System for Acquisition of Weak Murmurs Related to Coronary Artery Diseases

John Hansen[1], Henrik Zimmermann[2], Samuel E Schmidt[1],
Dorte Hammershøi[2], Johannes Jan Struijk[1]

[1]Department of Health Science and Technology, Aalborg University, Aalborg, Denmark
[2]Acoustics, Department of Electronic Systems, Aalborg University, Denmark

Abstract

The aim of the present study is to describe the design of an acquisition system for the specific purpose of recording heart murmurs originating from stenosis in the coronary arteries. The design and development of such a system require knowledge in many disciplines: acoustic couplers, microphones, skin adhesives, electronic hardware, software and patient safety. Special considerations are needed in order to record these murmurs since they have a 60 dB lower sound level, than that of the closing heart valves. The system was implemented and successfully used for collection of heart sounds in a clinical trial including 463 patients referred for elective coronary angiography.

1. Introduction

Coronary artery disease (CAD) is one of the leading causes of death in the world [1] and it is predicted to remain so for the next 20 years [2]. Early detection of CAD is thus very important since proper treatment at its early stage can stop the progress of the disease. Current diagnostic methods such as coronary angiography and exercise tests are both costly, time consuming and not without an element of risk for the patient.

Previous studies have shown that heart sounds may contain weak murmurs caused by turbulence in the poststenotic blood flow in the coronary arteries and that this turbulence-related sound is a potential diagnostic indicator of CAD [3]. An acquisition system for recording heart sounds and potentially heart murmurs was designed and developed in order to evaluate the diagnostic potential.

2. Method

The developed acquisition system for the specific purpose of recording heart murmurs originating from stenosis in the coronary arteries is shown in figure 1. The major parts include:

1. Double adhesive patch
2. Transducer (see figure 2)
3. Sound acquisition system (see figure 3)
4. Laptop with custom build acquisition software
5. Optional headphones with volume control
6. Sound level calibrator

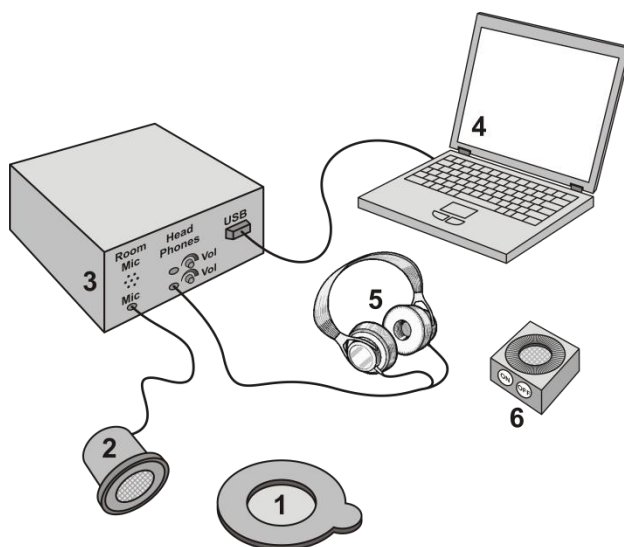Data acquisition hardware and software will be described independently in the following sections.

Figure 1. System overview, showing all major parts in the setup.

2.1. Data acquisition hardware

Double adhesive patch
The transducer is placed on the left 4th intercostal space on the chest of patients using a double adhesive patch. This will reduce handling noise and create an air tight coupling to the air cavity show in figure 2.

Transducer

The transducer consists of a hollow plastic housing with a mounted ½-inch condenser microphone (Type 40AD from G.R.A.S. Sound & Vibration, Holte, Denmark) and a custom built FET-preamplifier (Type 4037-aau from DPA, Alleroed, Denmark). The preamplifier has a unity gain and acts as an impedance matcher (converts the high impedance of the microphone to a low output impedance which makes it possible to transfer the signal to the sound acqusition system). The air tight cavity between the chest and the microphone is approx. 300 mm^3 and has been designed for the specific purpose of recording weak heart sounds [4].
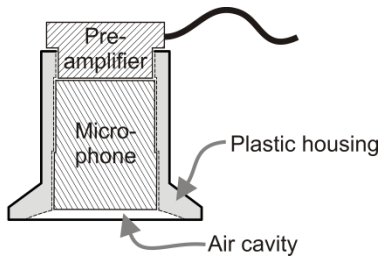

Figure 2. A cut through of the transducer showing the air cavity, plastic housing, microphone and pre-amplifier.

