A Brief Review of the Use of a Digital Stethoscopes and Wavelet Transform to Detect Compensated and Decompensated Stages in the Congestive Heart Failure Patient

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Abstract

The current research work aims at suggesting a potential methodology to address the medical condition of Congestive Heart failure which is one of the leading causes of deaths. The suggested system holds a potential to improve the current diagnostic interventions, improving quality of care, reducing incidents of emergency hospitalizations and potential reduction in cost of care. The suggested methodology analyzes acoustic signals of heart and lungs as a differentiator for compensated and decompensated states with patients of congestive heart failure. The compensated conditions refers to a stable condition for congestive heart failure patients whereby the fluid are not retained within the lungs of the patients whereas in a decompensated state the fluid gets retained within the lungs of the patient which necessitates the need for medication and in extreme condition hospitalization.

The research analyzed the acoustic signals of heart and lungs using wavelet transforms to ascertain the changes in status of the CHF patients within the compensated and decompensated conditions. The research methodology entailed using a digital stethoscope and an electro cardiogram (ECG) to measure the existing condition of the research subjects as well as to ascertain their condition management and monitoring. The acoustic sounds of heart occur due to opening and closing of the heart valves while the acoustic signals of lungs results due to the respiration process. The signals were analyzed using the wavelet transforms, short time Fourier transform and Fourier transform to determine the best method to detect the conditional shifts in the CHF patients. The Fourier transform were used to obtain the power spectra which in turn were used to differentiate signals among the CHF and healthy patients. The short term Fourier transform didn't provide much of insight and this was not pursued. However, the wavelet transform provided the most promising results among the three methods. They provided better resolution for higher frequency in time and better resolution in frequency for lower frequencies.

Keywords: Digital Stethoscopes; Wavelet Transform; Congestive Heart Failure (CHF)

Introduction

This paper reviews work reported earlier showing the possibility that a digital stethoscope and signal processing can be used to detect changes in the condition of congestive heart failure patients [1]. Congestive heart failure (CHF) is the chronic medical condition which is generally characterized by the inability of the heart to pump a sufficient quantity of oxygen-rich blood to the body leading to excess fluid buildup in lungs and leading to the condition called pulmonary edema [2]. The current approaches to monitor CHF patients include monitoring daily weight or measurement of the electrical impedance of lung fluid between the leads of a pacemaker, or other implanted cardiac devices [3-5]. The latter tends to far better than the former (77% vis-à-vis 23%).

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Methodology

A digital stethoscope is placed on the chest of the patient just below the ribs and a little to the left of center of the gap between them and heart sounds are recorded for about ten beats while the patient is holding their breath. Lung sound is recorded for a full deep breath inhale and exhale. The recorded sounds are then analyzed using Fourier and Wavelet Transforms.

This study focused on two groups of people. Group 1 comprised of healthy people aged 20 to 80 years. Group 2 was comprised of adult CHF patients (compensated and decompensated). The inclusion criterion for group 1 having no significant medical history including heart or edema related complications. Group 2 inclusion criterion was subjects having no other heart conditions except CHF.

Results

The results show that Fourier transform was successful in predicting approximately 55% for decompensated condition and around 75% for compensated condition in patients whereas the results obtained from the Wavelet transform predicted with a 85% success rate in a patient's condition from compensated to decompensated and vice versa. Usage of a wavelet transform (WT) vis-à-vis the Fourier transform results in better frequency resolution for lower frequencies and better time resolution for higher frequencies. The WT gives better temporal spread with the frequency content which is a key impediment with Fourier transform which just provides a good resolution in frequency.

The specific WT selected from a pool of hundreds of basis wavelets. The analysis using the Haar wavelet, provided the infinite support for a analyzed vanishing moments, which were well localized in time domain but provided substandard frequency resolution. Conversely, the Shannon (or sinc) wavelet is perfectly localized in frequency but faired poorly localized in the time dimension. Out of the evaluated approaches for several WT, the Daubechies wavelet were found to the best approach for analyzing the compensated and decompensated states. This adopted method displayed minimum filter length for vanishing moments in the spatial domain. The Daubechies scaling and wavelet functions act as low- and high-pass filter coefficients, respectively. To achieve the first level of decomposed wavelet coefficients, the scaling and wavelet functions were down sampled by a factor of 2 along with convolution.

A detailed analysis for wavelet transforms was undertaken for decompensated, marginally decompensated, compensated, and healthy subjects. Figure 1 illustrates the diagonal coefficients at two different time points for the same patient.

