Research Statement

1. Overview

Auscultation dynamics is generally concerned with the technology necessary to perform diagnostics based on analyses of sounds produced by the human physiological system. This includes areas such as heart sound separation and analysis, fetal heart sound analysis, snore sound analysis, and possibly other physiological sounds, such as the lung and gastrointestinal sounds. My research involves design and development of algorithms to detect and isolate physiological sounds from their environment and process them to extract diagnostically relevant features. Most of my current research concentrates on cardiac auscultation, which involves analysis of heart sound to determine cardiac well-being. Many pathological conditions that occur in the cardiovascular system surface as murmurs and aberrations in a phonocardiogram (PCG) much before they are reflected in other symptoms, such as changes in the electrocardiogram (ECG) signal. The PCG is a trace of acoustic energy produced by the mechanical activity of various cardiac components and processes. As a result, any abnormality in cardiac components manifests itself in the corresponding sounds in the PCG.

Clinicians have long depended on the stethoscope as the clinical tool that helps them to characterize heart sounds and identify abnormalities suggestive of underlying cardiac disease. However, with the advancement of technology, the confidence of most physicians in their ability to accurately detect abnormal cardiac findings through physical examination has diminished. Advanced medical diagnostic technologies have become so much the standard in the practice of cardiology that physicians have abandoned basic clinical assessment techniques and are unable to appreciate the capability of the stethoscope for preliminary cardiac diagnosis. Despite the current emphasis on technology in medicine, it still holds true that most patients seen in clinical practice today for evaluation of cardiovascular disease can be accurately diagnosed in the physician’s office through careful cardiac clinical examination.

With increasing healthcare costs, accurate clinical assessment that remains least expensive has become important. There exists a need for physicians to return to basic skills of clinical assessment, which includes cardiac auscultation. However, in most of the cases, the physicians are not properly trained and they suggest costly tests and procedures. However, with the advancement in digital data recording technology, it has become possible to record heart sounds on a portable computer. Subsequently, automated algorithms can be utilized to analyze heart sounds by extracting clinically important features that assist in clinical assessment and diagnosis. Automated diagnostic algorithms can incorporate the knowledge of a cardiologist and assist the physician to evaluate and screen cardiac sounds. Furthermore, automated diagnostic algorithms can reduce the stress on physicians who monitor large amounts of cardiac sound data and therefore are prone to error, and such algorithms can also overcome the disadvantages of performing auscultation in noisy wards.

2. Current Research

During the last two years, I have imbibed sufficient knowledge about the functioning of the heart and made myself familiar with various theories associated with the genesis of heart sounds. I have proposed a hypothesis that the various components of heart, that involves various heart valves, cardiac structures and different hemo-dynamic processes, function independently of each other to produce their characteristic sounds, which mix together to generate the PCG that is heard through the stethoscope. Therefore, by isolating the sound made by each component of the heart, from the PCG, it would be possible to access the condition of cardiac structures and pinpoint the exact cause of cardiac abnormalities, in case any exist. I have developed digital signal processing (DSP) based algorithms to detect the presence of major heart sound in a PCG, by utilizing the dynamics of the heart. Subsequently, I investigated the use of blind source separation (BSS) algorithms, that are capable of isolating
statistically independent signals from their mixtures, to extract individual heart sounds from composite PCG. Then, I proposed simplicity based characterization of cardiac murmurs that gives consistent patterns for a particular kind of murmur irrespective of its amplitude. Such characterization is necessary to detect cardiac murmurs that are very weak in amplitude and cannot be accessed by auscultation alone. Subsequently, I developed pattern recognition based approach for automated classification of systolic murmurs that classifies cardiac murmurs according to their time of occurrence in a cardiac cycle and their most probable cause of generation. Currently I am developing algorithms to extract clinically relevant features of cardiac murmurs that includes their shape, time duration, time of maximum intensity and quality. With these features in hand, any cardiac murmur can be represented in a form that is most suitable for human representation and therefore can be further classified using fuzzy logic and neural networks. The end product of this research will be a Cardiac Sound Separator™, that will be a smart digital chip that would fit into existing traditional stethoscopes, and would be responsible for automated extraction of cardiac sound components from composite PCG and their subsequent analysis.

In the process of researching cardiac sounds, I developed an algorithm to separate fetal PCG from their mixtures in case of multiple pregnancy, in which a pregnant woman carries more than one fetuses, and currently accounts for 3% of all pregnancies in the United States. Since women carrying multiple fetuses have a higher chance of developing pre-delivery complications, access to the PCG of individual fetuses would be highly beneficial to detect symptoms of fetal heart abnormalities. This research led to the development of a Multiple Fetus PCG Separator™ that is capable of extracting PCG of multiple fetuses from their mixtures in a multiple pregnancy.

