Automatic Analysis of Vibro-Acoustic Heart Signals

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Abstract

The mechanical processes within the cardiovascular system produce low-frequency vibratory and acoustic signals that can be recorded over the chest wall. Vibro-acoustic heart signals carry valuable clinical information, but their use has been mostly limited to qualitative assessment by manual methods.

The purpose of this work is to revisit automatic analysis of mechanical heart signals using modern signal processing algorithms, and to demonstrate the feasibility of extracting quantitative information that reliably represent the underlying physiological processes.

A digital data acquisition system was constructed and used to acquire carotid pulse, apexcardiogram, phonocardiogram, electrocardiogram and echo-Doppler audio signals from healthy volunteers and cardiac patients. Signal processing algorithms have been developed for automatic segmentation of the vibro-acoustic signals and extraction of temporal and morphological features on a beat-to-beat basis. Spectral analysis was used to reconstruct the Doppler sonograms and estimate reference values.

A good agreement was observed between systolic and diastolic time intervals estimated automatically from the vibro-acoustic signals, and manually from the echo-Doppler reference.

The results demonstrate the technological feasibility and the medical potential of using automatic analysis of vibro-acoustic heart signals for continuous non-invasive evaluation of the cardiovascular mechanical functionality.

Objectives

Research hypothesis

- Vibro-acoustic heart signals bear significant physiological and clinical information
- This information can be extracted automatically to achieve continuous non-invasive monitoring of cardiac functionality

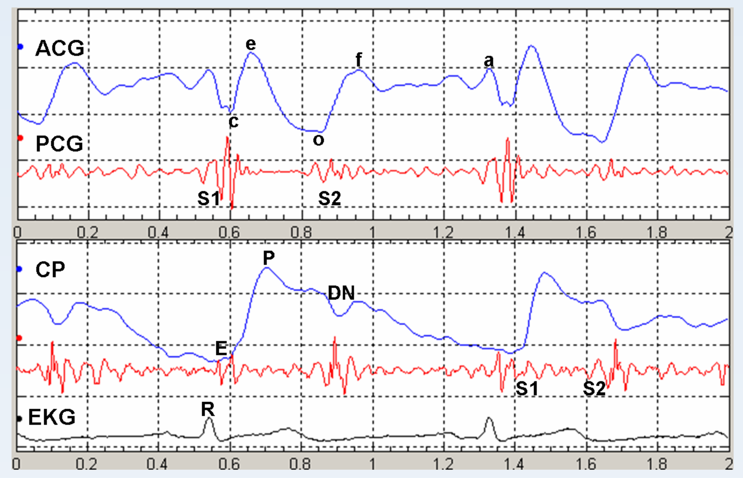
Methodology

- Signal processing algorithms for automatic extraction of temporal and morphological features from vibro-acoustic heart signals
- Validation of the extracted features against a 'gold standard' echo-Doppler reference

Methods

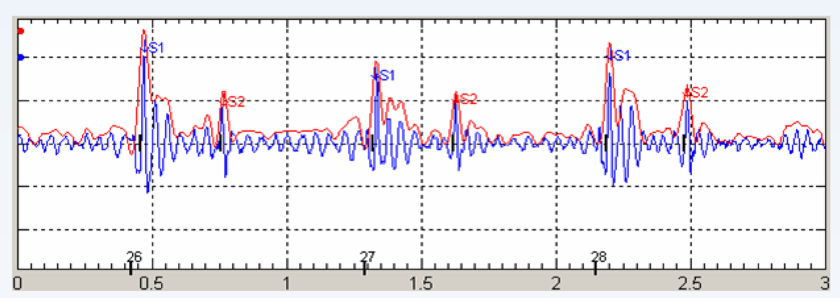
Data Acquisition

Carotid pulse (*CP*), apexcardiogram (*ACG*), phonocardiogram (*PCG*), electrocardiogram (*EKG*) and Doppler-audio signals were digitally acquired from healthy volunteers and cardiac patients