Figure 1 shows the diagonal coefficients for one patient. The measurement was taken at two different times. One was taken when the patient was in the decompensated stage and the other, at the compensated stage. The analysis was performed for 10 s duration heart signals at location on the front left side of the chest, beneath the pectoral muscle on the second last rib, in order to capture approximately 10 to 12 heart beats.
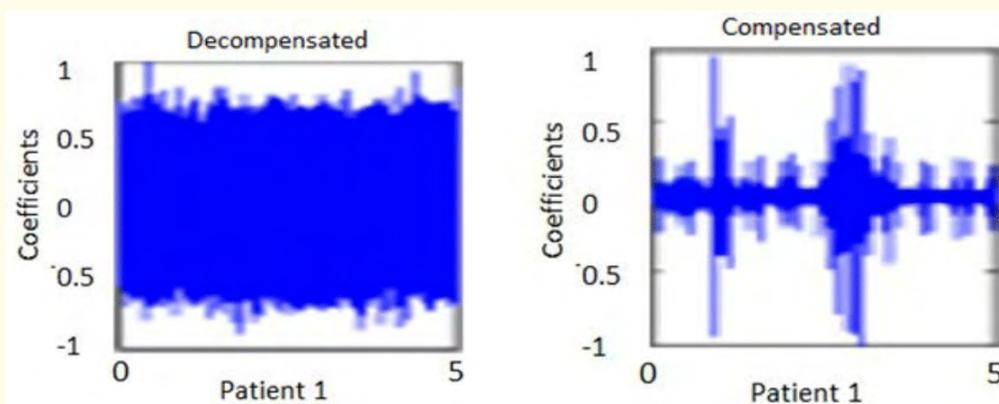
Figure 1: (a) Diagonal details (coefficients) of heart signals measured at location on the front left side of the chest, beneath the pectoral muscle on the second last rib for one of the patient, with decompensated state, as analyzed using the wavelet transform. (b) Diagonal details (coefficients) of heart signals measured at location on the front left side of the chest, beneath the pectoral muscle on the second last rib for the same patient as in (a), with measurement taken at compensated state, as analyzed using the wavelet transform.

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As is evident that through the WT analysis which permit the discrimination among the stages of compensated v/s the decompensated. Consistent changes are also evident among the compensated and decompensated patients when seen through the diagonal and horizontal details. In the horizontal and diagonal representations of the data, the same patient's decompensated sate coefficents are broader and condensed vis-à-vis the compensated state.

The analysis was undertaken on 8 different individuals for a small duration signal spanning for two adjacent S1s signals for the initiation of the heart beat. The average of multiple heart sounds yeilded a more consistent result vis-à-vis that of one heart sound (Figure 2), which displays a normalized mean of vertical coefficients for compensated and decompensated patients. However, two patients including patient number 2 were found to be outliers to this obersvation with their magnitude of the verticle details mean for the compensated wavelet coefficients was higher than the decompensated state. The multiple sounds are n intervals between two adjacent S1.
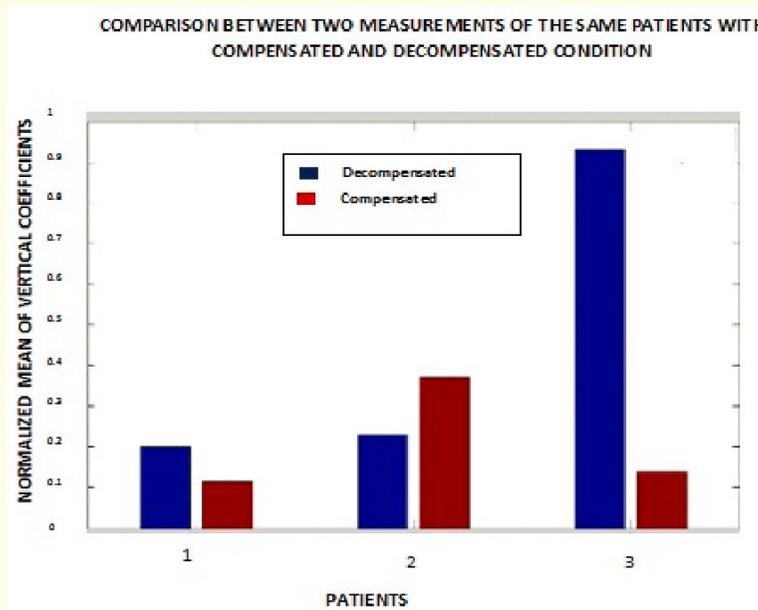
Figure 2: Comparative results of averaging many short duration heart signals (from one S1 sound to the next).

Conclusions

The study results displays that non invasive systems like ECG signals and stethoscope measurements can be effectively used by doctors to ascertain the changes in a patient's condition from a decompensated to compenstated states and vice versa. For CHF patients a strong correlation also exists with changes in weight. For same individuals the wavelet analysis gives promising results in context of displaying consistent differences in spectra. For any given individual in compensated and decompensated stage for the same duration signal the wavelet decomposed coefficients was narrowed in spectra for the same duration.

For the same patients, the diffrences in the compensated and decompensated stages, the mean values of vertical coefficients in a heart beat cycle spanning across two adjacent S1 including the the average of several heart beats dispalyed a diffrence.

For analysis of acoustice signals of heart and lungs the wavelet analysis appeared to be a better approach than Fourier analysis. The analysis also showed no shift in the density of the wavelt coeffients in one of the patients during the two measurements points, and this was inconsistent with the medical results. This patient subsequently expired. Despite some challenges in clearly distinguishing changes among CHF patients due to large variabality among multiple patients, the acoustic analysis, appears to be a useful methdology which can be used for determination of changes in the individual status for a given individual patient over time.The results thus may form a basis for analyzing a larger data sets in order to provide doctors with a system to remotely monitor changes in a patient's condition.

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In furtherance the signal based approach to differentiate among the three stages, namely health, decompensated, and compensated holds a potential for the developing a wearable system for fluid retention diagnosis. The research findings also opens avenues for research in the body sensors, point of care devices, and tele health which would eventually lead to improved quality of care [5]. The principle limitation of the study is the small number of cases that were taken for both the data on compensated and decompensated conditions for the patient.

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