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RESEARCH ARTICLE

A Simple Laptop-based Phonocardiography System: A Novel and Inexpensive Instrument for Research and Clinical Use

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Abstract:

Background:

Cardiac auscultation is a frequent first step in diagnosing heart disorders. However, the lack of dependability of ordinary auscultation in the hands of inexperienced clinicians remains a problem.

Objectives:

We sought to develop an inexpensive system for digital cardiac auscultation (digital phonocardiography) using a Windows laptop computer, freely downloadable software and an inexpensive USB microphone.

Description:

The system, based on the free open-source Audacity software package, offers advanced features such as phonocardiogram storage and retrieval, low-pass and high-pass waveform filtering and variable-speed signal playback with pitch preservation.

Results:

Sample results for both raw and digitally filtered phonocardiograms are provided.

Conclusion:

An innovative laptop-based phonocardiogram system offering advanced features can be easily produced at minimal cost.

Keywords: Audio signal processing, Audacity audio software package, Digital phonocardiography, Digital signal processing, Heart sounds, Phonocardiogram.

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1. INTRODUCTION

Listening to the emitted sounds from the heart using a stethoscope (auscultation) is a frequent first step in cardiac diagnosis. Auscultation is often followed by echocardiography when the auscultatory findings are abnormal. However, the limited reliability of ordinary auscultation in the hands of ordinary clinicians [1 - 5] and the expense and awkwardness of echocardiography may make it desirable to develop a more advanced approach to cardiac auscultation based on computer-based techniques (digital phonocardiography). This technical report discusses how through the addition of an inexpensive USB (Universal Serial Bus) miniature microphone one can convert an ordinary stethoscope and a Windows laptop computer into a phonocardiogram system offering advanced features such as phonocardiogram storage and retrieval, low-pass and high-pass waveform filtering and signal playback at selectable speeds with pitch preservation.

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2. CONSTRUCTING THE SYSTEM

To convert a Windows laptop computer into a phonocardiogram system, one need only add two elements. The first is the needed software (Audacity, discussed below) and the second is an easily constructed USB stethoscope that plugs into the USB port of the laptop computer. To construct the USB stethoscope, one begins by obtaining a USB lavalier microphone (Fig. **1**) and connecting it to a stethoscope head via a short piece of tubing (Fig. **2**). Once the assembly is plugged into the laptop's USB port, it will be necessary to ensure that the new microphone is recognized. To do this under Windows 10, one must go to the Windows "Settings" menu, and select the "Sound" tab. With successful registration of the new microphone, one should see something akin to the information displayed in Fig. (**3**).

3. THE AUDACITY SOFTWARE PACKAGE

Central to this project is the Audacity software package. Audacity is a particularly well-supported and well-documented open-source digital audio editor and recording application available for the Windows, macOS/OS X and Linux operating systems. It can be freely downloaded at https://www.audacityteam.org. Shown in Fig. (**4**) is a brief musical passage (Beethoven's Symphony No.5 in C Minor) being processed using Audacity.

Although Audacity has an almost overwhelming array of features and options, three classes of features found in the "Effect" menu are likely to be of special interest to phonocardiographers. These include [1]: the Amplify feature that scales the signal [2], the Normalize feature that "normalizes" the signal to a chosen maximum amplitude (*e.g.*, 0 dB), and [3] three digital filtering options (Low Pass Filter, High-Pass Filter and Notch Filter).

Fig. (1). This miniature electret microphone with an integral USB interface was purchased on eBay for under $7.00, including shipping (https://www.ebay.com/itm/Mini-Clip-on-USB-Lavalier-Lapel-Condenser-Microphone-Mic-for-PC-Internet-DIY/223411911450). When used for phonocardiography applications the lapel clip and the foam microphone cover are discarded and the unit is attached to a stethoscope head *via* a short piece of tubing (Fig. **2**).

Fig. (2). The miniature electret microphone shown in Fig. (**1**) acoustically connected to a 3M Littman Classic II SE stethoscope head *via* a short piece of tubing.

