treatment of lung disorders. Bronchoscopy can be performed by either rigid or flexible bronchoscope and thus known as rigid bronchoscopy or flexible/fibereoptic bronchoscopy respectively. In their review Andrew R. Haas et al., (2010), have observed that the flexible bronchoscopy has given improved access to the trachiobronchial tree as compared to the rigid bronchoscopy and the emerging technologies have significantly enhanced the diagnostic capabilities of flexible bronchoscopy [45]. In rigid bronchoscopy the bronchoscope is inserted through the mouth of the patient while in flexible bronchoscopy the bronchoscope can be inserted through nose or mouth. The advantages of flexible bronchoscopy over rigid bronchoscopy is that it can be done under topical anaesthesia, have less chances of trauma and have ability to visualize and sample more peripheral bronchial pathologies than with rigid bronchoscope. Though the diagnostic
capabilities with flexible bronchoscopy have improved, but the view obtained by it is inferior to that seen through rigid bronchoscope [46]. Some bronchoscopy images are shown here for illustration. Figure 5 shows the typical bronchoscopy images for normal and abnormal cases.

![Normal Case](image1.png) ![Abnormal Cases](image2.png)

**Figure 5**: (a) Normal Case. (b) Abnormal Cases

Usually the procedure is performed after patient is sedated with nose or mouth numbed. A small needle is inserted into a vein so that additional medications can be given. Patient will be connected to a heart and blood pressure monitor and will be given extra oxygen through the nose during the exam. If needed, additional sedation may be given through the needle in the vein. Then physician inserts a bronchoscope through the nose or mouth and into the windpipe of the patient. A small canal in the device allows tissue and fluid samples to be collected, if required.

Research work has been carried out and is going on to improve the procedure of bronchoscopy. Prominent works amongst them have been reviewed here. Mellor, J.R.et al, (1995), presented an image processing technique for reconstructing the bronchial tree from continuous volume scanning data, and representing it as an image that closely resembles bronchoscopy [47]. In their work Bricault I. et al., (1998), has presented a procedure for computer assisted transbronchial biopsy [48]. Oliveira P.P.D.M. Jr. et al., (2000), used computer graphics techniques to develop a virtual endoscopic system for non-invasive bronchoscopy for the cases where biopsy is not required [49]. In their work, Kourelea, S. et al, (2000), have established the utility of virtual bronchoscopy over fiberoptic bronchoscopy for the patients with hemoptysis [50]. The work of Mori K. et al, (2000), describes a method for the automated anatomical labeling of the bronchial branch, necessary for realizing a computer-aided diagnosis system, extracted from a three-dimensional (3-D) chest X-ray CT image and its relevance to a virtual bronchoscopy system [51]. Kiraly, A.P. et al,
(2004), developed a lung-cancer estimation system, which facilitates virtual bronchoscopy three dimensional multidetector computed-tomography image analysis and track on image guided bronchoscopy [52]. Cebral J.R. et al, (2004), have suggested that virtual bronchoscopy can be used to execute aerodynamic computation in anatomically realistic models by computing the pressure and flow patterns in a human airway noninvasively to determine region of a stenosis [53]. Chung A.J.et al, (2006), has offered an image-based technique for virtual bronchoscope with photo-realistic rendering. The proposed method is based on recovering bidirectional reflectance distribution function (BRDF) parameters in an surroundings where the option of viewing position, directions, and illumination circumstances are limited. [54]. Sang Joon Park et al, (2008), established a new process for thickness-mapped virtual bronchoscopy with an analysis of airway information by a developed algorithm. It is indicated in this paper that this approach is suitable, precise, automatic and well visual in approximating airway wall thickness [55]. Wilson S. et al., (2005), suggested a procedure that deals with the problem of measuring and navigating through the airway using a bronchoscope during bronchoscopy, without the need of any additional data, localization systems or other external components. It provides a range of numerical measurements and inferences to physicians in real time, using standard computer hardware [56]. Rai L. et al., (2006), have described a fast robust method that provides three dimensional computed tomography image based image guidance during live bronchoscopy to improve the success rate in the assessment of lung cancer [57]. Negahdar M. et al, (2006), have developed an automated path planning method appropriate for quantitative airway analysis and proper virtual navigation, which allows virtual bronchoscopic 3D multidetector computed tomography image analysis and follow on image-guided bronchoscopy [58]. Bountris P. et al, (2009), presented an intelligent computing system based on combined texture features, feature selection methods and classification models, for improved classification of suspicious areas of the bronchial mucosa, in order to decrease the rate of false positive findings, to increase the specificity and sensitivity of autofluorescence bronchoscopy and enhance the overall diagnostic value of the autofluorescence bronchoscopy method [59]. Graham M.W. et al, (2010), have presented a robust method of segmentation of the peripheral airway tree from a 3-D multidetector computed tomography chest scan for planning of peripheral bronchoscopy [60]. Xu Di et al., (2010), have proposed a feature-based 2D/3D registration method for the image fusion between the datasets of the two imaging modalities to improve X-ray guided bronchoscopy of peripheral pulmonary lesions, airways and nodules [61].

