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A modular approach to computer-aided auscultation: Analysis and parametric characterization of murmur acoustic qualities

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ABSTRACT

In the present work, a modularized approach to computer-aided auscultation based on the traditional cardiac auscultation of murmur is proposed. Under such an approach, the present paper concerns the task of evaluating murmur acoustic quality character. The murmurs were analyzed in their time-series representation, frequency representation as well as time-frequency representation, allowing extraction of interpretable features based on their signal structural and spectral characters. The features were evaluated using scatter plots, receiver operating characteristic curves (ROC), and numerical experiments using a KNN classifier. The possible physiological and hemodynamical associations with the feature set are made. The implication and advantage of the modular approach are discussed.

1. Introduction

Heart murmur is one of the most encountered cardiac findings during routine cardiac examination, particularly among children. The examination requires careful evaluations for possible signs of pathological cardiac conditions [1,2]. Cardiac auscultation (CA) is a crucial component of the examination that has a long history of development ever since the invention of the stethoscope by Laennec in 1816. It is a sophisticated procedure, containing a set of well-defined techniques and guidelines. Despite heart sounds being very informative, they are pieces of indirect information that rely largely on limited human ear perception and the subjective sound interpretations. Therefore, CA skill requires well-structured trainings and a long period of practices to achieve a high level of sensitivity and specificity [3,4].

Under the current climate of increased reliance on the medical imaging modalities, CA is struggling to position itself in modern physician practices [2,5,6]. Computer-aided auscultation (CAA) of murmurs is one notable area of effort to improving reliability and accuracy and reducing the subjective nature of the heart sound diagnosis [7–19]. The major goal of the existing approaches to CAA implementations is to develop a pattern classification process to obtain an optimal set of features that maximize the success rate of classifying a set of selected heart diseases. Such approach undermines the fact that diagnostic CA decision-making is a modular process that requires numerous intermediate conclusions, using both acoustic and non-acoustic information, to reach the final diagnosis. The subsequent developed system is optimized to deal with a very specific set of heart diseases such that the system may provide little useful information or become not applicable beyond the range of the predefined classification problems. While such drawback is not as crucial when concerning heart murmur screening (as found in [7–12]), it may be necessary for a diagnostic CAA system (as found in [13–19]) to be able to handle a wide variety of heart sound based diagnosis. In other words, like the traditional CA, CAA should also be modular such that not only could it handle the commonly occurred heart conditions, but also the rare cases by applying the well-established CA guideline and techniques. Therefore, it is of advantageous to develop a CAA system with multiple modules in mind. It is such that each developed module does not focus on drawing conclusions on specific diseases, but accomplishing one or more tasks that are part of the CA diagnosis process. There are a number of existing works that falls within the above concept, such as Ning et al. [20] who tackled the task of classifying different configurations of the murmurs, Yildirim et al. [21] who developed a solution for robust measure of the timings of the second heart sound split components, and Javed et al. [22] who developed a framework for heart sound segmentation and classifications of murmurs by their timing within the corresponding cardiac cycles.

The intent of the present work was to look into the matter of the characterization of the cardiac murmurs by their acoustic qualities. In traditional CA, murmurs are generally characterized by characters including: intensity, origin of location, pitch, configuration,

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duration, radiation, and quality [2,23,24]. The acoustic qualities of cardiac murmurs are closely related to the hemodynamical and the physiological state of the heart. However, there is currently no quantitative measures available to distinguish between the different murmur qualities, making it a highly subjective task in CA. Therefore, the goal was to first obtain quantitative features that can be used to determine different murmur qualities. Second, it was to investigate the possible physical meaning of the features with respect to the murmur qualities and their correlation with the conditions of the heart. Third, it was to discuss how the present study fits into the concept of modularized CAA approach discussed above.

2. Method

Due to the qualitative nature of characterizing heart murmurs according to their acoustic qualities, the present work required a set of heart sound data containing diagnostic information regarding to the acoustic quality of murmurs. An educational database from Cor Sonics Inc. coauthored by M.D. Douglas L. Roy [25] was used. There were roughly 100 heart sound data contained matching diagnostic descriptions for references. No information on the recording apparatus was available for reference. Recording files had sampling rate of either 11 kHz or 22 kHz. 48 heart sound data with the required characterization of murmur qualities were selected for use and all 22 kHz files were down sampled to 11 kHz format. Because the recording apparatus for each of the sound data was unknown, *Z*-score was used to normalize the heart sound.

