Pulmonary (Cardio) Diagnostic System for Combat Casualty Care Capable of Extracting Embedded Characteristics of Obstructive or Restrictive Flow

Glenn O. Allgood[*a], Dale A. Treece[a], Frederick J. Pearce[b], Timothy B. Bentley[b]

[a] Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6007

[b] Walter Reed Army Institute of Research, Division of Resuscitative Medicine, Washington D. C. 20307-0001

ABSTRACT

Walter Reed Army Institute of Research and Oak Ridge National Laboratory have developed a prototype pulmonary diagnostic system capable of extracting signatures from adventitious lung sounds that characterize obstructive and/or restrictive flow. Examples of disorders that have been detailed include emphysema, asthma, pulmonary fibrosis, and pneumothorax. The system is based on the premise that acoustic signals associated with pulmonary disorders can be characterized by a set of embedded signatures unique to the disease. The concept is being extended to include cardio signals correlated with pulmonary data to provide an accurate and timely diagnoses of pulmonary function and distress in critically injured soldiers that will allow medical personnel to anticipate the need for accurate therapeutic intervention as well as monitor soldiers whose injuries may lead to pulmonary compromise later.

The basic operation of the diagnostic system is as follows: (1) create an image from the acoustic signature based on higher order statistics, (2) deconstruct the image based on a predefined map, (3) compare the deconstructed image with stored images of pulmonary symptoms, and (4) classify the disorder based on a clustering of known symptoms and provide a statistical measure of confidence. The system has produced conformity between adults and infants and provided effective measures of physiology in the presence of noise.

Keywords: Automated pulmonary diagnostics, feature descriptors, respiratory disorders, image analysis, statistical confidence

1. INTRODUCTION

Accurate and timely diagnoses of pulmonary (lung) function and respiratory disorders in critically injured soldiers can mean the difference between life and death for our military forces. It should not come as a surprise that a rapid diagnostic capability is even more critical in combat where field surgeons must make decisions under extreme conditions and duress. An enhanced capability to detect life threatening pulmonary injuries would allow medical personnel to anticipate the need for acute therapeutic intervention (i.e., chest tube, endotracheal untubation, etc.) as well as monitor soldiers whose injuries may lead to pulmonary compromise later on. A team composed of researchers from Oak Ridge National Laboratory (ORNL) and Walter Reed Army Institute of Research (WRAIR) are currently developing an advanced pulmonary monitoring system for both field and clinical use. This work has focused on developing algorithms that synthesize attributes from acoustic signatures and characterizes them in terms of structure and disorders. The goal is to develop tools that provide clinically useful information from noisy environments and eliminate the need for individual baselines. Studies to date have investigated the application of novel sensors (to include fiber optic technology) and advanced signal processing in differentiating acoustic signatures from normal and pathological states (i.e., emphysema, pulmonary fibrosis, and pleural rub).

We envision that this sensor technology may someday provide Army medical personnel with a rapid and accurate diagnostic tool to assist in the management of life-threatening respiratory problems. It is being developed for use in mobile hospital units, helicopters, and hospital emergency rooms. The technology may one day find its way into the general medical community.

2. NEED FOR TIMELY, ACCURATE PULMONARY ASSESSMENTS

In the normal clinical setting, a physician has several options for assessing pulmonary function in a patient[1]. One option is to develop a complete medical history by interviewing the patient to obtain critical physical and mental health information. The physician seeks to learn the patient's chief complaints or symptoms through careful listening, questioning, and skillful observation. The physician will also try to characterize any joining symptoms such as dry or productive cough, chest pains, difficulty in breathing, or fever. In addition, the physician will compile a complete history of the patient's occupation, smoking and family and social relationships.

To obtain more detailed medical information on the patient, the physician may use diagnostic tools such as roentgenograms, physical examinations, and pulse oximetry. Clinicians typically use a combination of these tools to make a diagnosis, formulate a treatment plan, and monitor progress. Each is favored in different situations. Auscultation, for example, is preferred for diagnosing cystic fibrosis, carcinoma and certain pneumonia's, but the advantage of roentgenogram (a radiographic examination of the lungs) is its greater sensitivity. The physical exam (auscultation, palpitation, percussion, and cardia examination) is preferred for diagnosing obstructive airway diseases such as chronic bronchitis and chronchial asthma. In addition, the physician also has available a pulmonary function test that can uncover clinically undetectable dysfunction and measure quantitatively a disease's severity.

