Noise and the detection of coronary artery disease with an electronic stethoscope

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Abstract—Recent studies demonstrated that diastolic heart sounds, recorded with an electronic stethoscope, contain markers of coronary artery disease (CAD). A difficult is that the CAD-related sound is very weak and recordings are often contaminated by noise. The current study analyses the noise contamination of 633 stethoscope recordings from a clinical environment. Respiration noise, ambient noise, recording noise and abdominal noise were identified in the recordings and were classified according to duration and intensity. To monitor how noise influences the classification performance AR-pole magnitudes were extracted from both the 25-250 Hz frequency band and the 250-1000 Hz frequency band. The classification performance was quantified by the Area Under the receiver operating Characteristic (AUC). Ambient noise was present in 39.9% of the recordings and was the most common noise source. Abdominal noise was the least common noise source, present in 10.8% of the recordings. The best pole, with respect to detection of CAD, extracted from the 250-1000 Hz frequency band was sensitive to noise, since the AUC dropped from 0.70 in to 0.57 when noisy recordings were included. Contrary the best pole from the 25-250 Hz frequency band was relatively robust against noise, since the AUC dropped from 0.73 to only 0.70 when noisy recordings were included. The study demonstrated that noise contamination is a frequent problem and that features from lower frequency bands are more robust against noise than features from higher frequency bands.

Keywords - coronary artery disease, stethoscope, heart sound

I. INTRODUCTION

Although the role of the stethoscope in the modern clinic seems to be fading, new electronic stethoscopes with integrated diagnostic algorithms might alter the trend and again expand the clinical potential of the stethoscope. An example of such a type of algorithms is a detector of coronary artery disease (CAD).

Previous studies have shown that the diastolic sound from CAD patients differ from non-CAD patients [1]. The difference is likely caused by weak murmurs originating from post-stenotic turbulence in the coronary arteries. One method for quantifying the difference in diastolic heart sounds is based on autoregressive (AR) models of the diastolic sounds. Akay et al. found that the pole magnitudes in AR-models of the diastolic heart sounds in CAD patients differed from non-CAD patients [1].

Originally, the weak sounds were collected using very sensitive custom-made sensors, but the advent of electronic stethoscopes offers new opportunities [2],[3]. Advances of the electronic stethoscopes are portability, low cost and ease of use. The potential of implementing a CAD detection algorithm in electronic stethoscopes would yield an easily applicable CAD test. However the CAD related murmurs are very weak and the difference between CAD and non-CAD sounds is small. Detection algorithms are, therefore, likely to be sensitive to other types of noise, such as ambient noise and physiological noise, which will limit the usability of the method.

The purpose of the current study was to examine the noise sensitivity of AR-models of heart sound, when the models were applied for identification of CAD patients.

II. METHOD

To analyze the influence of noise at the CAD detection algorithm, recordings from CAD and non-CAD subjects were obtained in hospital rooms, with four beds per room. Subsequently was the noise in the recordings quantified by listening and visual inspection of the recording by an expert in the field of heart sounds. At last was the classification performance of the AR-model evaluated under inclusion and exclusion of different types of noisy recordings.

A. Data collection

Bedside recordings (633 in total) were made from the left 4th intercostal space on the chest of 140 patients using a commercially available electronic stethoscope (3M Littmann E4000). Inclusion criteria were: normal heart rhythm and a recording quality allowing visual recognition of the first and second heart sounds. Each recording was of 8 seconds duration, corresponding to the capacity of the stethoscope. They were subsequently transferred to a portable PC. Between one and six recordings were collected from each patient. The patients were referred for coronary angiography at the Department of Cardiology at Aalborg Hospital. The coronary angiography images from the patients were analyzed with quantitative coronary angiography, giving the dimensions of the stenosis.
variance. The power of the noise was subjectively classified as falling into one of the following groups:
- Insignificant noise. The noise is not audible or only very weakly audible in a short event.
- Weak noise. The noise is audible under careful listening.
- Moderate noise. The noise is clearly audible.
- Powerful noise. The noise is the dominating sound.

C. The AR-pole magnitude

Using the sub-segmentation method by Schmidt et al. [3] the pole-magnitudes of the AR-models were extracted from the diastolic segments. The sub-segmentation method divided the diastolic periods into sub-segments of short duration and removed sub-segments with high variance. AR-pole magnitudes were calculated from the remaining sub-segments. The sub-segmentation method improved the robustness against noise of short duration, such as friction spikes. AR-models with order 2, 4, 6 and 10 were constructed using the forward-backward method [4]. The pole magnitude which obtained the best classification performance in recordings without noise ("insignificant noise" in all four noise categories) was used for classification between CAD and non-CAD in all recordings. Early studies of heart sounds from CAD patients focused mainly on frequencies in the 180-1200 Hz range since CAD was associated with increases in spectral energy above 250 Hz [1], whereas recent studies include lower frequencies [2], [5]. To mimic these studies the AR-pole magnitudes were extracted from the 25-250 Hz frequency band as well as the 250-1000 Hz frequency band. The frequency bands were created using 8th order Chebyshev band pass filters.

