Università degli Studi di Napoli Federico II

itee PhD information technology electrical engineering

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Cardio-respiratory monitoring via Forcecardiography

Tutor: Prof. Paolo Bifulco

Cycle: XXXV

Year: Third

itee PhD information technology electrical engineering

BACKGROUND

- **M.Sc. in Biomedical Engineering** (University of Naples “Federico II”)
- **Ph.D. in Information Technology and Electrical Engineering (ITEE)**

- **Start date:** 1st November 2019 **End date:** 31st January 2023
- **Scholarship:** UNINA
- **Research group:** Biomedical Engineering group (Biomedical Instrumentation Laboratory)
- **Collaborations:** Prof. Gaetano D. Gargiulo (Western Sidney University), IRCCS Neuromed
- **Research activity abroad:** School of Engineering, Design and Built Environment, Western Sydney University (1st June 2021 – 31st August 2021)

MAIN STUDY ACTIVITIES

- Study on non-invasive methods for heart and respiration monitoring;
- Study on cardiovascular and pulmonary mechanical activity;
- Study on biomedical applications of force sensors;
- Study on Forcecardiography;
- Statistical Data Analysis for Science and Engineering Research – ad hoc course;
- Strategic Orientation for STEM Research & Writing – ad hoc course;
- Data Science for Patient Records Analysis – ad hoc course;
- Matrix Analysis for Signal Processing with Matlab Examples – ad hoc course;

MAIN STUDY ACTIVITIES

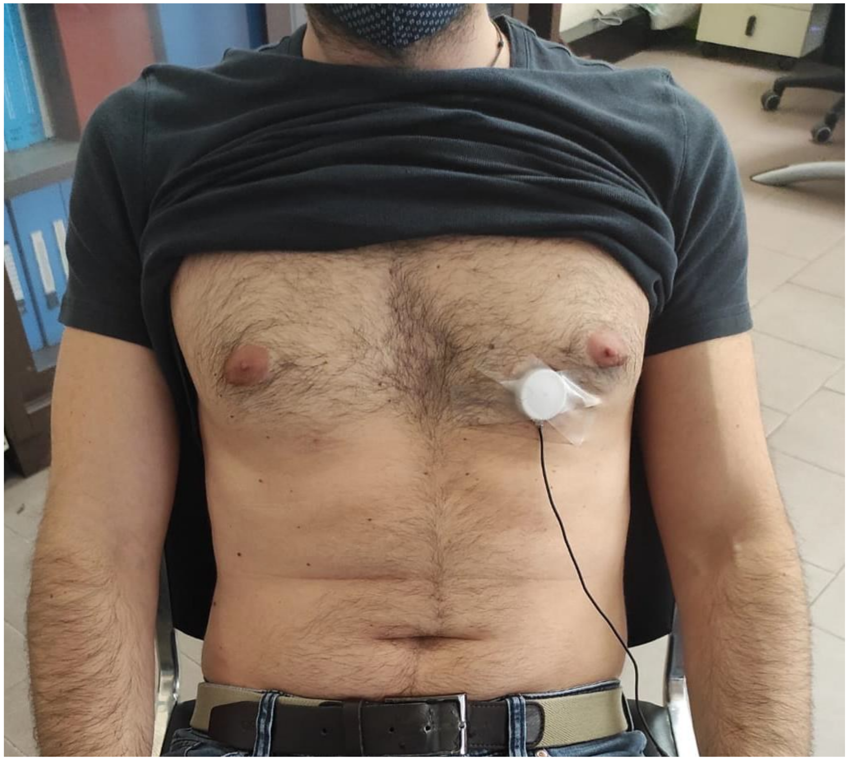
- Biosignals Measurement and Analysis – ad hoc course;
- Muscle-based Human Machine Interfaces – ad hoc course;
- Computer Interface for Biological Systems – MSc course;
- Study on detection of cardiac cycle events and estimation of cardiac time intervals in Forcecardiography signals;
- Study on muscle activity monitoring via force sensors;
- Study on cardio-respiratory interactions in Forcecardiography signals;
- Study on Human Machine Interfaces for assistance and rehabilitation;
- Study on pulse wave detection via Forcecardiography sensors.