Sound acquisition system

The sound acquisition system was built with a combination of custom made electronics and a commercially available sound card, USB hub and a flash memory stick. A system overview can be seen in figure 3.

Battery power unit

The acquisition system is powered by two 14.8 V high power rechargeable Li-ion battery modules with a total capacity of 3200 mAh. The batteries are charged with a power supply unit delivering a charge current of 1.5 A. This gives a maximum charge time of just over 2 hours and the system can run for approx. 10 hours when fully charged. A safety relay disconnects everything but the battery module when the charge unit is connected to mains.

Power supply

Power for the acquisition system is delivered by two ultra-compact isolated DC/DC converters (Type JHM0312D15 and JHM0612S05 from XP Power, Sunnyvale, USA) delivering ±15 V for the analog front end and +5 V for the sound card, respectively. They are both in compliance with the medical electrical equipment safety standard IEC 60601-1.

Analog front end

The analog front end amplifies and low pass filter the audio signals from the transducer as well as from a chassis mounted room microphone. The gain is 24 dB and the low pass cutoff frequency is 20 kHz. A second gain and band pass filter feeds the transducer signal out to two headphones with individual volume control. The band pass filter will give an output to the headphones with a stethoscope like behavior. The high and low pass cutoff frequencies of the band pass filter are 35 Hz and 2 kHz, respectively.

Sound card

A 24-bit USB audio capture device (Type UA-25EX from Cakewalk by Roland, Boston, USA) is used for digitizing the analog audio signals. Data acquisition is handled by software on the laptop. Two channels (room microphone and heart sound transducer) are stored at 48 kHz each with 24 bit resolution.

USB isolator

Additional patient safety is provided with a USB isolator (Type USI-01 from SonoWin, Berlin, Germany) that provides a galvanic isolation between the patient and the laptop. The device is approved according to the Medical Device Directive 93/42/EEC.
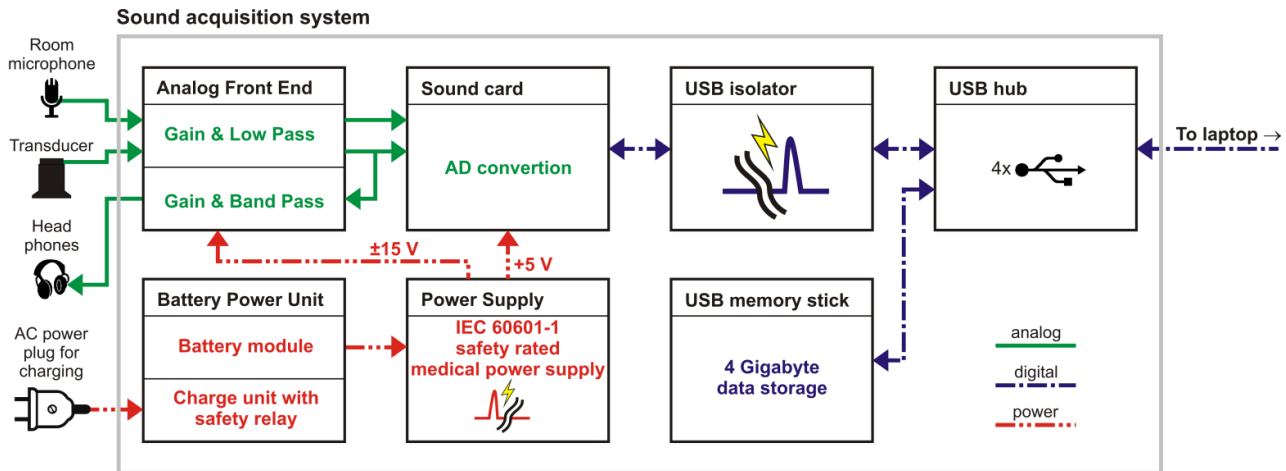

Figure 3. Block diagram, showing all major parts in the sound acquisition system.

USB hub

A USB hub is used in order to simultaneously connect a laptop with the sound card and an onboard data storage facility.