**Advantages of Bronchoscopy**

Bronchoscopy is one of the important diagnosis and treatment procedure for diseases of the respiratory system. The advantages of bronchoscopy are listed below.

- Internal images of the respiratory system are obtained with the help of bronchoscopy. These pictures can be recorded for further analysis.
- An improved technique of virtual bronchoscopy is non-invasive.
• For diagnosis of certain disorders, bronchoscopy is used to collect tissue and fluid samples from respiratory system.

• In addition to diagnosis, bronchoscopy is also used for the treatment of certain disorders of respiratory system.

Limitations of Bronchoscopy
Bronchoscopy is a complicated diagnostic and treatment procedure for the diseases of the respiratory system. It has following limitations.

• It is a complex diagnostic technique and requires initial setup.

• Bronchoscopy is an invasive technique and hence complications due to it may occur.

• Standard bronchoscopy provides live video information of inner side of the lung airways but it does not give any information of the outer side of the airways.

• View obtained during bronchoscopy can be easily obscured which requires removal of the bronchoscope for cleansing and reinsertion [46].

• Bronchoscopy is performed in a clinical environment by a specially trained physician bronchoscopist for interpreting the results and is assisted by a specially trained healthcare professional to avoid any serious consequence due to human error [62, 63].

• The adverse effects of flexible bronchoscopy may be attributable to the sedation, the local anaesthesia or the procedure. They may include collapsed lung, air leak from lung, bleeding, an allergic reaction, hoarseness, and fever. Mortality from the procedure is about 0.02%. [63, 64]. Cardiovascular complications are well known to occur as a result of premedications, topical anaesthetics and the hypoxemia engendered during the procedures [65-69].

• Home and long term monitoring is not possible by bronchoscopy and distant monitoring and diagnosis cannot be done by this technique.

• Infection in respiratory system can occur by the bronchoscope. Hence it is essential to clean and disinfect all instruments before use.

• Entire lung particularly the peripheral airways cannot be examined using this technique.

• Even after the bronchoscopy test, the patient is being kept in observation for any chest pain, difficulty in breathing, or more flecks of blood in the phlegm. It is normal to cough up a small amount of blood for 1 to 2 days after the procedure. Blood pressure, pulse, and breathing rate will be checked and a chest x-ray may be taken prior to the discharge. One cannot eat or drink anything before 6 hours and 2 hours after the bronchoscopy procedure.

• For children and mentally challenged persons bronchoscopy is not convenient and can be difficult to perform.