The critical issue in managing potentially life-threatening respiratory compromise is time. In a combat setting, it takes too long to set up the tools typically used by clinicians especially when the field trauma surgeon can be faced with managing multiple trauma victims simultaneously. Thus, tools that allow physicians to make a diagnosis quickly would be invaluable during combat. Equipment designed for this purpose will need to provide reliable diagnostic information in a timely fashion. We anticipate that the enhanced ability to monitor pulmonary function will allow field health care providers to better anticipate critical care needs and improve management of severely injured soldiers whose care in the field is prolonged. This is the task that WRAIR's Division of Resuscitative Medicine and ORNL's Instrumentation and Controls Division have taken on in support of WRAIR's Combat Casualty Care Program – the development of an automated pulmonary diagnostic system.

3. HARDWARE CONFIGURATION

The system is currently based on commercially available off-the-shelf PC hardware, which allows the system to be deployed as a laptop or desktop system. It has a graphical user interface for running the application, configuring data acquisition and data analysis program, and partitioning symptomatology into functional pulmonary disorders. The current version will allow the user to run only the prognostics and health assessment program in an off-line mode. One of the tasks in the project will be to develop a real-time version for interrogation and diagnostics of lung function or pathology.

Figure 1 shows the Main Screen for the current generation application. As seen, it allows a user to select one of four distinct actions: Ntuple transform table calculation, Baseline/Case study calculation, Data analysis, and Case study. The first three actions are used to develop the partitioning scheme and classification network for case studies.

4. SENSING ELEMENTS

Currently, stethoscopes are the primary tools used by physicians to gather respiratory information. In developing the prototype pulmonary diagnostic system, the team has considered the use of a digital stethoscopes. However, use of these devices has some inherent limitations, such as their non-uniform transfer functions that characterize their frequency response. But even with these limitations, they can provide effective measurements.

For the next generation system, the team is looking into integrating novel acoustic devices in both passive and active configurations. A study is under way to characterize specific sensors for their abilities to extract signals and provide sufficient sensitivity in the presence of environmental noise.

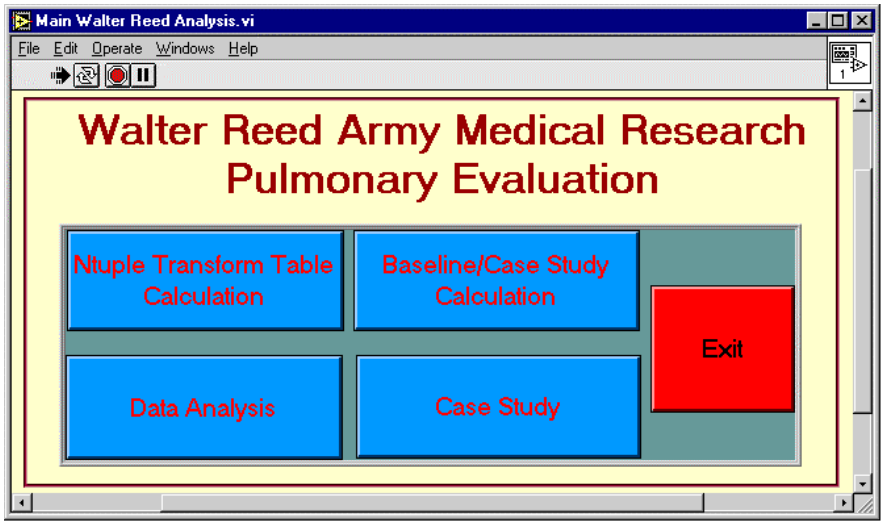


Figure 1. Main screen for the computerized acoustic identification of the pulmonarypathophysiology system.

