IAES Journal of Electrical and Electronics Engineering
Vol. 8, No. 1, June 2021, pp. 21~24
ISSN: 2338-7432, DOI: 10.11591/jeee.v8i1.pp21-24

PC-based visualization of heart sounds: phonocardiogram acquisition, digital signal processing, and graphical interpretation-a review

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Article Info

Article history:

Received Aug 26, 2019
Revised Dec 30, 2019
Accepted Feb 17, 2020

Keywords:

Computer-aided auscultation
Digital signal processing
Electronic stethoscope
Heart sound visualization
Phonocardiogram
Spectrogram

ABSTRACT

Heart sound visualization using personal computers (PCs) provides a practical approach to documenting and examining cardiac acoustic signals beyond conventional auscultation. Traditional listening depends heavily on the examiner's experience and may be affected by environmental noise, limited auditory perception, and difficulties in recognizing subtle temporal variations. This review examines the principles and development of PC-based heart sound visualization, emphasizing phonocardiogram (PCG) acquisition, signal conditioning, digital processing, graphical representation, and potential clinical applications. The reviewed literature covers electronic stethoscopes, noise reduction, cardiac-cycle segmentation, time-frequency analysis, spectrogram generation, and computer-assisted classification. Particular attention is given to the presentation of first and second heart sounds, additional cardiac components, and murmurs through waveform and spectral displays. The review also discusses technical challenges associated with sensor placement, recording quality, sampling, processing delays, and interpretation of graphical outputs. Existing studies demonstrate that digital visualization can improve signal documentation and support systematic examination, although visual patterns alone cannot establish a clinical diagnosis. Further development should prioritize accessible interfaces, reproducible acquisition procedures, robust signal processing, and clinical validation.

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1. INTRODUCTION

Heart sounds provide acoustic information associated with cardiac mechanical activity, particularly valve closure, blood flow, and vibrations of cardiovascular structures. Conventional auscultation remains widely used because it is inexpensive, non-invasive, and does not require complex instrumentation. However, its effectiveness depends considerably on the examiner's hearing ability, clinical experience, and the acoustic conditions of the examination environment. These limitations have encouraged the development of electronic recording and computer-assisted approaches that allow heart sounds to be stored, processed, and displayed graphically [1]–[3].

A phonocardiogram (PCG) is a recorded representation of heart sound activity that can be examined in both the time and frequency domains. Unlike ordinary listening, PCG visualization enables repeated inspection of signal amplitude, duration, timing, and frequency distribution. A personal computer (PC) can function as the central platform for acquiring digital recordings, applying signal-processing algorithms, and presenting the results through graphical interfaces. This capability makes PC-based visualization relevant to medical education, research, preliminary screening, and clinical documentation [1], [2].

The principal research problem is how to convert weak and often noisy cardiac acoustic signals into graphical information that is sufficiently clear and reliable for examination. Environmental interference, respiratory sounds, sensor movement, and variations in recording position can distort the original signal.

Furthermore, a waveform or spectrogram may be visually attractive without necessarily preserving the clinically important characteristics of the recorded sound. This review therefore examines the complete process from signal acquisition to graphical interpretation, while distinguishing visualization support from automated disease diagnosis.

2. PCG ACQUISITION AND SYSTEM ARCHITECTURE

A PC-based heart sound visualization system generally consists of an acoustic sensor, an amplification stage, an analog-to-digital converter, a computer interface, and visualization software. An electronic stethoscope or contact microphone captures vibrations from selected auscultation locations on the chest. The analog signal is conditioned to improve its amplitude and reduce unwanted interference before being digitized. The resulting samples are transferred to a computer, where software can display, store, filter, and analyze the recording [2], [3].

Sensor selection and placement strongly influence the quality of the acquired PCG signal. A contact sensor should maintain stable coupling with the chest surface because movement can introduce artifacts that resemble genuine cardiac events. Recording locations are also important because different auscultation areas emphasize different acoustic characteristics associated with cardiac structures. Studies involving electronic stethoscopes and digital phonocardiography demonstrate the importance of reliable acquisition when measuring cardiac sound components and their timing [4], [5].

The computer platform provides flexibility in signal processing and graphical presentation. Software can display recordings in real time, save individual examinations, compare successive cardiac cycles, and export data for further analysis. A practical interface should include recording controls, signal-quality indicators, time scaling, amplitude adjustment, and options for selecting different visualization modes. Such functions are important because the usefulness of a PCG system depends not only on its processing algorithms but also on how clearly users can inspect the recorded information [1], [2].

3. DIGITAL SIGNAL PROCESSING

Signal conditioning is necessary because heart sounds are relatively weak and can be contaminated by environmental and physiological noise. Common interference sources include speech, movement, breathing, muscle activity, and electrical disturbances from nearby equipment. Digital filtering and wavelet-based methods have been investigated to suppress unwanted components while retaining relevant cardiac information [6]–[9]. The objective is not simply to produce a smoother waveform, but to preserve the acoustic events that may be important during subsequent examination.

Segmentation is another essential processing stage because a cardiac cycle contains several events with different temporal characteristics. The first heart sound (S1) and second heart sound (S2) provide important landmarks for identifying systolic and diastolic intervals. Additional components, including S3 and S4, may also appear under particular physiological or pathological conditions. Algorithms based on hidden semi-Markov models, envelope analysis, and other signal-processing techniques have been developed to identify cardiac events and improve the consistency of PCG interpretation [4], [10]–[12].

Feature extraction can provide additional information beyond the visual appearance of the raw waveform. Time-domain features describe amplitude, duration, and temporal relationships, while frequency-domain features reveal the distribution of acoustic energy. Time-frequency techniques, including short-time Fourier transform and wavelet analysis, are useful because heart sounds are non-stationary signals whose frequency characteristics change over time. Research has demonstrated the use of these representations in PCG analysis and classification, including approaches based on spectrograms and image-derived features [13]–[18].