In traditional CA, qualitative descriptors are used to specify the inherited acoustic quality from a murmur. Some examples of commonly used descriptors include: soft, harsh, blowing, rumbling, coarse, and musical. Based on the diagnostic descriptions from the available heart sound data, four major quality descriptors were used to describe the quality of murmurs and were used in the present study: blowing, musical, coarse, and non-coarse. The murmurs used in this study were then divided into four different categories according to the four quality descriptors. In each of the heart sound recordings, three to five systolic segments, depending on the quality of the recordings, were extracted manually for analysis. 50 segments of musical quality murmurs, 35 segments of blowing quality murmurs, 30 segments of coarse quality murmurs, and 33 segments of non-coarse quality murmurs were obtained, which resulted in a total of 148 murmur segments.

Murmurs were first visually analyzed in their original time-series representations (TR), frequency representation (FR) through the Fourier transform (FT), and time-frequency representation (TFR) through the continuous wavelet transform (CWT). The magnitudes of the frequency spectrum from FT and the scalogram from CWT were normalized by dividing by the maximum amplitude to observe only the distribution of the frequency components without being affected by the amplitude of the murmur from one sample to another. The analysis provided clues to the potential features extractions for characterizing the murmur qualities. The extracted features were then examined and tested using scatter plot and receiver operating characteristic (ROC) curve analysis to determine the effectiveness of each feature. Four binary classification schemes were used to implement ROC curve analysis. The four schemes were: blowing murmurs vs. others, musical murmurs vs. others, coarse murmurs vs. others, and non-coarse murmurs vs. others. Areas under the curves (AUC) were computed for numerical comparisons and the results were used to select a suitable set of features for murmur quality characterization.

The selected features were further tested under the four schemes using a k-nearest neighbor (KNN) classifier. KNN was considered a suitable choice in the present work due to its ease of implementation while providing a quick reference for the overall performances of the features. To determine a proper k value for the KNN classifier, a heuristic technique based on the 10-fold cross validation was implemented. k values from 1 to 100 were used for the technique. The classification performances were then evaluated again using the 10-fold cross validation.

3. Results

Figs. 1–4 depict the sample results of different murmur quality in their TSR, FR, and TFR. For the musical quality murmur as shown in Fig. 1, the TSR had a strong representation of a sinusoidal like waveform and a relatively simpler structure. It was shown in FR and TFR that the frequency bandwidth was narrow with an apparent dominant frequency. The frequency distribution across the time axis was also very condensed and uniform. For the blowing quality murmur shown in Fig. 2, components of much higher frequencies above 200 Hz were presented in FR and TFR, extending as far as 400 Hz. The distribution of the frequency along the time axis showed a high degree of irregularities. TSR also showed a much more complex structure, an implication of more frequency components presenting within the signal. For the coarse quality murmur shown in Fig. 3, more dominating frequencies

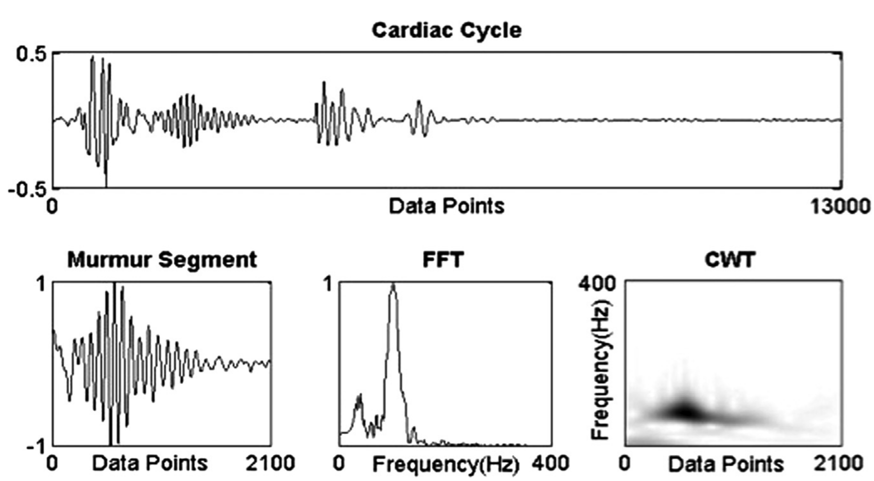

Fig. 1. Examination of the musical quality murmur in its TSR, TFR, and FR. The musical quality murmur has a distinct tonal quality with simple sinusoidal like signal oscillation in TSR. An apparent dominant frequency can be observed in both FR and TFR.