RESEARCH FIELD

Innovative bioengineering methods for diagnosis and monitoring

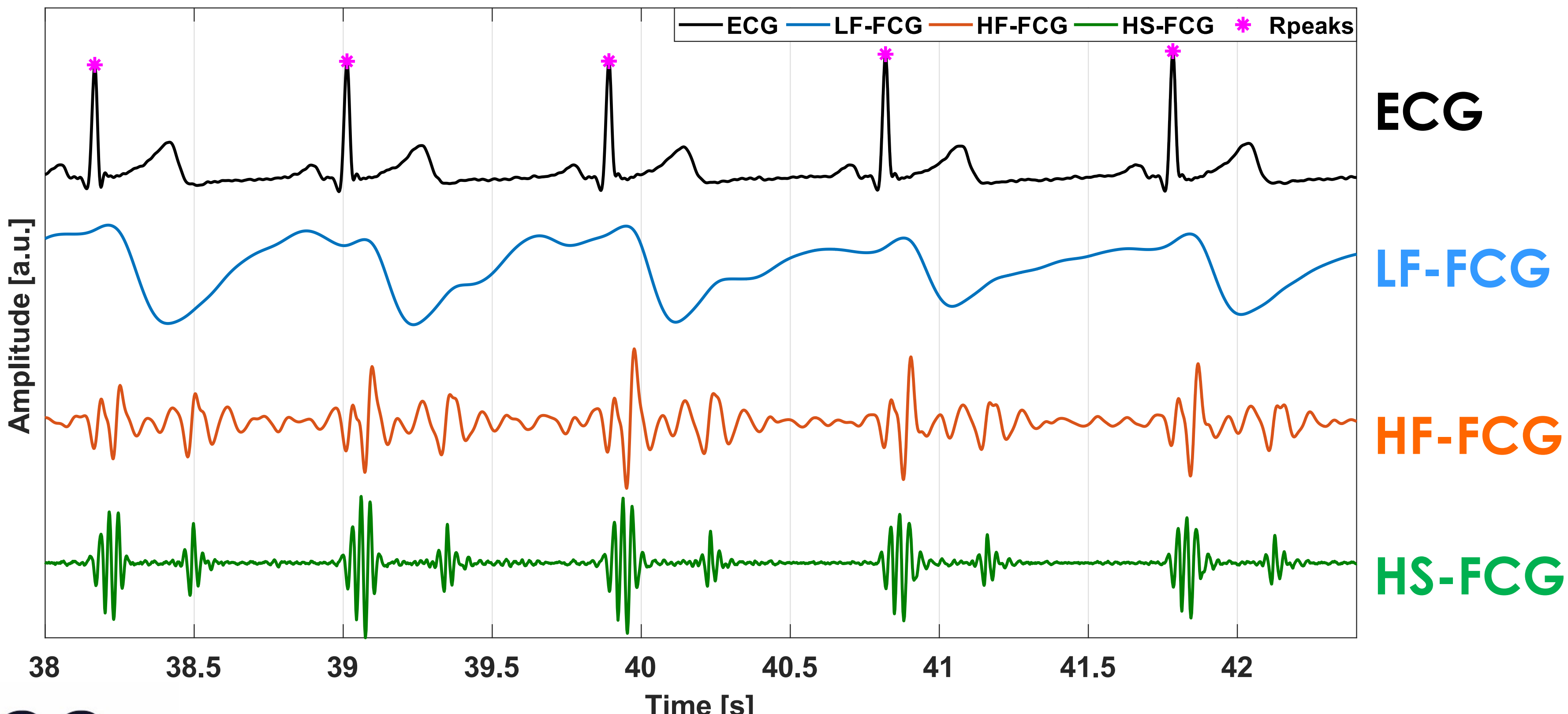
Forcecardiography (FCG) is a novel, non-invasive technique, first introduced in 2020, that records the weak forces induced onto the chest wall by the mechanical activity of the beating heart via broadband force sensors.

FCG is a very promising wearable technique for continuous, long-term monitoring of cardiac mechanical function.