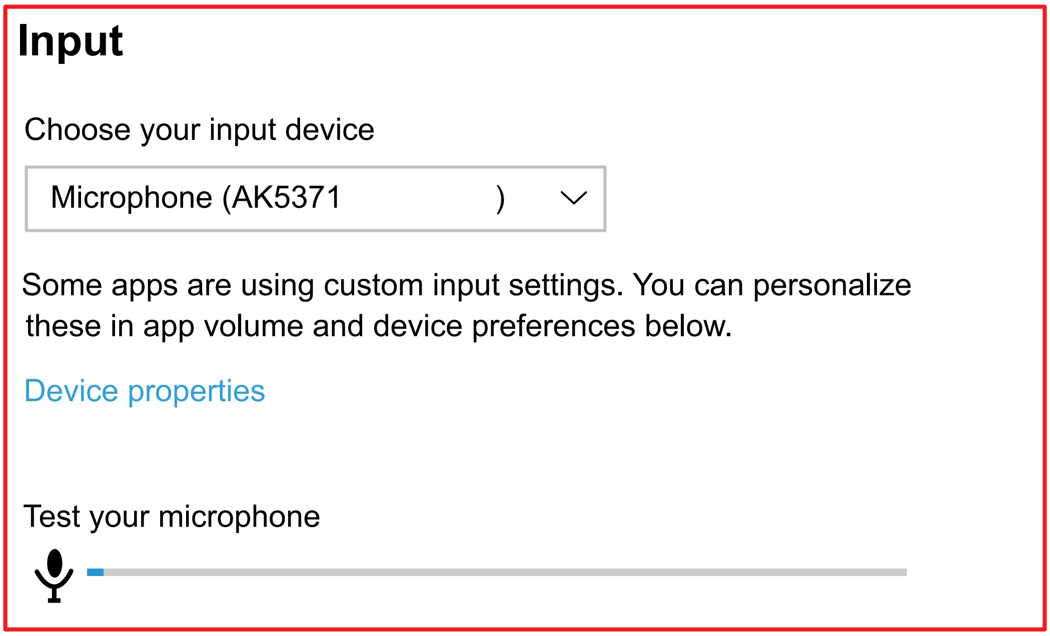

Fig. (3). Screenshot of a portion of the "Sound" portion of the "Settings" menu in Windows 10. In the case of the microphone shown in Figs. (**1** and **2**), the device goes by the name "AK5371", but a different name might be expected when using a different USB microphone. The "Test your microphone" feature displayed on the bottom of the panel allows users to watch the bar graph amplitude change as they speak into the microphone under test.