5. NEW ALGORITHM: SYNTHESIZED ATTRIBUTES AND CHARACTERIZATION

The feature extraction algorithm is based on the tenet that lungs have a common structure that is consistent among adults, children, and infants (at least beyond a certain age). Research to date has focused on discovering those invariant features that can be used to detect changes in pulmonary structure and function. In conducting the investigation, several functional requirements were established to act as measures of algorithm performance. They are:

- The algorithm must provide sufficient discrimination to capture structure and underlying function.
- The algorithm must provide conformity (consistency) between adults and infants and males and females.
- The algorithm must provide effective measures and characterization of the physiological process in the presence of noise.
- The algorithm must provide distinct quantified measures between normal physiology and pathological disorders.

Lung sounds have two major properties that must also be considered in the investigation and final formulation. One property of lung sounds is they are composed of two elements: breath and adventitious sounds. Breath sounds are the normal acoustics heard on the chest wall. Adventitious sounds are the abnormal sounds, superimposed on the breath sounds that usually indicate respiratory problems. Therefore, an algorithm must have an inherent capability of partitioning and analyzing internal signal content, not just the signal itself.

The second property is that within the breath cycle, artifacts associated with different disorders will present themselves at different times within the acoustic signal. A drawing of this is seen in Figure 2. Here, a normal breath cycle (inspiration and exhalation) is superimposed on the adventitious lung signals characteristic of fine-late inspiratory crackles (Case 1) and early, fine inspiratory crackles (Case 2). Each represents a different pulmonary disorder with varying implications for medical treatment. The key here would be the development of an algorithm that can resolve the relative time-phase differences within a repeating signal and provide a consistently stable metric that characterizes a particular pulmonary disorder.

As previously stated, to successfully characterize pulmonary function and diagnose respiratory ailments, an algorithm must be able to analytically partition the signal into its base components and then address temporal resolution and frequency distinction. The pulmonary diagnostic system uses higher order statistics (higher order spectral analysis- HOS) to decompose the signal and resolve the temporal and relative phase of specific signal content associated with respiratory problems. This image, representing the feature space, is then coupled with a connectionist scheme/image deconstruction algorithm to provide spatial projections that are indicative of developing problems. Figure 3 shows the basic block flow diagram used by the automated pulmonary diagnostic system to characterize acoustic signals in terms of pulmonary disorders.

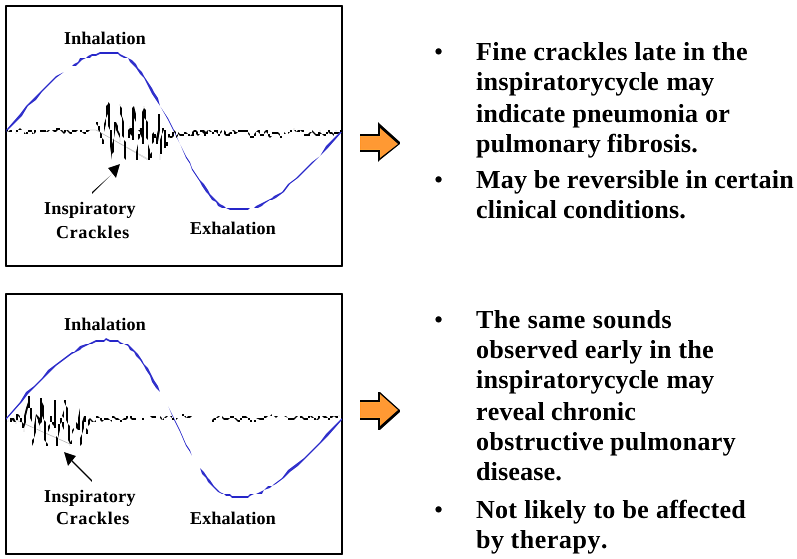


Figure 2. Simulation of a pneumograph superimposed on two adventitious signals representing pneumonia or pulmonary fibrosis (Case 1) and chronic obstructive pulmonary disease (Case 2).