Bronchoscopy gives the images of the respiratory system. Thus there is lot of scope for image processing techniques which may reduce some limitations of this technique.
D. Lung Auscultation Technique

In this technique lung sounds are heard using a stethoscope and are used for the prediction of the lung health. Use of a conventional stethoscope to listen lung sound makes lung auscultation technique simple, easy to use and most popular non-invasive method for diagnosis. Presently conventional stethoscope is being used by medical professionals for preliminary diagnosis of pulmonary diseases. It is a very common and handy tool [3, 4, 5]. The sound heard with the help of stethoscope depends on three important factors. They are vibration present at the chest wall, the perception of sound by the human ear (psychoacoustics) and the acoustics of the stethoscope itself. The perception of the sound is a composite process but it basically consists of three factors. They are the ability to focus on particular frequencies, the presence of different higher frequencies which gives the auscultated respiratory sounds their typical nature, and the fact that low frequency components of a sound may cover components of a higher frequency. The critical factor in determining the usefulness of the acoustic stethoscope is its reliance on the expertise and experience of the physician to distinguish between normal and pathological case [70].

The invention of the basic stethoscope was done by Laennec RTH when he came up with a hollow tube of wood, 3.5cm in diameter and 25cm long in 1818 [3,71]. Rober Bowles invented the diaphragm of the stethoscope. Later on Sprague combined the bell with the diaphragm, in one chest piece, in 1926. Aubrey Leatham, at St. George’s Hospital, in London, designed a binaural stethoscope with a bell which had two components, big and small. In 1961 Littmann redesigned the stethoscope devised by Sprague. It was easier to use and much lighter. This is the conventional mechanical stethoscope being used nowadays by most of the physicians [72]. Now electronic stethoscopes are available that records the breath sound [73, 74]. But some limitations of electronic stethoscope are their expensive retail price, the common problem of background noise, heart sound interference and most of them were unable to interface with the computers earlier. With the recent development in technology, these shortcomings are getting minimized. Now some electronic stethoscopes are available with ambient noise filtering [75, 76]. Woywodt A. et al., (2004), developed an electronic stethoscope which can be interfaced to a laptop. This setup was used for the teaching of cardiac auscultation [77]. Here we would like to define the technique ‘of listening respiratory sound using an electronic stethoscope for analysis and diagnosis of diseases related to respiration system as ‘Phonopulmonography’ (PPG) to differentiate it from conventional lung auscultation technique. In the previous work of one of the author of this paper it has been concluded that PPG technique is the best technique for diagnosis of pulmonary disease [78].