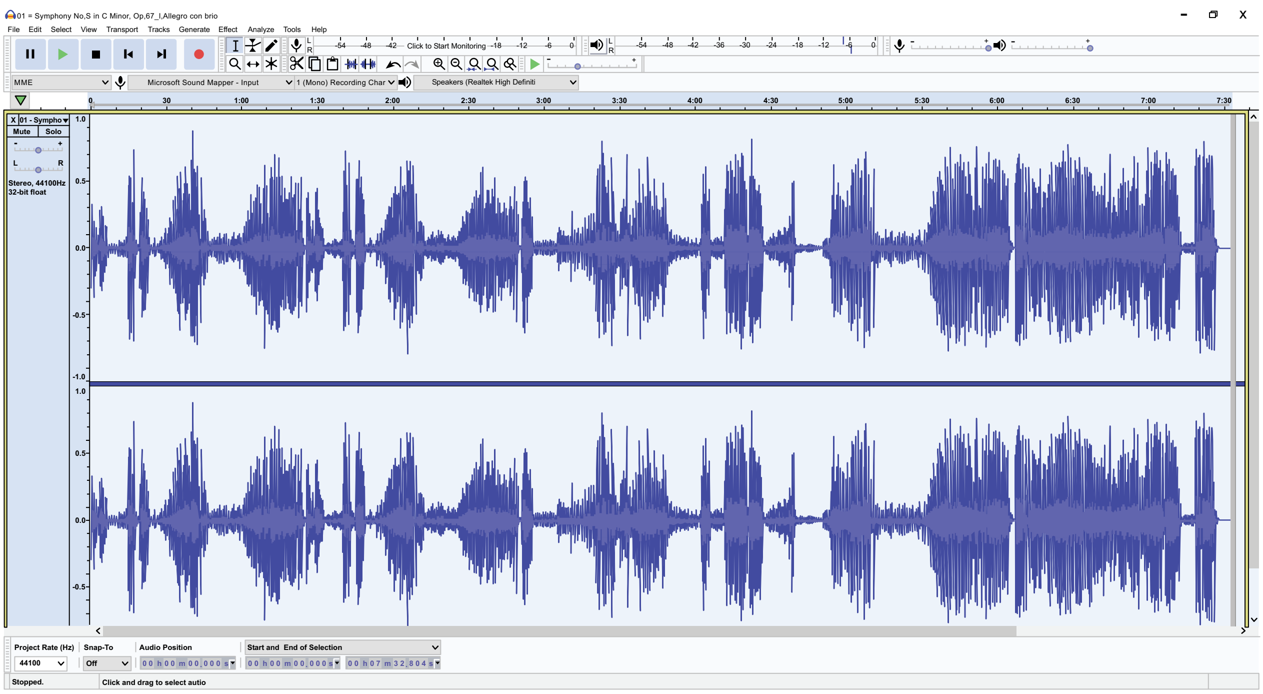

Fig. (4). Screenshot of the Audacity audio software package displaying the first portion of Beethoven's famous Symphony No.5 in C Minor. This powerful, free, open source software package offers numerous features for processing audio signals, many which are of potential value for phonocardiography applications.

One final feature known as "Change Tempo" that may captivate some users is the ability to change the speed of a recording without changing the sound pitch, a feature of potential value in listening to heart sounds in tachycardic patients.

A YouTube video demonstrating the basics of using Audacity is available at https://www.youtube.com/watch?v=LQ7n9pA0qc0

4. SAMPLE RECORDING

Fig. (**5**) shows a sample phonocardiogram recording obtained from the author with the USB stethoscope placed over the second left intercostal space adjacent to the sternal border (pulmonic valve area). The top portion of Fig. (**5**) shows 13.3 seconds of the phonocardiogram recording, comprising approximately 16 cardiac cycles. Investigators wanting to “zoom in” on a portion of the recording so as to be able to examine events more closely can easily do so with the Audacity waveform “zoom” feature. As illustrated in the middle panel of Fig. (**5**), the “zoomed-in” phonocardiogram now shows only the first 3.3 seconds of the recording, making the first and second heart sounds somewhat clearer. Finally, the bottom of Fig. (**5**) shows the same 3.3 seconds of the recording after high-pass filtering (200 Hz, 6 dB/octave roll-off) and normalization. Notice how this high-pass filtering operation helps make the separate heart sounds even more distinct.

5. COLOR SPECTROGRAPHIC ANALYSIS OF THE PHONOCARDIOGRAM

It will be of interest to some readers that additional signal processing techniques have been described that might be applied to phonocardiograms collected using the described system. As an example, color spectrogram analysis of phonocardiogram signals allows phonocardiography to be carried out in the frequency domain [6].

Fig. (**6**) shows the phonocardiogram presented in Fig. (**5**) analyzed in this manner using the Spectrogram16 software package, available as a free download at https://auditory neuroscience.com/sites/default/files/gram16_setup.zip.

Numerous other analytical techniques for phonocardiogram analysis have also been advocated [7 - 10].