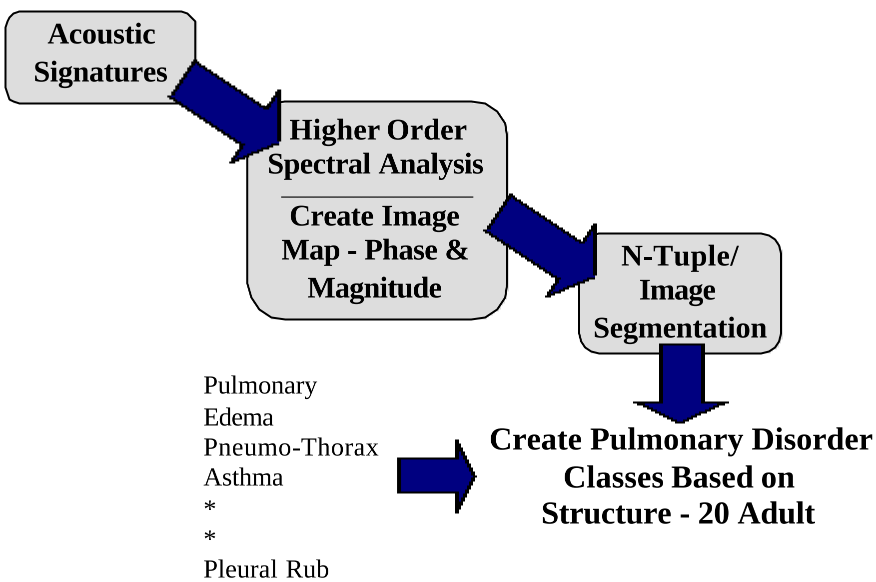


Figure 3. Basic block flow diagram of algorithm used in the Automated Pulmonary Diagnostic system. Current generation has basic image processing capabilities. Next generation will incorporate tie points, warping, and image segmentation for better statistical closure on class schema.

6. PRELIMINARY RESULTS FROM AUTOMATED PULMONARY DIAGNOSTIC SYSTEM

To date, 29 data sets representing different pulmonary functions and varying respiratory disorders for both adults and infants have been analyzed by the system. Each functional respiratory element defined by location and health status has developed its own unique image based on the HOS/connectionist/image algorithm suite. The following figures (Figures 4 through 7) provide a general overview of the Automated Pulmonary Diagnostics System's capability to extract distinct features from the adventitious signals acquired with an analog stethoscope. It should be noted that the images presented have not been segmented to extract the non-redundant information.

Figure 4 shows the images generated from the HOS feature development portion of the HOS/connectionist/image algorithm suite for tracheo-bronchial, bronchial-vesicular, and vesicular breath sounds. These are presented to show that structures (image similarities) are conserved under the HOS projections. This is important when considering physiological aspects of any algorithm.