Working on the similar lines, I developed a Portable Snore Recorder™ that could separate the snore signals of sleeping subjects from their mixtures. This device is useful for in home monitoring of subjects who suffer from obstructive sleep apnea, which is a common sleep disorder that effects 2% of females and 3% of males in the adult population. The snore recorder is particularly useful in cases were both the sleeping partners snore, creating the necessity of extracting the individual snores efficiently, in order to look for the symptoms of obstructive sleep apnea. The algorithm removes the restriction of the subjects sleeping by themselves, thereby providing the most favorable sleeping ambience.

3. Future Plans

The possibilities of exploring new avenues of research in auscultation dynamics are immense and in the near future I see myself setting up an auscultation dynamics laboratory to further the research that I have been so vigorously pursuing over the last several years. In few years from now, I see myself equipping the auscultation dynamics lab with modern state of art digital signal processing (DSP) instruments that would be used to acquire variety of physiological signals, including bio-acoustic signals like PCG, snore, and gastrointestinal signals as well as non-acoustic signals like the electroencephalogram (EEG), ECG and electromyogram (EMG). Subsequently, novel DSP techniques will be developed to design algorithms to extract diagnostic information from collected physiological sounds. Some possibilities of research are:

- Exploring the possibility of applying BSS techniques to isolate physiological sounds from their mixtures, like separating the aortic and the pulmonary valve sounds from the composite second heart sound to estimate the time interval between them. This time interval is a non-invasive indicator of pulmonary artery pressure, which when exceeds the normal values gives rise to pulmonary hypertension that is the cause behind third most fatal cardiac disorder.
- Designing BSS algorithms to isolate cardiac murmurs from the PCG and studying their timing, quality, and spectral characteristics to diagnose the cause of their production.
- Extracting diagnostic features from the snore sound to detect symptoms of OSA. With increasing costs of polysomnography, which is the gold standard of detecting symptoms of OSA and
requires patients to spend an entire night in a clinic with sensors attached all over the body, finding cost effective clinical methods for detecting symptoms of OSA through in-home monitoring is becoming imperative.

Once, relevant diagnostic features have been extracted, soft computing techniques, that involve neural network, fuzzy logic and probabilistic reasoning would be employed to represent the diagnostic information in a form that would be most suitable for humans to understand. The amalgamation of DSP techniques with methods of soft computing is very promising to solve medical problems that still remain difficult to tackle, for example the accurate representation and automated classification of cardiac murmurs. **Fuzzy clustering techniques** together with **decision tree algorithms** would be utilized to design algorithms that behave similar to human logic and result in more intelligent diagnosis. Since no branch of engineering could survive by itself, I see myself collaborating vigorously with researchers in other disciplines that are essential for the growth electrical engineering. For example, active collaboration with researchers in bioengineering would help me to identify new problems that can be efficiently solved by using tools from electrical engineering. Similarly, collaboration with researchers in Physics would lead to the development of instrumentation (like ultra sensitive sensors) that could capture faintest of physiological signals.

Over the last few months while working on pattern recognition based classification of cardiac murmurs, I have developed deep interest in the field of **biometrics**, which is recognition based on distinctive personal identifiers. Biometrics faces many challenges that include: 1) **accuracy** of acquired personal identifier(s), 2) **scalability** of biometric systems with an increase in the number of patterns against which a given pattern is to be matched, 3) **security** of biometric systems against fraudulent patterns and 4) the issue of the **privacy** of individuals. I feel that physiological signals have a good potential to provide us with features that could be used as identifiers in biometric systems because unlike identifiers like fingerprints, facial features, iris pattern, hand patterns etc., that are external to the human body, and hence can be tampered and spoofed, physiological signals are intrinsic to a human being and chances of imitating them is very low. I would like to explore the possibility of extracting features from signals like the ECG, the PCG and the EEG that can identify a person uniquely and would like to study their variation with physical activities and mental conditions. Moreover, I would like to investigate the possibility of fusing the features obtained from physiological signals with traditional biometric identifiers to construct a comprehensive identifier that may result in robust identification. However, fields like biometric involve processing large volume of data, and in many applications, like airport surveillance, delays are not tolerable. During my stay at the University of Illinois at Chicago, I took several courses in the field of parallel computing and VLSI systems because together with DSP algorithms they provide us with a complete framework to design and develop efficient algorithms and port them on integrated chips (ICs). I feel that the performance of pattern recognition and soft computing algorithms can be improved substantially if parallelism is introduced into them. Since the end product of any DSP based research is a set of algorithms, whose efficient implementation, in terms of space, noise immunity and power consumption is most crucial to their performance, I see myself researching in all the three fields to develop intelligent medical ICs and efficient biometric systems.