Lot of research work has been done since invention of stethoscope and is still going on to improve lung auscultation technique to make it the best technique for the diagnosis of pulmonary diseases. Some of these works has been revived here. Raymond L Murphy, (1981), has suggested a multidisciplinary effort to understand the mechanism of generation of normal breath sounds and adventitious sounds to devise an improved non-invasive diagnostic auscultation tool [79]. Giuliana Benedetto et al., (1988), have used three micro-
phones simultaneously, arranged in three different subsequent configurations to show that the acoustical characteristics of adventitious lung sounds change significantly when the location of auscultation is changed [80]. In his review work M.J. Mussell, (1992) have highlighted the need of standardization in recording and analysis of respiratory sounds so that different works in this field can be compared [81]. Bettencourt PE et al., (1994), have applied the techniques of lung sound mapping and time-expanded waveform analysis to investigate the usefulness of chest auscultation in pulmonary disease [82]. In their review, P. Piirila et al., (1995), discussed about the origin, auscultation, recording and analysis of crackles from the point of view of clinical significance of crackles for detecting the pulmonary disorders [83]. Martin Kompis et al., (1995), have studied the similarity of breath sounds recorded simultaneously at different sites on the chest as a function of frequency and intermicrophone distance [84]. Volker Gross et al., (2000), have examined the relationship between lung sounds, age, and gender and found that these changes were too small to be clinically relevant and hence there is no need to consider a patient’s age during automated lung auscultation [85]. Yasemin P. Kahya et al., (2003), have compared the performances of k-NN (k-nearest neighbours) classifiers with different feature sets evaluated from respiratory sound data obtained from healthy and pathological subjects [86]. Ipek Sen et al., (2003), has designed and implemented five channel analog amplifier and filter stage for acquisition of pulmonary sound signal [87]. Huseyin Polat et al., (2004), have designed a computer based measurement and analysis system for pulmonary auscultation sounds using the software package DaisyLAB [88]. Anderson et al., (2001), have suggested that, even without specialized equipment, mobile phones can noninvasively monitor tracheal breath sounds in patients who suffer exercise induced asthma and other chronic airway diseases [89]. In their work Fragasso G et al., (2003), have established that an internet based system permits even delicate and sensitive diagnostic processes such as heart and lung auscultation to be conducted remotely [90]. Inan Guler et al., (2005), have presented a study for neural networks and genetic algorithm approach intended to aid in lung sound classification and it was used to predict the presence or absence of adventitious sounds [91]. In their work Yasemin P. Kahya et al., (2006) used different feature sets in conjunction with k-NN and artificial neural network classifiers to address the classification problem of respiratory sound signals [92]. In their work Styliani A. Taplidou et al., (2006), have captured and analyzed the nonlinear characteristics of asthmatic wheezes, reflected in the quadrature phase coupling of their harmonics, as they evolved over time within the breathing cycle [93]. Saiful Huq et al., (2007), have investigated the difference between the average power and log-variance of the band-pass filtered tracheal breath sound of inspiratory and expiratory phase [94]. Gwo-Ching Chang et al., (2008), have investigated the effect of various noise conditions on lung sound feature representations and found that bispectrum diagonal slices was more immune to noise [95]. In his study, Zumray Dokur, (2008), suggested a novel incremental supervised neural network for classification of nine different respiratory sounds and the classification performances of this network has been compared with that of multi-layer perceptor and grow and learn network [96]. Claudia C. Ceresa et al., (2008), have established that the auscultation technique is the most suitable procedure in the diagnosis of the
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respiratory disease [97]. N. Gavriely et al., (1994), have examined and established that if lung sounds analysis is considered with spirometry then it enhances the sensitivity of detection of pulmonary diseases by objective tests, and gives an early sign of lung disease that was not detected by spirometry alone [98]. A B Bohadana et al, (1995), have shown that during bronchial provocation testing the precise classification of wheeze can be useful in avoiding or shortening the test due to deduced relationship between wheeze and airways hyper responsiveness [99]. D Faistauer et al, (2005), have developed a model for normal lung sound generation based on a discretization of air flow in particle-like elements to explain the origin of the lung sound [100]. H. Pasterkamp et al., (1999), have studied and analyzed the effect of ambient sounds, generated during breathing that reaches a sensor at the chest surface by the transmission from mouth and nose through air in the room, rather than through the airways, lungs and chest wall [101].

Work also has been carried out specifically to minimize or cancel the heart sound from lung sound signal. Recursive least squares adaptive noise cancellation and wavelet transform based adaptive noise cancellation have been applied and compared by January Gnitecki et al., (2005), for heart sound reduction from lung sounds recordings [102]. Jen-Chien et al., (2006), used fast independent component analysis algorithm to separate heart sound and lung sound to reduce human factor in telemedicine and home care system [103]. M.T. Pourazad et al., (2006), have proposed a method of heart sound cancellation from lung sound recordings using time-frequency filtering and found that it successfully removes heart sound from lung sound signals while preserving the original fundamental components of the lung sounds [104]. Daniel Flores-Tapia et al., (2007), have presented a novel method for heart sound cancellation from lung sound recordings using multiscale product of the wavelet coefficients of original signal to detect the segments of heart sound in it [105]. Thato Tsalaile et al., (2007), have demonstrated a technique for separating heart sound from lung sound signal using adaptive line enhancement [106]. In their study, F. Jin et al., (2008), have worked on the problem of heart sounds localization from single channel respiratory sounds recordings by applying wavelet-based localization scheme [107]. T E Ayoob Khan et al., (2010), in their work have implemented a virtual instrument for heart sound cancellation from lung sound recordings using the advanced signal processing toolkit of LabVIEW 8.2 [108]. Yuan-Hsiang Lin et al., (2010), developed a digital auscultation system with a USB port for data transmission and a PC-based graphic user interface for waveform display and data recording. This system would be useful for aiding the auscultation diagnosis and telemedicine applications [109]. Mayorga P. et al., (2010), have proposed acoustic evaluation methodology based on the Gaussian Mixed Models to assist in broader analysis, identification, and diagnosis of asthma [110]. Zhen Wang et al, (2009), used a non-invasive computer aided acoustic based imaging procedure to establish that the patients with acute dyspnea due to obstructive airway disease had distinguishable features in their respiratory sound [111]. A fully automated method was developed by Yadollahi A. et al., (2010), for the detection and monitoring of obstructive sleep apnoea that uses tracheal breathing sound along with blood oxygen saturation level [112]. Alice Jones et al., (1998), have compared three type of stethoscope chest pieces and demonstrated that their acoustic
The lung sounds are of two types namely the normal lung sound and the adventitious lung sound (abnormal lung sound) [116]. Typical waveforms for lung sounds for normal case and an abnormal lung sound wave is shown in Figure 6.