USB memory stick

A 4 gigabyte flash memory device is used for data backup. When a recording is over, data are stored on the hard drive of the laptop and a compressed version is stored on the backup drive inside the acquisition system. Thus, data can always be restored as long as both devices do not fail simultaneous.

Laptop with custom build acquisition software

A laptop (Type ThinkPad R400 from Lenovo, China) running custom made acquisition software is handling the patient setup and data collection. A graphical user interface (GUI) was designed and implemented in LabVIEW (Version 8.6 from National Instruments Corp., Austin, USA). See section 2.2 for details on software.

Optional headphones with volume control

Correct placement of the transducer can be supervised by using one of two optional headphones. An air tight coupling should be achieved when connecting the double adhesive patch with the transducer. A potential leakage is easily detected when listening to the sound via headphones.

Sound level calibrator

A sound calibrator (Type 4231 from Brüel & Kjær Sound & Vibration Measurement A/S, Nærum, Denmark) was used at the onset of every recording day in order to verify and log the quality of the transducer. The device sends out a 1 kHz calibration frequency (accuracy ±0.1 %) with amplitude of 94 dB SPL (accuracy ±0.2 dB).

2.2. Data acquisition software

A LabVIEW GUI was designed to handle subject setup and data collection. The layout is shown in figure 4 and consists of 4 main elements:

1. Operator/Subject Setup
2. PC Battery Status
3. Recording Setup
4. Waveform and Data Recording

Initially, when launching the LabVIEW program a status was shown with information on the remaining disk capacity of both laptop and backup drive (located inside the acquisition system). This ensured that recordings for all subjects on a given day could be completed. The battery status would likewise give an indication on the time left to operate the system. No data collection was possible when charging the laptop.

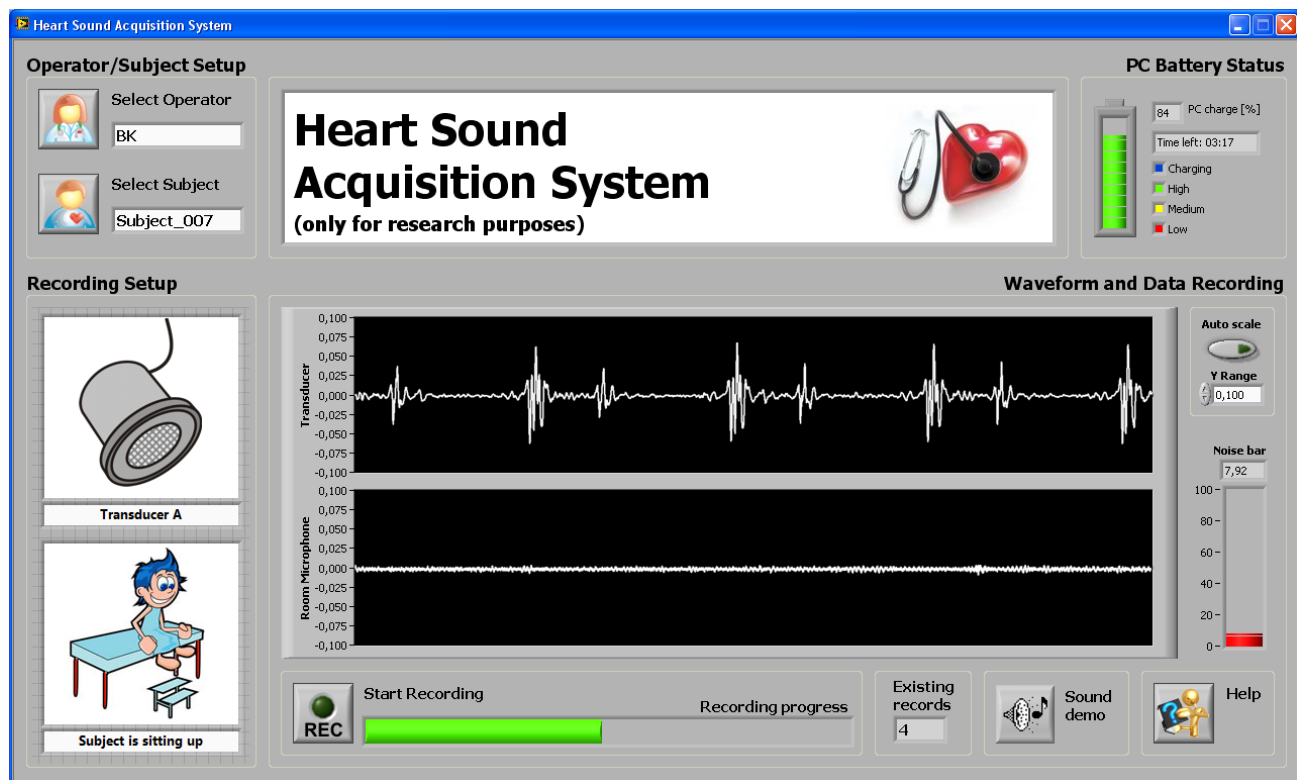The operator then had to identify him or herself and