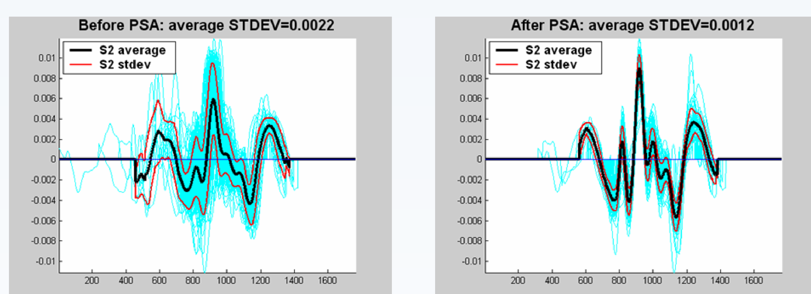


Segmentation – Sound Signals

- PCG envelope obtained by Hilbert transform
- Heuristic detection of S1 and S2 peaks

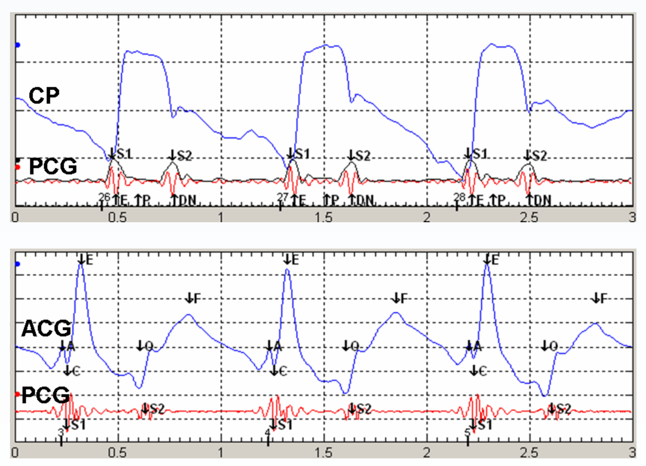


- Variability reduction by Phase-Shift-Averaging (*PSA*)



Segmentation – Pulse Signals

- Detection of extrema points, using heart sounds for orientation
- Extracted features: systolic and diastolic time intervals, ejection amplitude, ejection slope