![Normal Vesicular Lung Sound](image1)

![High Pitched Crackles](image2)

Figure 6: (a) Normal Vesicular Lung Sound. (b) High Pitched Crackles

Research work also has been carried out to find out the location and reason for the generation of respiratory sound. A broadly accepted theory is as follows. When the laminar flow of gas in the airways of breathing system at a certain critical velocity breaks up, small parcels of gas begin to move in random direction, sometimes even in the opposite direction of the flow. This gives rise to the turbulent flow where the energy transfer between colliding parcels of gas is associated with transient pressure variation. The breath sound is generated due to this rapid fluctuation of gas pressure. The critical flow velocity at which turbulence begins depends on the interaction of inertia of parcels of gas and frictional resistance of viscosity. The interaction of these two forces is expressed as Reynolds Number and can be calculated from the following formula:
Reynolds Number = (Flow velocity × Tube diameter × Gas density) ÷ Gas viscosity

In a straight pipe turbulence occurs at Reynolds Number of about 2000. Turbulence also depends upon obstacle in flow path and abrupt change in the direction of the flow [117-121]. Abnormal lung sounds are generally associated with narrowing or closure of the airway by contraction of bronchial smooth muscle, viscid mucus, abnormal narrowing of airway due to scarring, foreign bodies and tumors. The correlation between forward and lateral pressure in bronchi and flow velocity in bronchi is known as the venturi or Bernoulli effect. The venturi effect and dynamic compression of the bronchi play an important role in generating wheezing. Sudden reopening of closed airways determines change in the gas pressure which results in crackling sound [122-125]. In another work Steve S. Kraman, (1983), have employed a computerized lung sound measurement technique to study the sites of origin and amplitudes of these sounds [126]. In order to explain the acoustic phenomena during lung auscultation, V.I. Korenbaum et al., (2003), have proposed an acoustic model to establish that the contributions of both air-borne and structure-borne sound are significant in the transmission of respiratory noise to the chest wall [127].

For lung auscultation technique different sounds with their characteristics and possible disease is presented in Table 2 [128, 129].

<table>
<thead>
<tr>
<th>Sound</th>
<th>Characteristics</th>
<th>Disease/Indications</th>
<th>Frequency range (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vesicular breath sounds</td>
<td>Relatively soft, low pitched; inspiratory phase is markedly longer than expiratory phase; Expiration is much quieter than inspiration; No pause between inspiration and expiration.</td>
<td>Normal</td>
<td>150 to 500 peak freq-200 to 250</td>
</tr>
<tr>
<td>Tracheal breath sounds</td>
<td>Very loud, very high pitched and have a harsh, hollow quality; Expiratory phase is slightly longer than inspiratory phase</td>
<td>Normal</td>
<td>Upto 1200</td>
</tr>
<tr>
<td>Bronchial breath sounds</td>
<td>Relatively loud, high pitched; Resembles the sound of air blowing through the hollow pipe; Expiratory phase is louder and longer than inspiratory phase; Distinct pause between inspiratory and expiratory phases</td>
<td>Pneumonia, Lung fibrosis, (Consolidated lung tissue)</td>
<td>Upto 600 to 1000</td>
</tr>
</tbody>
</table>