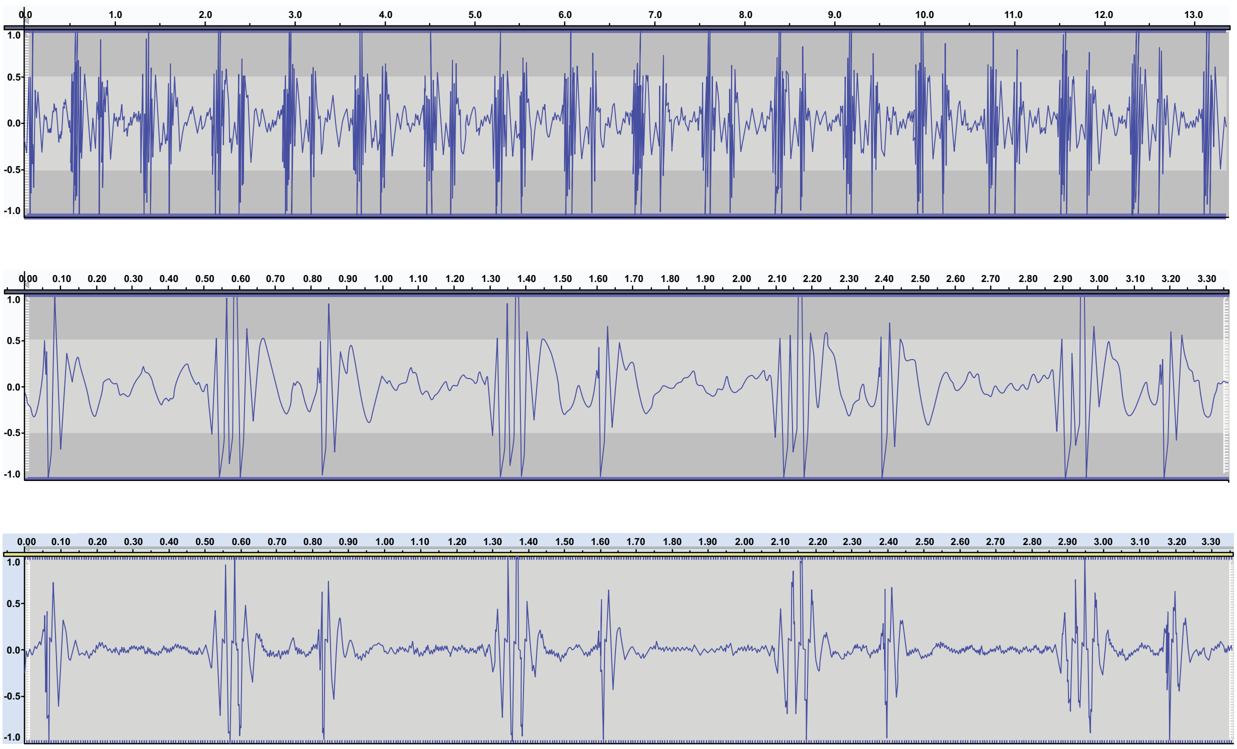

Fig. (5). Sample phonocardiogram recording obtained under apneic conditions. The recording was from the author with the USB stethoscope placed over the second left intercostal space adjacent to the sternal border (pulmonic valve area). **Top:** First 13.3 seconds of the recording. **Middle:** “Zoomed in” portion of the above phonocardiogram showing the first 3.3 seconds of the recording, making the first and second heart sounds somewhat more distinct. **Bottom:** First 3.3 seconds of the recording after high-pass filtering (200 Hz, 6 dB/octave roll off) and normalization. Notice how this filtering operation helps make the separate heart sounds more distinct.