RESEARCH FIELD

The raw FCG sensor signal consists of two infrasonic components, namely **low-frequency FCG (LF-FCG)** and **high-frequency FCG (HF-FCG)**, and a sonic component that captures **heart sounds (HS-FCG)**.



RESEARCH RESULTS

- ✓ The HF-FCG signal has a very high similarity with the Seismocardiogram (SCG) and provides accurate detection of aortic valve opening and closure events and estimation of pre-ejection period and left ventricular ejection time.

- ✓ A low-frequency component similar to the LF-FCG, which is related to heart walls motion, can be extracted from SCG signal by means of a specific processing.

- ✓ In addition to the cardiac activity, FCG sensors capture a large, very low-frequency component related to respiration, namely the Forcerespirogram (FRG).

- ✓ The amplitude modulations of LF-FCG and HF-FCG, as well as the respiratory-induced variation of two parameters of heartbeat morphology, have a good consistency within the respiratory cycle.

- ✓ FCG sensors can monitor pulse waves at various body sites (e.g., carotid, wrist, finger, etc.)

RESEARCH PRODUCTS 1/3

[P1]	J. Centracchio, A. Sarno, D. Esposito, E. Andreozzi, L. Pavone, G. Di Gennaro, M. Bartolo, V. Esposito, R. Morace, S. Casciato, P. Bifulco, *Efficient automated localization of ECoG electrodes in CT images via shape analysis*, **International Journal of Computer Assisted Radiology and Surgery**, vol. 16, pp. 543–554, 2021, DOI: 10.1007/s11548-021-02325-0.
[P2]	E. Andreozzi, J. Centracchio, V. Punzo, D. Esposito, C. Polley, G.D. Gargiulo, P. Bifulco, *Respiration Monitoring via Forcecardiography Sensors*, **Sensors**, vol. 21(12), 3996, 2021, DOI: 10.3390/s21123996.
[P3]	D. Esposito, J. Centracchio, A. Andreozzi, G.D. Gargiulo, G.R. Naik, P. Bifulco, *Biosignal-based Human-Machine Interfaces for Assistance and Rehabilitation: A Survey*, **Sensors**, vol. 21(20), 6863, 2021, DOI: 10.3390/s21206863.
[P4]	C. Polley, T. Jayarathna, U. Gunawardana, G.R. Naik, T. Hamilton, E. Andreozzi, P. Bifulco, D. Esposito, J. Centracchio, G.D. Gargiulo, *Wearable Bluetooth Triage Healthcare Monitoring System*, **Sensors**, vol. 21(22), 7586, 2021, DOI: 10.3390/s21227586.
[P5]	D. Esposito, J. Centracchio, E. Andreozzi, S. Savino, G.D. Gargiulo, G.R. Naik, P. Bifulco, *Design of a 3D-Printed Hand Exoskeleton Based on Force-Myography Control for Assistance and Rehabilitation*, **Machines**, vol. 10(1), 57, 2022, DOI: 10.3390/machines10010057.

RESEARCH PRODUCTS 2/3

[P6]	J. Centracchio, E. Andreozzi, D. Esposito, G.D. Gargiulo, P. Bifulco, *Detection of Aortic Valve Opening and Estimation of Pre-Ejection Period in Forcecardiography Recordings*, **Bioengineering**, vol. 9(3), 89, 2022, DOI: 10.3390/bioengineering9030089.
[P7]	E. Andreozzi, J. Centracchio, D. Esposito, P. Bifulco, *A comparison of heart pulsations provided by Forcecardiography and Double Integration of Seismocardiogram*, **Bioengineering**, vol. 9(4), 167, 2022, DOI: 10.3390/bioengineering9040167.
[P8]	J. Centracchio, E. Andreozzi, D. Esposito, G.D. Gargiulo, *Respiratory-induced amplitude modulation of Forcecardiography signals*, **Bioengineering**, vol. 9(9), 444, 2022, DOI: 10.3390/bioengineering9090444.
[P9]	E. Andreozzi, R. Sabbadini, J. Centracchio, P. Bifulco, A. Irace, G. Breglio, M. Riccio, *Multimodal Finger Pulse Wave Sensing: Comparison of Forcecardiography and Photoplethysmography Sensors*, **Sensors**, vol. 22(19), 7566, 2022, DOI: 10.3390/s22197566.
[P10]	D. Esposito, J. Centracchio, E. Andreozzi, P. Bifulco, G.D. Gargiulo, *Design and Evaluation of a Low-Cost Electromechanical System to Test Dynamic Performance of Force Sensors at Low Frequencies*, **Machines**, vol. 10(11), 1017, 2022, DOI: 10.3390/machines10111017.