Table 2 Contd.
<table>
<thead>
<tr>
<th>Crackles</th>
<th>Short, explosive, nonmusical sounds; (Laennec compared it to the sound produced by heating salt in a frying pan); High pitched crackles are known as fine crackles and low pitched crackles are known as coarse crackles; Crackles are due to sudden opening of very small airways</th>
<th>Severe airway obstruction; Chronic bronchitis, Asthma, Emphysema, Restrictive; pulmonary disease; Interstitial fibrosis, Asbestosis, Pneumonia, Pulmonary congestion of heart failure, Left ventricular failure, Kidney failure, Pulmonary sarcoidosis, Scleroderma, Rheumatoid lung</th>
<th>100 to 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheeze (Rhonchus)</td>
<td>Wheeze is also known as Rhonchus, is a musical sound and is produced by a bronchus narrowed to the point of closure; The musical character is determined by the spectrum of frequencies that make up the sound; The lowest frequency (Fundamental), sets the pitch of the wheeze;</td>
<td>Malignancy, Foreign body, Asthma, All types of obstructive disease, COPD,</td>
<td>60-2000</td>
</tr>
<tr>
<td>Stridor</td>
<td>A loud musical sound of constant pitch; Most prominent during inspiration; Its intensity distinguishes stridor from a monophonic wheeze; Stridor can be heard very well at a distance from the patient unlike in the case of wheeze; Stridor comes from obstruction of central airways such as trachea or larynx whereas wheeze is produced in more peripheral airways</td>
<td>Obstruction of central airways such as trachea or larynx, Laryngeal tumors, Tracheal stenosis,</td>
<td>Peak freq-1000</td>
</tr>
<tr>
<td>Squawk</td>
<td>A distinctive inspiratory musical sound (almost invariably accompanied by inspiratory crackles);</td>
<td>Diffuse pulmonary fibrosis with hypersensitivity pneumonitis</td>
<td>Duration rarely exceeds 400ms</td>
</tr>
</tbody>
</table>

**Advantages of Lung Auscultation Technique**

The lung auscultation technique is the most used technique for diagnosis of pulmonary diseases. Its advantages are listed below.

- It is a very simple, safest yet accurate diagnostic technique for pulmonary diseases. No initial setup is required for the procedure.
- Lung auscultation technique is non-invasive in nature.
- Instrument is compact, portable and easy to handle.
- Recording, reproducing and replaying is possible with the help of lung auscultation technique in PPG configuration.
Home monitoring, long term monitoring and distant monitoring and diagnosis can be done with PPG.

PPG provides automated diagnostic technique for diseases of respiratory system which in turn eliminates human error factor.

PPG does not require a clinical environment or the supervision of the experienced physician for interpreting the results.

It is convenient for children and mentally challenged persons also.

Limitation of Lung Auscultation Technique

Auscultation with a conventional mechanical and electronic stethoscope has many limitations. They are as follows.

- The diagnosis of pulmonary disease using a conventional stethoscope is a subjective process that depends on the individual’s own hearing, experience and ability to differentiate between different sound patterns. Hence it becomes more dependent on the expertise and experience of the physician which increases the probability of human error in the diagnosis.

- It is not easy to produce quantitative measurements or make a permanent record of an examination in documentary form using a conventional stethoscope.

- Long-term and distant monitoring or correlation of respiratory sound with other physiological signals is also difficult using a conventional stethoscope.

- The conventional stethoscope has a good frequency response only up to 120Hz and tends to attenuates frequency components of the lung sound signal above about 120Hz whereas respiratory sounds ranges up to around 2KHz [4, 117, 130].

- Background noise should be as low as possible to minimize the interference while acquiring respiratory sound signal by an electronic stethoscope.

- Various sound signals generated in body such as heart sound signal, abdominal sound signal etc. acts as noise when they mix up with respiratory sound signal during acquisition with the help of an electronic stethoscope.

- Electronic stethoscope should be stationary during acquisition of respiratory sound signal to avoid shear noise generated due to friction between body and chest piece of the stethoscope.

If the limitations of the lung auscultation technique are reduced then it has the potential to become the best technique for diagnosis of pulmonary disease.