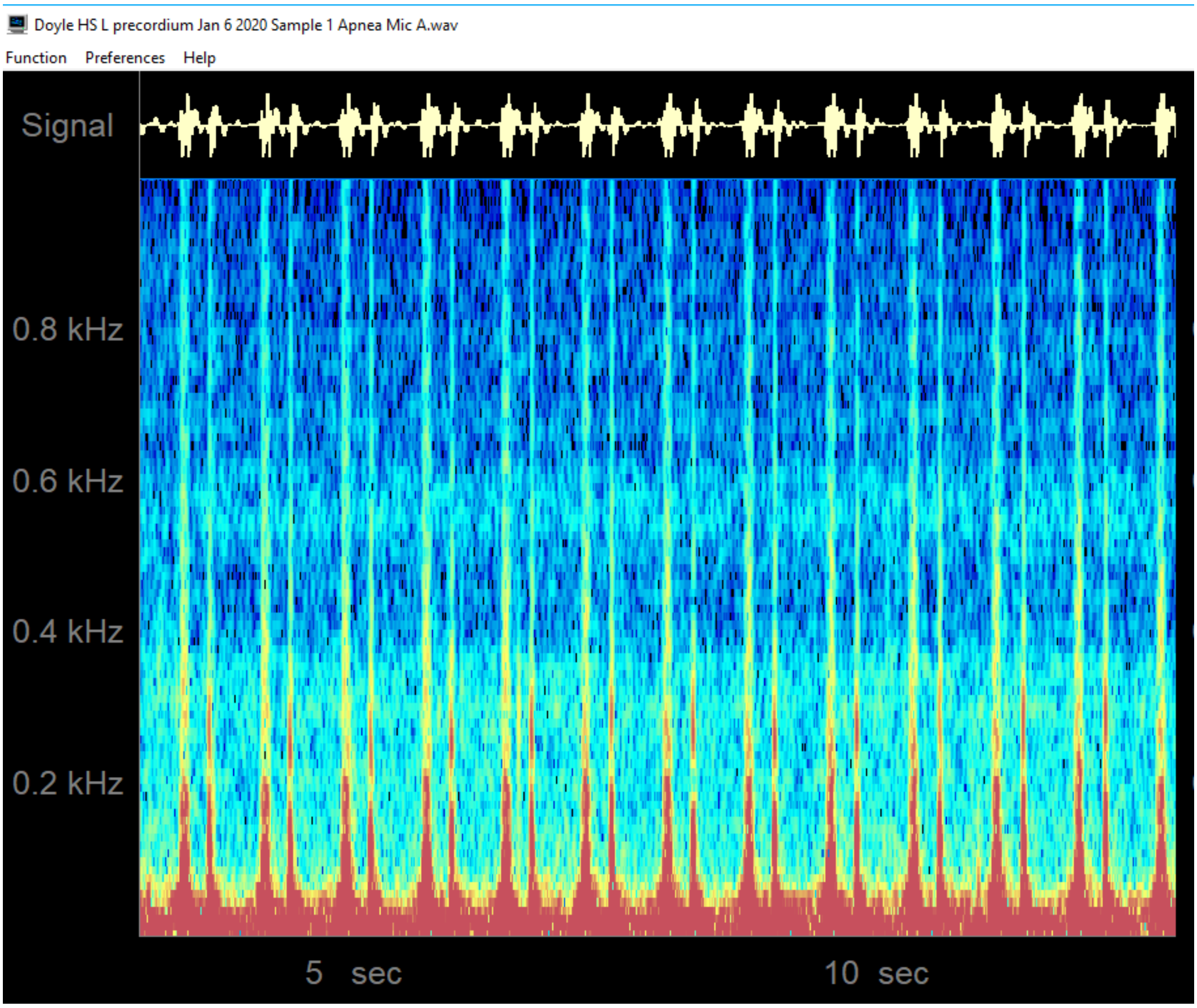

Fig. (6). The color spectrogram of the phonocardiogram signal shown in Fig. (**5**) obtained using the using the Spectrogram16 software package. This package is available as a free download at https://auditoryneuroscience.com/sites/default/files/gram16_setup.zip. Note that the specific image obtained will depend strongly on the analysis parameters chosen (*e.g.*, FFT size, frequency resolution, maximum and minimum spectrum levels, and chosen upper and lower frequency band limits).

6. DISCUSSION

The phonocardiography system described herein will interest many clinicians and investigators interested in exploring the science of digital phonocardiography. Perhaps the most appealing aspect of this system is its extremely low cost to individuals owning a laptop computer and willing to sacrifice a stethoscope, as the software used is available as free downloads and the USB microphone used for this project costed a mere $7.00 US.