Doppler-Audio Processing

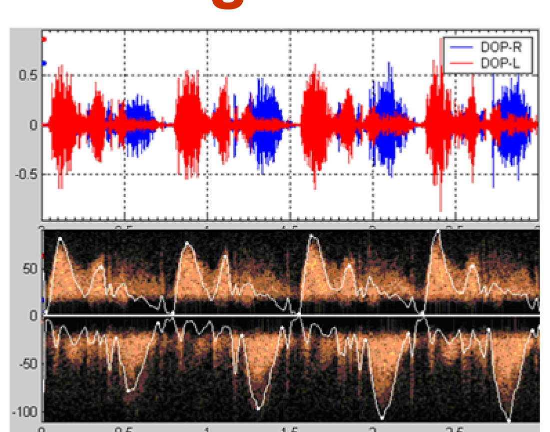
- Short-time Fourier transform

$$S(t,\omega)=\int_{-\infty}^{\infty} s(\tau)w(\tau-t)e^{-i\omega t}d\tau$$

- Amplitude filter & time shift
- Instantaneous flow profile

$$F(t)=\sum_{v} v(t)*I(v,t)$$

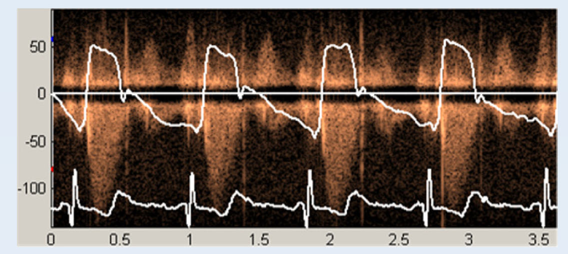
- Manual event annotation



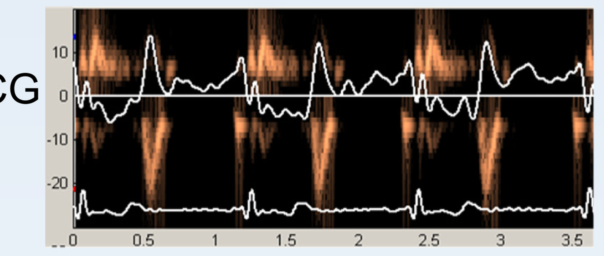
Results

Timing of Cardiac Events

Systolic events: Correspondence between CP and Continuous-Wave Doppler of the aortic valve blood flow



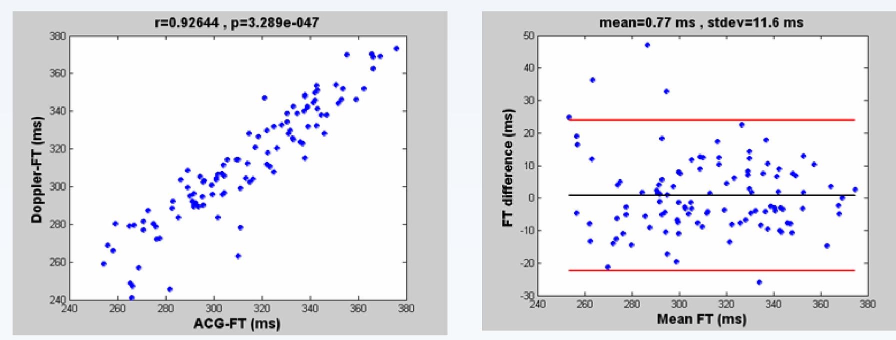
Diastolic events: Correspondence between ACG and Tissue-Doppler imaging of the lateral ventricular wall



Agreement between average values of time intervals estimated from CP, ACG and Doppler profile:

Time	ACG	CP	Doppler
PEP	59.4 ± 1.8	62.4 ± 5.7	66.4 ± 5.9
ET	268.2 ± 4.1	262.2 ± 7.3	262.1 ± 7.1
IVRT	88.9 ± 10.1	-	90.1 ± 9.3
FT	313.1 ± 29.7	-	312.3 ± 30.6

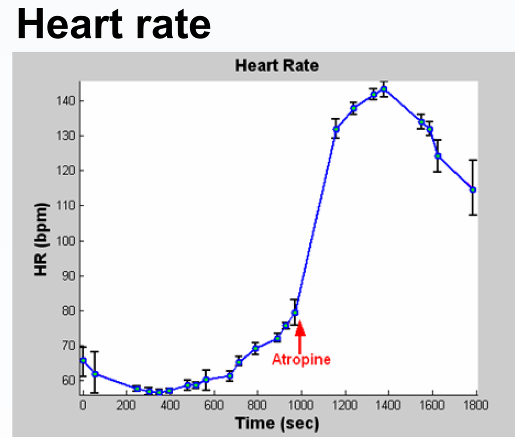
Beat-to-beat correlation and statistical agreement of the instantaneous filling-time (r=0.92)



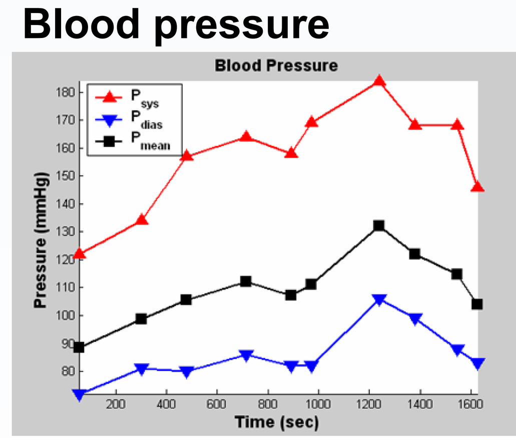
Pharmacological Stress Test

Continuous recording during 30 minutes of Dobutamine stress echo test, with a reference CW-Doppler