Figure 4. LabVIEW GUI for recording setup and data collection.

identify the subject. Next, information about the recording setup had to be entered. This included:

1. Calibrate Transducer (only once per day)
2. Transducer identification
3. Subject position information (recordings are performed with the subject sitting or lying down)
4. Sound demonstration (only once per subject)
5. Start recording

Potential murmurs could be hard to detect while breathing due to noise originating from airflow in the trachea. The sound demonstration therefore contains four different events: "Start Recording", "Hold your breath", "Breathe normally" and "Stop Recording" and each event will be accompanied by a unique sound. The subject was instructed to act according to the sound clip during the duration of a recording. Each recording lasts for 3 minutes and contains 4 periods where the subject was instructed to hold the breath. The subject started with normal breathing for 60 seconds followed by four periods of 8 seconds of holding the breath and 22 seconds of normal breathing.

3.   Results

The developed acquisition system was used at Rigshospitalet (Copenhagen University Hospital, Denmark) in a clinical trial with patients referred for elective coronary angiography. Trained project nurses collected heart sounds from 463 patients with a minimum of four recordings per patient. They found the system to be intuitively easy to use and no extensive training was required.

The transducer proved to be stable over time and both frequency and sound pressure level were measured to be well within the specification of the calibrator. No change was observed with either measure over the 12 month of data collection.

The sound acquisition system is capable of recording sounds up to 114 dB SPL. The noise floor of the system proved to be equivalent to 16 dB(A) re 20uPa, thus below the expected level of the murmur at approximately 30-40 dB SPL [5]. The dynamic range of 98 dB SPL is considered sufficient to include both murmurs and the sound of the closing heart valves.

4.   Discussion

The number of patients examined and the quality of the recordings provides a good data platform for future algorithm design. The sample rate, the bit resolution and the bandwidth were all higher than theoretically necessary. A smaller device is under development and the required specifications can be estimated by analyzing the collected recordings. The output of an algorithm running on the original data can be compared to the same algorithm running on data that has been either down sampled, bit reduced or band pass limited.

The end goal is the development of a definitive, noninvasive test for detection of coronary blockages. An algorithm design is ongoing and initial results are promising [6].

Acknowledgements

References

[1] World Health Organization. Cardiovascular Disease. Fact sheet N°317. September 2009.
Available: http://www.who.int/mediacentre/factsheets/fs317/en/
[2] Mathers CD, Loncar D. Projections of global mortality and burden of disease from 2002 to 2030. PLoS Medicine. 2006;3(11):2011-2030.
[3] Akay M, Semmlow JL, Welkowitz W, Bauer MD, Kostis JB. Detection of coronary occlusions using autoregressive modeling of diastolic heart sounds. IEEE Trans. Biomed. Eng. 1990;37:366-73.
[4] Zimmermann H, Schmidt SE, Hansen J, Hammershøi D, Møller H. Acoustic Coupler for Acquisition of Coronary Artery Murmurs. Computing in Cardiology 2011;38 (in press)
[5] Schmidt SE. Detection of coronary artery disease with an electronic stethoscope. Ph.D. Thesis, 2011; Aalborg University
[6] Schmidt SE, Hansen J, Zimmermann H, Hammershøi D, Toft E, Struijk JJ. Coronary artery disease and low frequency heart sound signatures. Computing in Cardiology 2011;38 (in press)

Address for correspondence.

John Hansen
CardioTechnology Lab., Medical Informatics Group
Department of Health Science and Technology
Aalborg University
Fredrik Bajers Vej 7, 9220 Aalborg Ø, Denmark
E-mail: joh@hst.aau.dk