4. VISUALIZATION TECHNIQUES ON PERSONAL COMPUTERS

The time-domain waveform is the most direct graphical representation of a recorded heart sound. It displays signal amplitude against time and allows users to identify prominent acoustic events, pauses, and variations across cardiac cycles. S1 and S2 can often be observed as relatively distinct waveform components, although their appearance depends on recording conditions and individual characteristics. Waveform visualization is therefore useful for initial inspection, but it may not reveal all frequency-related differences between normal and abnormal recordings [1], [4].

A spectrogram provides a complementary representation by showing how signal energy is distributed across time and frequency. This graphical approach can make frequency variations and transient acoustic components easier to inspect than a waveform alone. Studies using scaled spectrograms, time-

frequency features, and image-based representations demonstrate the relevance of graphical transformations in automated heart sound analysis [14]–[17]. Nevertheless, spectrogram interpretation depends on processing parameters such as window length, overlap, frequency range, and color scaling, which should be reported to support reproducibility.

Waveform and spectrogram displays can be combined in a single PC application to provide a more complete view of cardiac acoustic activity. The waveform helps users examine event timing, while the spectrogram provides information about frequency content and changes over time. A synchronized cursor or selection tool can connect a specific waveform interval with its corresponding spectral region. This arrangement can support teaching and research by allowing users to relate the acoustic event they hear to its graphical characteristics.

5. APPLICATIONS AND TECHNICAL CHALLENGES

PC-based heart sound visualization has potential applications in clinical documentation, medical education, research, and preliminary cardiovascular screening. Recorded signals can be stored for repeated examination, allowing clinicians and researchers to compare observations across different sessions. In educational settings, visual representations may help students understand the relationship between cardiac-cycle events and the sounds heard through a stethoscope. Computer-assisted analysis may also support the identification of unusual acoustic patterns, although diagnostic conclusions require clinical assessment and appropriate validation [1]–[3].

Several technical challenges must be addressed before such systems can be used reliably in routine environments. Poor sensor contact, inconsistent recording locations, background noise, and differences between acquisition devices can produce substantial variations in signal quality. Processing algorithms may also remove useful acoustic components if filtering parameters are selected without considering the characteristics of the original recording. These issues demonstrate why acquisition standards and transparent processing procedures are as important as the visual interface itself [6]–[9].

Another challenge concerns the interpretation of graphical information by users with different levels of clinical and technical experience. A large waveform or colorful spectrogram does not automatically provide meaningful clinical information unless its axes, scales, and relevant events are clearly identified. Software should therefore provide consistent labels, readable time and frequency scales, and the option to listen to selected signal segments. The distinction between a visual feature and a confirmed clinical abnormality must also remain clear to avoid overinterpretation [1], [2].

Table 1 summarizes the main visualization methods and their respective contributions to PC-based heart sound examination. The comparison indicates that no single representation provides all the information required for a comprehensive assessment. Combining waveform, spectrogram, and segmented cardiac-cycle displays can offer a more useful interface, provided that the underlying signal quality is adequate.

Table 1. Comparison of PC-based heart sound visualization methods

Visualization method	Information presented	Main benefit	Main limitation
Time-domain waveform	Amplitude and timing	Shows cardiac events and cycle intervals	Limited frequency information
Frequency spectrum	Distribution of signal energy across frequency	Helps examine dominant frequency components	Does not preserve event timing clearly
Spectrogram	Frequency content over time	Reveals transient and changing acoustic patterns	Sensitive to analysis parameters
Segmented PCG display	S1, S2, systole, and diastole intervals	Supports cardiac-cycle inspection	Segmentation errors may mislabel events
Combined waveform and spectrogram	Temporal and spectral information	Provides complementary graphical views	Requires careful interface and scale design

6. FUTURE RESEARCH DIRECTIONS

Future development should focus on improving recording consistency and making graphical interpretation more accessible. Standardized sensor placement, sampling procedures, and signal-quality assessment would make recordings easier to compare across users and devices. Software developers should also consider interfaces that allow users to move between raw recordings, filtered signals, segmented cycles, and spectrograms without losing the relationship between them. These improvements could strengthen the role of PC-based visualization in research, education, and clinical support.

Machine learning offers opportunities to extend visualization systems with automated pattern recognition. Previous studies have investigated neural networks, convolutional models, and other classification

techniques using PCG signals or their graphical representations [15]–[18]. However, high classification performance on a particular dataset does not guarantee reliable results across different populations, recording devices, or clinical environments. Future research should therefore emphasize independent validation, transparent datasets, explainable outputs, and evaluation under realistic recording conditions.

7. CONCLUSION

PC-based heart sound visualization provides a practical means of recording, displaying, and examining cardiac acoustic signals beyond conventional auscultation. The integration of electronic sensors, digital signal processing, and graphical software enables waveform inspection, frequency analysis, spectrogram generation, and cardiac-cycle segmentation. Existing research demonstrates that denoising, segmentation, and time-frequency representations can support more systematic PCG examination. These capabilities are valuable for documentation, education, research, and the development of computer-assisted analysis. The reliability of a visualization system depends on the quality of signal acquisition, the preservation of relevant acoustic information, and the clarity of the graphical interface. Waveforms and spectrograms should be treated as complementary representations rather than independent diagnostic tools. Future systems should prioritize standardized recording procedures, robust processing, accessible interfaces, and clinical validation across diverse recording conditions. With these considerations, PC-based heart sound visualization can provide a useful foundation for more accessible and reproducible cardiac acoustic assessment.

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