D. Evaluation of performance and noise sensitivity

The classification performances of the selected AR-poles were evaluated by calculating the Area Under the receiver operating Characteristic (AUC). The AUC was evaluated for each AR-pole and for each noise category.
under different allowable levels of noise intensity and durations. For each graph all other noise sources were kept at the level of no noise ("Insignificant noise").

III. RESULTS

Only 154 out of 633 recordings (24.3%) were clean, meaning that all four noise types were scored as "insignificant noise". This included recordings from 81 patients out of 140 patients (57.9%). Table 1a-d is a four-fold cross tabulation counting the number of recordings contaminated by the different noise types at different noise intensities and durations. 565 recordings (89.2%) were clean of significant abdominal noise, while only 385 recordings (60.1%) were free of ambient noise.

When the recordings were filtered with the 250-1000 Hz band pass filter the best performing pole for the "clean data" was the pole of the second order AR model. In the clean dataset the AUC was 0.700. When all noisy recordings were included the AUC dropped to 0.567. Figure 2 shows the AUC results from the 250-1000 Hz frequency band for the four types of noise as a function of maximum allowed noise intensity and noise duration. The thick black lines indicate the level of maximum allowed noise above which the AUC deteriorates to values below 97.5% of the maximally obtained value. For this plot the 250-1000 Hz frequency band was used.

The four plots illustrate the AUC result for the four types of noise as a function of maximum allowed noise intensity and noise duration. The thick black lines indicate the level of maximum allowed noise above which the AUC deteriorates to values below 97.5% of the maximally obtained value. For this plot the 250-1000 Hz frequency band was used.

IV. DISCUSSION

That only 24.3% of the recordings were clean of noise contamination demonstrates the difficulties related to the use of electronic stethoscopes with sensitive diagnostic algorithms in clinical environments. The ambient noise was present in nearly 40% of all recordings and was the most common source of noise. Abdominal noise was less common, only present in 10.8% of the recordings, and in most cases the abdominal noise was of short duration, see table1d. In contrast to the remaining noise sources abdominal noise is not controllable. Respiration noise can be limited by asking the patients to hold their breath. Recording noise might be
minimized by changing the design of the sensor and ambient noise might be reduced by active or passive noise reduction.

The AR-pole extracted from the high frequency part of the signal, 250-1000 Hz, was clearly sensitive to noise contamination. Even weak respiration noise and ambient noise affected the AUC, see Figure 2. When the AR-pole was extracted from the 25-250 Hz band the classification performance of the selected pole was not affected by the noise. The difference in noise robustness between the poles from the 25-250 Hz band and the 250-1000 Hz band is expected since heart sounds are dominated by low frequency sounds and the energy of hearts sounds declines at higher frequencies, see figure 1. Therefore, the signal to noise ratio is considerable better at lower frequencies compared to higher frequencies. This might explain why the selected AR-pole from the 25-250 Hz frequency band shows a slightly better classification performance than the AR pole from the 250-1000 Hz frequency band, even though prior studies mainly documented changes in the energy distributions above 250 Hz in CAD patients.

To define an acceptable level of noise contamination a boundary was defined where the AUC drops to below 97.5% of its maximum, in figure 2 and 3. If the “black line” criterion for the 250-1000 Hz band were followed only 39.2% of the recordings were useful, while if the “black line” criterion for the 25-250 Hz band were followed 80.4% of the recordings were useful. The robustness to noise and the AUC performances of the pole extracted from the 25-250 Hz frequency band indicate that features extracted from the lower frequencies of the heart sounds are most suitable for detection of CAD markers if the heart sounds are recorded with a handheld electronic stethoscope in a clinical environment.

V. CONCLUSION

The current study demonstrates that noise contamination of heart sound recordings is a widespread problem when recordings are collected with an electronic stethoscope in a clinical environment. Both pole magnitudes from AR-models of the 25-250 Hz frequency band and the 250-1000 Hz frequency band allowed reasonable classification between CAD and non-CAD subject, but only the pole extracted from the 250-1000 Hz frequency band was very sensitive to noise.

REFERENCES