RESEARCH PRODUCTS 3/3

[P11]	J. Centracchio, D. Esposito, G.D. Gargiulo, E. Andreozzi, *Changes in Forcecardiography Heartbeat Morphology Induced by Cardio-Respiratory Interactions*, **Sensors**, vol. 22(23), 9339, 2022, DOI: 10.3390/s22239339.
[P12]	J. Centracchio, V. Muto, *Heartbeats Localization in Forcecardiography Signals via Template Matching*, **International Conference on E-Health and Bioengineering (EHB) 2022**, Iasi, Romania, 17-18 Nov. 2022, pp. 1–4, IEEE Publisher, DOI: 10.1109/EHB55594.2022.9991505.
[P13]	J. Centracchio, *A new piezoelectric sensor for Forcemyography application*, **International Conference on E-Health and Bioengineering (EHB) 2022**, Iasi, Romania, 17-18 Nov. 2022, pp. 1–4, IEEE Publisher, DOI: 10.1109/EHB55594.2022.9991364.

Ph.D. THESIS OVERVIEW

PROBLEM

Cardio-respiratory monitoring via Forcecardiography (FCG)

FCG could improve the diagnosis and management of cardio-respiratory diseases via pervasive wearable monitoring.

OBJECTIVE

Extracting clinically relevant parameters of cardio-respiratory function

- Identification of cardiac cycle events in FCG signals
- Estimation of cardiac time intervals
- Estimation of cardiac and respiratory rates

METHODOLOGY

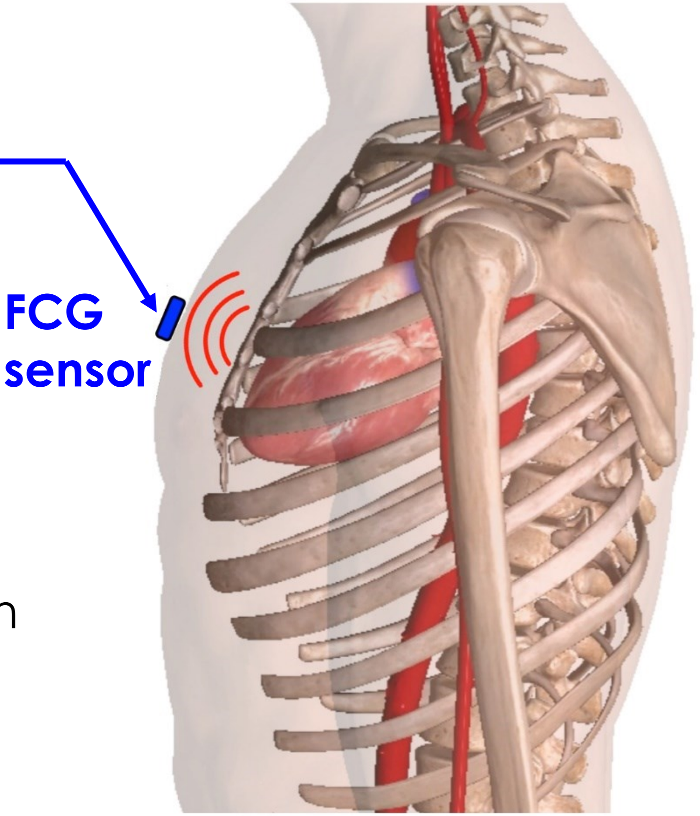
- **Analysis of FCG information content**
- **Assessment of FCG against reference techniques**

