

# Smart Stethoscope Systems: A New Paradigm for Bedside Patient Monitoring

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## Abstract

Bedside monitoring of patients often involves measuring pulse, temperature, respiratory rate, and blood pressure. Auscultation can also provide useful diagnostic information but requires the presence of a healthcare provider and hence is done intermittently. New technologies of optimally designed sound acquisition and processing systems can make this adaptable for continuous patient monitoring. The state of the art as well as some of the features, advantages and challenges for using this technology for patient monitoring are discussed.

**Keywords:** Monitoring; Stethoscope; Auscultation

## Introduction

### Current patient monitoring

Bedside patient monitoring is an important part of the standard of care of hospitalized patients. Typical monitoring (in, e.g., operating rooms, intensive care units, emergency departments) usually involves measuring pulse, temperature, respiratory rate, and blood pressure and may also include pulse oximetry and spirometry [1]. Changes in these vital signs can be indicative of life-threatening conditions that may require urgent intervention or triage to intensified level of care. Patient monitoring in general wards, however, is usually intermittent and is often based on tradition [2]. Low frequency monitoring may not be optimal for the current hospital population, which tends to be older, more vulnerable, and having more complex procedures and possible higher rates of complications.

### Manual and automated auscultation

Auscultation is a widely used procedure that provides useful diagnostic information, is readily available, is non-invasive and can be performed at a relatively low cost. The procedure is usually performed using a stethoscope that transmits sounds from the patient skin to the healthcare provider ear. Auscultation is typically performed by skilled personnel and is therefore, used intermittently for patient care. Early stethoscopes [3] were mechanical devices whose evolution has reached a plateau. These stethoscopes do not lend themselves to continuous monitoring because of their constant reliance on the human operator.

Electronic stethoscopes have also been developed and are typically based on transducers that convert sounds and vibrations at the skin surface into electrical signals. The transducers used vary in their principle of operation and may involve electret microphones, accelerometers, optical sensors, or piezoelectric films or discs. Electronic stethoscopes offer inherent flexibilities since their electrical output can be manipulated with relative ease. For example, filters and amplifier can be incorporated in the design of these stethoscopes to supplement the human hearing, which has frequency-dependent

sensitivity and may not hear subtle sound changes. For example, the typical human hearing sensitivity drops by about 70 decibels at 20 Hertz (Hz) compared to that at 1000 Hz. As a result, some useful diagnostic information, especially at low frequencies may not be easily detectable by the unaided human ear. Most electronic stethoscopes are, however, expensive, non-disposable and, hence, require cleaning after each use to avoid cross contamination.

Advances in digital signal processing, artificial intelligence and the availability of electronic stethoscopes have increased interest in the development of systems that can automatically acquire and analyze biological sounds and vibrations and provide diagnostic information that may be used by healthcare providers and patients. Several studies have shown that computer assisted analysis was able to find correlations between acquired body sounds and certain pulmonary [4-12], gastrointestinal [13-18] or cardiovascular conditions [19-21].

Body sound acquisition and analysis systems can be designed for bedside patient monitoring in, for example, the emergency room, the intensive care unit, or operating room. Although these systems can provide useful diagnostic information to healthcare providers, they are often not utilized. This is likely due, at least in part, to the uncertainty of the benefit to the patient and the burden of having to attach the additional sensors and wires (i.e., in addition to the EKG electrodes and wires that are currently usually attached). To reduce this burden new optimally designed sensors should be designed and constructed. Desirable sensor characteristics include: high sensitivity and signal-to-noise ratio in the frequency range of interest, small size, low cost, easy attachment to the skin, disposability to avoid need for disinfection, and capability to integrate with EKG electrodes to reduce need for extra wires and reduce burden on the user.

The sensitivity and frequency response of most readily available stethoscopes is usually unknown, which makes it difficult to compare the results of different studies or chose optimal sensors for the sounds to be measured. Optimal sensors for different studies are expected to be different as acoustic energy may be concentrated in different frequency bands. For example while most of the heart sound energy is below 100 Hz, breath sounds energy is more dominant between 100-1000 Hz. Testing of sensors is another important area of

investigation and optimization. Special sensors testing phantoms are needed to properly document the frequency response and compare the performance of different stethoscopes. While there are no widely accepted methods for testing stethoscopes, there have been studies [22-26] that proposed certain phantom designs. Desired phantom characteristics include being made of materials that has density and elasticity similar to soft tissue, having high temporal stability, ready availability, low cost, and being made of materials that are easy to mold into desired shapes. The phantom also needs to be compact in size and able to supply surface acoustic signals that have high spectral and spatial uniformity, and able to test sensors of different sizes.

Computer simulations of acoustic phenomena in humans and animals have been also attempted [5,24,27-35]. The advantages of the in silico approach include its ability to quantify both surface and subsurface acoustic levels and predict acoustic values in areas where these are hard or not possible to measure. They may also be used in parametric studies that can elucidate the effects of the different parameters relatively quickly and economically. The resulting insights from these studies can help reduce the need for a large number of bench and animal studies needed for the development of new monitoring systems.

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