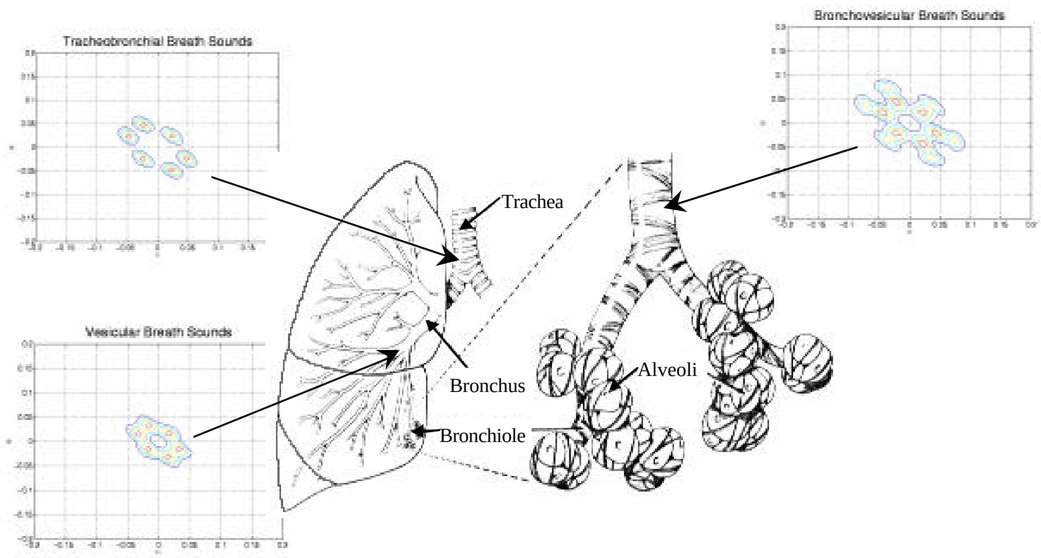
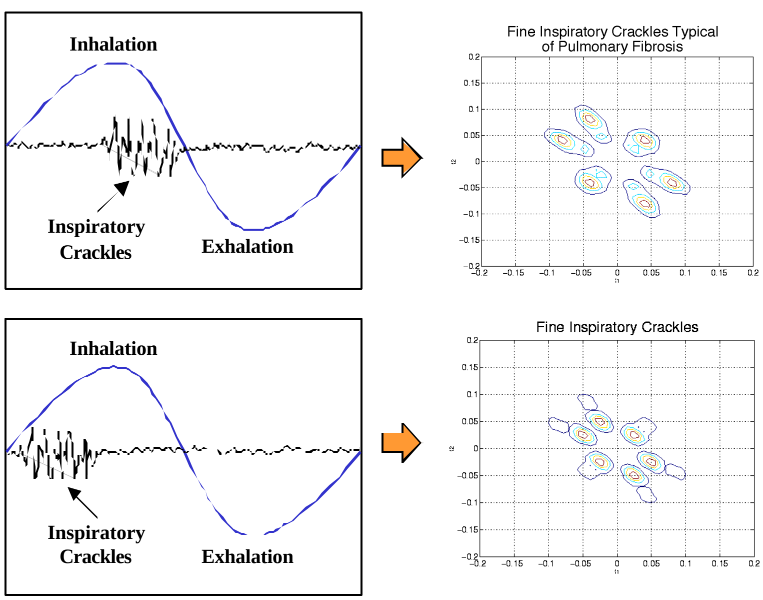


Figure 4. Bispectrum projections for tracheobronchial, bronchialvesicular, and vesicular breath sounds showing structure (similarities) is conserved under the HOS transform. Important when considering feature extraction based on physiology.

Figure 5 shows the HOS transform for the actual signals represented in Figure 2. As seen, each is distinct in its feature projection yet similar in topology. This ability to conserve structure while differentiating function is one of the strengths of the HOS/connectionist/image analysis transform that is being taken advantage of in the pulmonary diagnostic system.



- **Fine crackles late in the inspiratory cycle may indicate pneumonia or pulmonary fibrosis.**
- **May be reversible in certain clinical conditions.**

- **The same sounds observed early in the inspiratory cycle may reveal chronic obstructive pulmonary disease.**
- **Not likely to be affected by therapy.**

Figure 5. HOS transform of fine, late inspiratory crackles (indicative of pulmonary fibrosis) and early fine, inspiratory crackles (indicative of a chronic obstructive pulmonary disease).
The former being treatable while the latter no likely to be affected by therapy.

Figure 6 is an example of the conserving of structure in the presence of noise. Here a comparison is made of an infant's normal vesicular breath sound to that of an infant's normal breath sound captured when crying. Comparing the topological structures (orientation, elongation, roundness, etc…) one sees that the HOS/connectionist/image analysis algorithm does provide excellent closure when considering these features. It seems that the only artifact of applying the HOS algorithm to a noisy copy of a signal is an expansion of the projection of the structures onto the phase or intensity space.