3. COMPARATIVE ANALYSIS AND RESULT

The purpose of the comparative analysis is to find out a simple, noninvasive yet efficient diagnostic tool for pulmonary disease. There viability for home monitoring, long term monitoring and distant monitoring and diagnosis was also studied. The analysis was carried out using different parameters such as simplicity, safety, economy etc. From the above
findings and literature review following conclusions has been drawn. Lung auscultation technique is the simplest of all techniques where as other techniques require special training and can only be performed in a clinical environment under the supervision of the experienced physician for interpreting their results. The risk involved in bronchoscopy is highest amongst these techniques as it is an invasive process. Lung auscultation is very cost effective as the instrument is cheap and does not require any setup. Accuracy of the diagnosis is more for lung auscultation technique in phonopulmonography configuration. With the advancement in the soft computing, lung auscultation technique in phonopulmonography configuration and to some extent spirometry can be used for home monitoring. In some pulmonary disease long term monitoring is required which can be done only by lung auscultation technique. Distant monitoring and diagnosis is also possible by using lung auscultation technique (PPG). Home monitoring and distant monitoring are particularly very important and useful for rural area where people are bit reluctant to visit a hospital. Lung auscultation technique (PPG) requires minimal expertise and with soft computing it can be reduced further. Compactness, handling and portability of lung auscultation technique (PPG) instruments are most convenient among all the techniques. From this analysis it is clear that the lung auscultation technique with phonopulmonography configuration is the best technique for detection of pulmonary diseases. The result of comparative analysis of diagnostic techniques for pulmonary disease is summarized in Table 3.

<table>
<thead>
<tr>
<th>Techniques ⇒ Parameters ↓</th>
<th>Lung auscultation with PPG</th>
<th>Spirometry</th>
<th>Roentgenography</th>
<th>Bronchoscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplicity/ minimal expertise</td>
<td>Simplest with minimal expertise</td>
<td>Require expertise</td>
<td>Require expertise</td>
<td>Complex &amp; require expertise</td>
</tr>
<tr>
<td>Safety</td>
<td>Safest</td>
<td>Safe</td>
<td>Risk of radiation</td>
<td>Risk involved is highest</td>
</tr>
<tr>
<td>Economy</td>
<td>Most cost effective</td>
<td>Moderate cost</td>
<td>Expensive</td>
<td>Expensive</td>
</tr>
<tr>
<td>Accuracy</td>
<td>Most accurate</td>
<td>Accurate</td>
<td>Less accurate</td>
<td>Accurate</td>
</tr>
<tr>
<td>Home/distant monitoring</td>
<td>Possible</td>
<td>Possible</td>
<td>Not possible</td>
<td>Not possible</td>
</tr>
<tr>
<td>Long term monitoring</td>
<td>Possible</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Not possible</td>
</tr>
<tr>
<td>Recording and reproducing the data</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Replaying the recorded data</td>
<td>Possible</td>
<td>Not possible</td>
<td>Not possible</td>
<td>Possible</td>
</tr>
<tr>
<td>Compactness /Handling/portability</td>
<td>Most convenient</td>
<td>Convenient</td>
<td>Less convenient</td>
<td>Most difficult to handle</td>
</tr>
</tbody>
</table>
4. CONCLUSION

Pulmonary diseases are one of the important causes of deaths worldwide. To control the casualties due to pulmonary diseases, their diagnosis should be more effective and accurate. From the descriptions and findings, it is clear that spirometry, roentgenography and bronchoscopy can only be performed properly in a clinical environment under the supervision of the experienced physician for interpreting their results and moreover these techniques are complicated. Woywodt et al., believed that the electronic stethoscope has the potential to become efficient diagnostic tool if it is exploited in the right way [78]. Phonopulmonography has the potential to eliminate the limitations of lung auscultation technique. Home and distant monitoring as well as long term monitoring in the case of pulmonary disease is possible using lung auscultation technique with PPG configuration and hence it is an efficient and best diagnostic tool for respiratory systems disease.

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