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Estimating heart activities from multichannel sounds and ECG signals

Heart health monitoring with sounds and electric signals

Abstract

Early detection of heart problems requires estimation of heart activity based on information that can be easily measured on a daily basis. To this end, we are researching technologies to estimate and visualize the mechanical and electrical activities within the heart based on the non-invasive observations on the surface of the body. Our technique called Physically-Constrained Unsupervised Signal Decomposition (PCUSD) method incorporates a physical heart sound generation model and makes it possible to estimate cardiac vibration components such as opening and closing of valves inside the heart that cannot be directly heard with a conventional stethoscope. In addition, our newly proposed technique called tensor electrocardiography can capture and visualize the action potentials of cardiac muscle cells, and has the potential to detect abnormalities that are not readily apparent in conventional electrocardiograms. Potential applications of these techniques will include a system that allows users to easily assess the condition of their cardiovascular system by themselves which can contribute to early detection of heart diseases such as heart failure, ischemic heart disease, and arrhythmia associated with sudden death. The same system can also be used to support rehabilitation after treatment of heart disease as well as training for healthy people.

Estimation of Activity within the Heart

Tasks: Biometric information ➡ Activity within the heart

Biometric information that can be easily measured non-invasively:

Heart Sounds

Mainly caused by the opening/closing of valves in the heart.

Doctors have used stethoscopes for centuries to listen to heart sounds, a process called auscultation, in order to diagnose the health and condition of the heart.

Electrocardiogram (ECG)

Caused by the action potentials of cardiac muscle cells.

Medical institutions widely use ECG to estimate heart activity.

[Technical hurdles]

Both types of signals are mixtures of signals transferred from multiple internal sources, and therefore, difficult to infer them only from data observed on the surface.

[Approach]

(1) Process biometric data using novel statistical / physical models.

(2) Capture multiple channels of observed data from different locations on the body surface to enable localization of various internal signal sources.

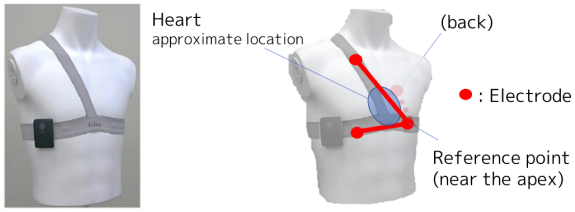
† Investigational (unapproved)

ECG Technique † ➡ Acoustic Technique †

Tensor Electrocardiography

(1) The timing of potential changes (depolarization and repolarization) is statistically modelled with Gaussian distributions. [1]

(2) The closest point between the heart and the body surface (near the apex of the heart) is used as the reference point. Electrodes are placed on three nearly orthogonal axes to gather spatial information.



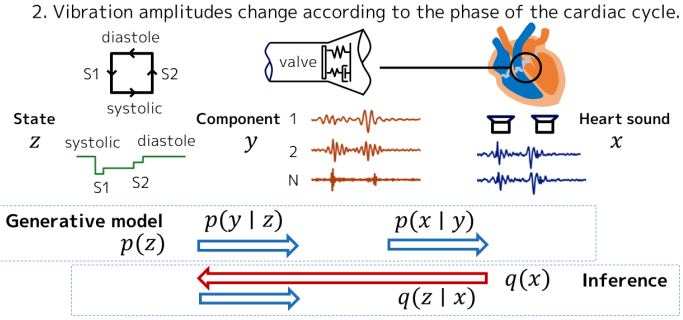
Appearance and electrode arrangement of wearable tensor electrocardiograph

PCUSD (Physically-Constrained Unsupervised Signal Decomposition)

(1) A probabilistic model is defined to describe the physical mechanism of heart sound generation.

Assumptions:

1. Multiple components vibrate to generate heart sounds based on physical models of valves.
2. Vibration amplitudes change according to the phase of the cardiac cycle.



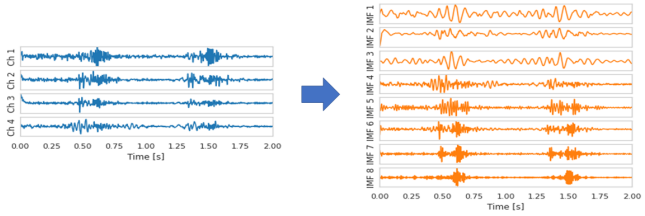
An example of experimental results

F1	PCUSD (proposed)	Conventional method
S1	**96.1**	86.5
S2	**96.4**	85.7

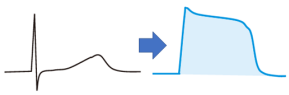
Improvement of segment estimation accuracy (F1) for S1 and S2 is shown. Conventional method (right) refers to a decomposition method without a generative model.

(2) Application to multi-channel signals

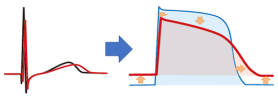
An example of estimation of 8 vibration components from 4 channels of acoustic signals observed on the body surface.



Observed signals (left) and estimated vibration components (right)



Potential difference observed on the body surface (left) and action potential (right)



Clearer anomaly visualization by tensor electrocardiogram (schematic)

References

[1] S. Tsukada, "Wearable textile electrodes for long-term vector ECG monitoring 'Tensor Cardiography'," in *Proc. ISMICT 2020*, 2020.

[2] R. Shibue, M. Nakano, T. Iwata, K. Kashino, H. Tomoike, "Unsupervised heart sound decomposition and state estimation with generative oscillation models," in *Proc. EMBC 2021*, pp. 5481–5487, 2021.

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