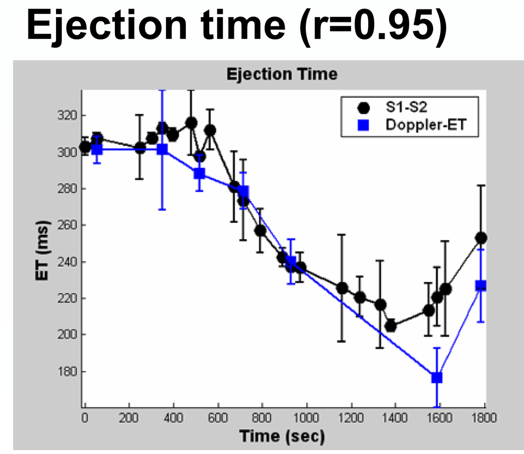
Heart rate



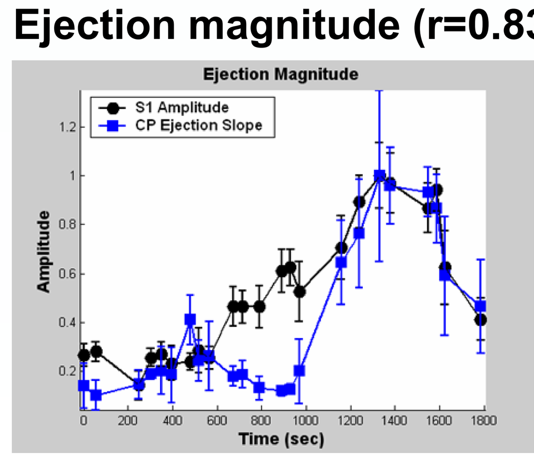
Blood pressure



Ejection time (r=0.95)

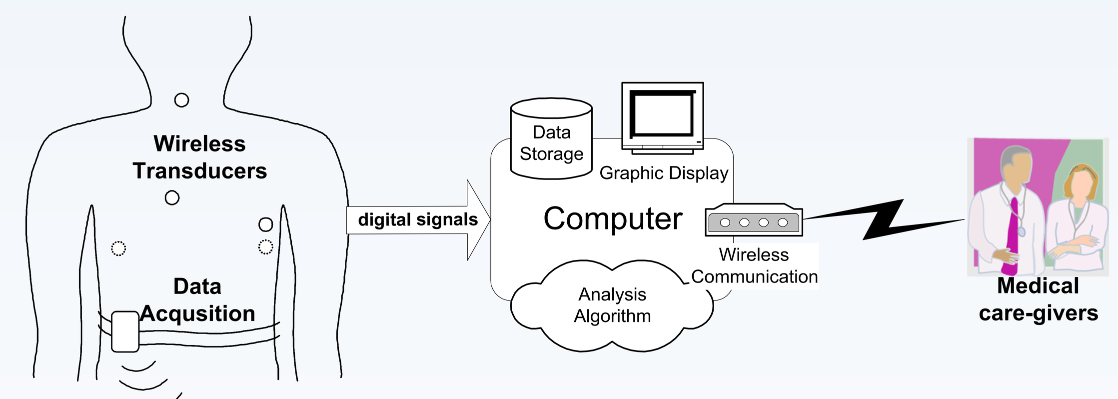


Ejection magnitude (r=0.83)



Conclusions

- Quantitative physiological information can be automatically extracted from vibro-acoustic heart signals
- A good agreement between the estimated systolic and diastolic time intervals and the echo-Doppler reference was observed both in rest and stress conditions
- **Main challenges**: noise handling, accurate recording location, accurate reference estimation
- **Future work**: large-scale data collection, more complex features, invasive reference measurements
- **Potential application**: improving non-invasive continuous monitoring of cardiovascular mechanical functionality



References

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