Work is continuing at our laboratory to further develop the system for use in limited-resource settings. As an example, we have started working on the development of a dual-channel phonocardiogram system based on a low-cost USB 2.0 dual microphone setup[1]. The use of dual-channel phonocardiography will allow investigators to compare two precordial recording sites simultaneously rather than relying on the comparison of sequential recordings which would not ordinarily be able to be aligned with respect to influencing events such as inspiration and expiration. (Note that because respiration changes the heart position due to movement of the diaphragm, cardiac waveforms such as the electrocardiogram, the blood pressure wave and the phonocardiogram will vary at least slightly within the respiratory cycle.)

A second area where work is continuing at our laboratory to further explore the research and clinical roles of digital high-pass filtering of the phonocardiogram. For example, from Fig. (**5**), we saw that following high-pass filtering at 200 Hz, the separate heart sounds were somewhat more distinct. This raises the question as to what specific digital filtering parameters might be best employed to help identify some particular cardiac events, such as to identify a split heart sound or to better detect a faint diastolic murmur. As a specific example, where phonocardiogram filtering has been helpful, Zuber and Erne [11] searched for potentially pathologic fourth heart

[1] For example, https://www.ebay.com/itm/Dual-Head-Condenser-Microphone-Mic-USB-Plug-Clip-on-Microphone-Black/202867577023

sounds in a frequency band of 60-180 Hz "that occurred in the interval between the onset of the ECG P wave and the first heart sound" in patients undergoing exercise testing.

A related research area is to explore phonocardiogram digital filtering methods to more precisely identify the onset times for the first and second heart sounds for use in cardiac time interval research [12]. Cardiac time intervals that have been studied include the pre-ejection period (PEP), the electromechanical activation time (EMAT), the left ventricular ejection time (LVET), the duration of total electromechanical systole (QS2), the isovolumic contraction period (IVCP) and the degree of electromechanical delay (EMD) [12]. As the onset of the first heart sound corresponds to the beginning of mitral and tricuspid valve closure and the onset of the second heart sound corresponds to the closure of the aortic and pulmonic valves (and thus are important timing markers for cardiac time interval studies), one can see that the development of phonocardiogram digital filtering strategies to help ensure accurate times for the onset of these sounds may be of potential value.

We are also exploring possible means to inexpensively incorporate a concurrent electrocardiogram signal into the system. Our proposed approach is to use an inexpensive dual-channel USB audio signal capture card[2] with one signal channel fed with an amplified phonocardiogram signal derived from an ordinary (non-USB) microphone / stethoscope head assembly, and with the other channel fed with an electrocardiogram signal based on the Analog Devices AD8232 chip.[3] This arrangement would allow some forms of acoustic cardiography to be performed [13 - 16]. Additionally, the availability of a QRS complex timing reference would allow the phonocardiogram to be segmented into the individual cardiac cycles that are required to allow cardiac murmur detection *via* the novel technique of digital subtraction phonocardiography [17].

Finally, consideration should be given to taking advantage of recent developments in the field of wireless phonocardiography sensors, such as the efforts of Sa-Ngasoongsong *et al*. [18].

CONCLUSION

Through the addition of an inexpensive USB miniature microphone and the free open-source Audacity software package, one can convert a laptop computer into a phonocardiogram system offering features such as phonocardiogram file storage and retrieval and digital waveform filtering.

[2] For example, https://www.ebay.com/itm/USB-Audio-Capture -Audio-Grabber-for-Cassette-Tapes-to-MP3-Converter-for-MAC/202625388637

[3] For example, https://www.ebay.com/itm/Single-Lead-AD8232- Heart-Rate-Monitor-ECG-Developemt-Kit-Arduino-Compatible/311683200420

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

A repository of the sample phonocardiograms and the analysis software described herein is available as a single downloadable compressed data file in ZIP format from https://www.dropbox.com/s/3obhsmazr2r3iti/Phonocardiogram%20Project%20Data%20Repository.zip

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CONFLICT OF INTEREST

The author declares no conflict of interest, financial or otherwise.

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Declared none.

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[http://dx.doi.org/10.1371/journal.pone.0112673] [PMID: 25393113]

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