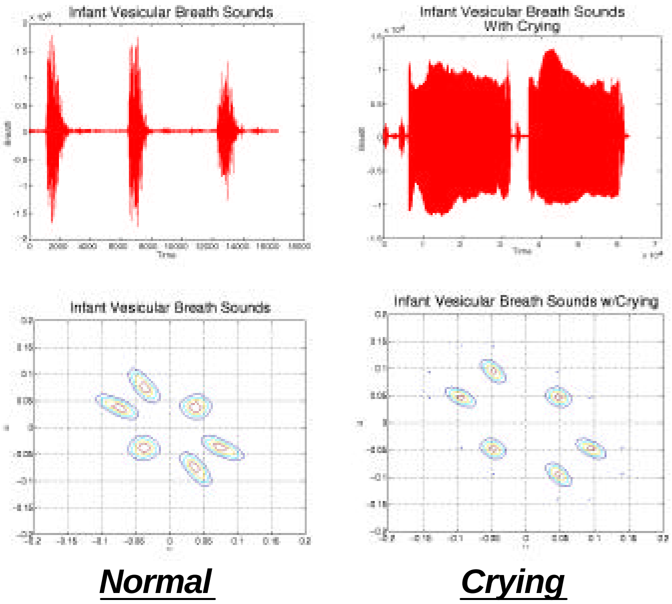


Figure 6. Comparison of an HOS transform of a healthy infant's vesicular breath to that of a healthy infants vesicular breath when crying. Impact of crying (noise) is an expansion in the phase and/or intensity space but conservation of structure.

The last figure (Figure 7) compares healthy (normal) vesicular breath sounds with that of diminished breath indicative of a pneumothorax problem. As seen as in previous examples, structure is conserved but with distinct features that would allow for a qualified diagnosis. This assertion was further qualified by running a case study of diminished breath against the diminished breath classification developed using the automated pulmonary diagnostic system.

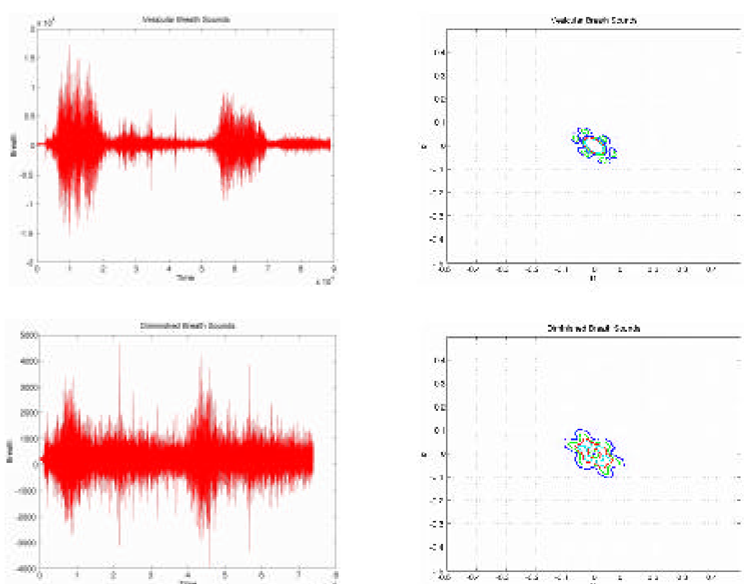


Figure 7. Comparison of normal adult breath sounds to that of diminished adult breath sounds. Distinct features are seen that could provide a statistically significant diagnosis.

7. PROJECT STATUS

Currently, a prototype system is in the latter stages of development for possible deployment in a private clinical study by ATI Corporation. There are additional projects to enhance the abilities of automated pulmonary diagnostic system. One is through Walter Reed Army Institute of Research, Division of Resuscitative Medicine, to develop prototype non-invasive detection system for pneumothorax on the battlefield based on the computational elements that have been developed in this project. A second project involves the development of computational fluid dynamic (CFD) model of obstructive and restrictive flow based on the preliminary results from this effort. This project is being supported through a Laboratory Directed Research Directive (LDRD) at Oak Ridge National Laboratory. A third project has been identified that will conduct a comparative study of structure and form between human lungs and current animal models.

8. CONCLUSION

In closing, today's medical community is in search of new sensors and computational methods to help doctors make timely, accurate assessments of a patient's physiological condition. Rapid diagnoses (that make possible early treatments) are especially important in situations where minutes can make the difference between life and death. Also needed is an ability to help physicians better anticipate the progression of disease over time so the best course of extended medical care can be selected to resolve a patient's conditions before they reach a critical stage. The WRAIR-ORNL development of the pulmonary diagnostic system shows promise to support such an endeavor and help doctors in the military and civilian arenas meet the escalating challenges of the 21st Century.

9. REFERENCES

1. Breath Sounds Methodology, Noam Bavriely, MD, D.Sc., CRC Press, Inc., 1985