Experimental tests on a cohort of healthy volunteers

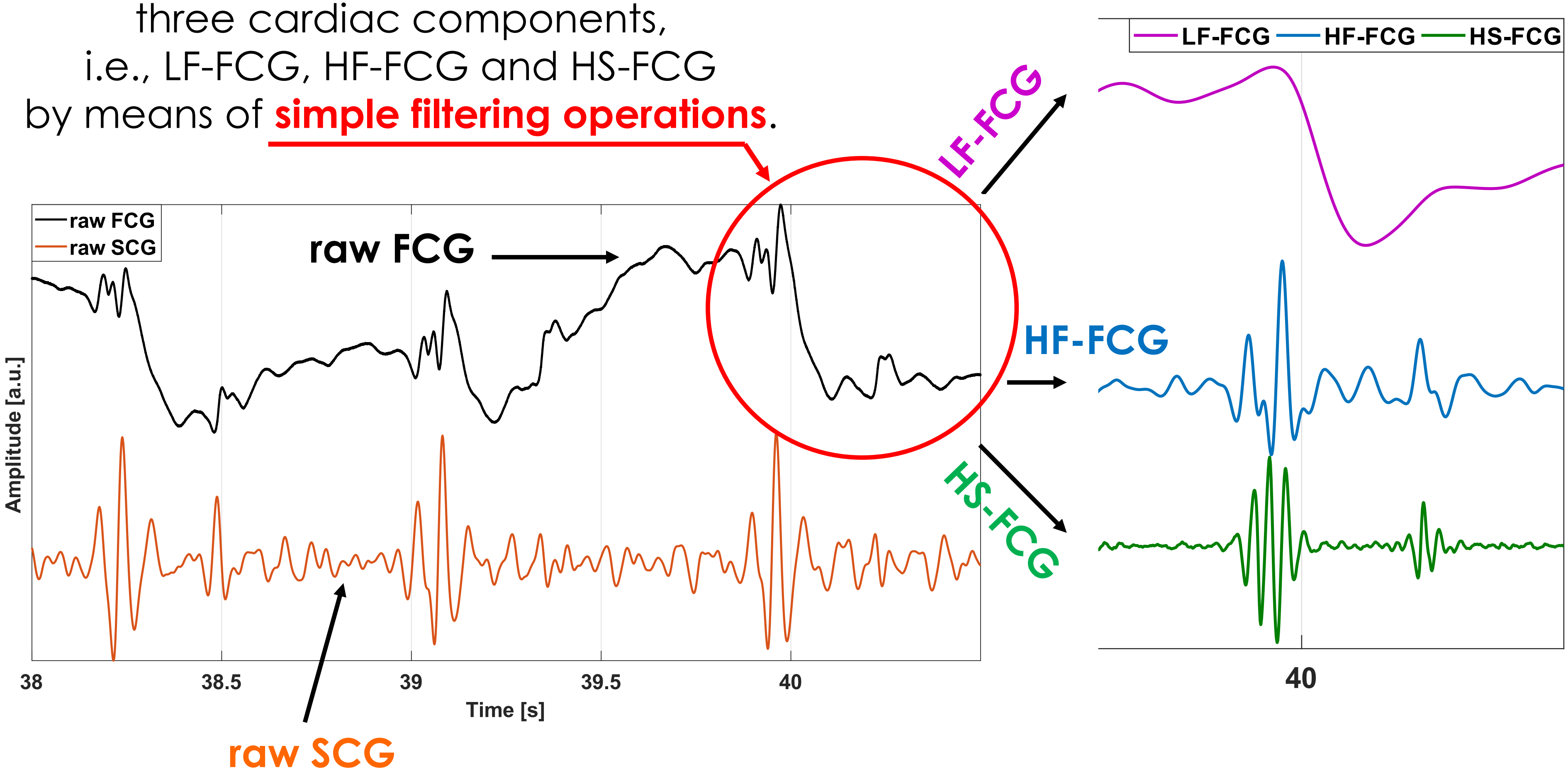
FORCECARDIOGRAPHY (FCG)

Forcecardiography (FCG) uses
a small, lightweight force sensor,
placed on the thorax of a subject,
to record the small, mechanical
vibrations generated by the heart,
which propagate through
the surrounding tissues,
reaching the surface.

The FCG signal has a richer information content than the accelerometric Seismocardiogram (SCG).

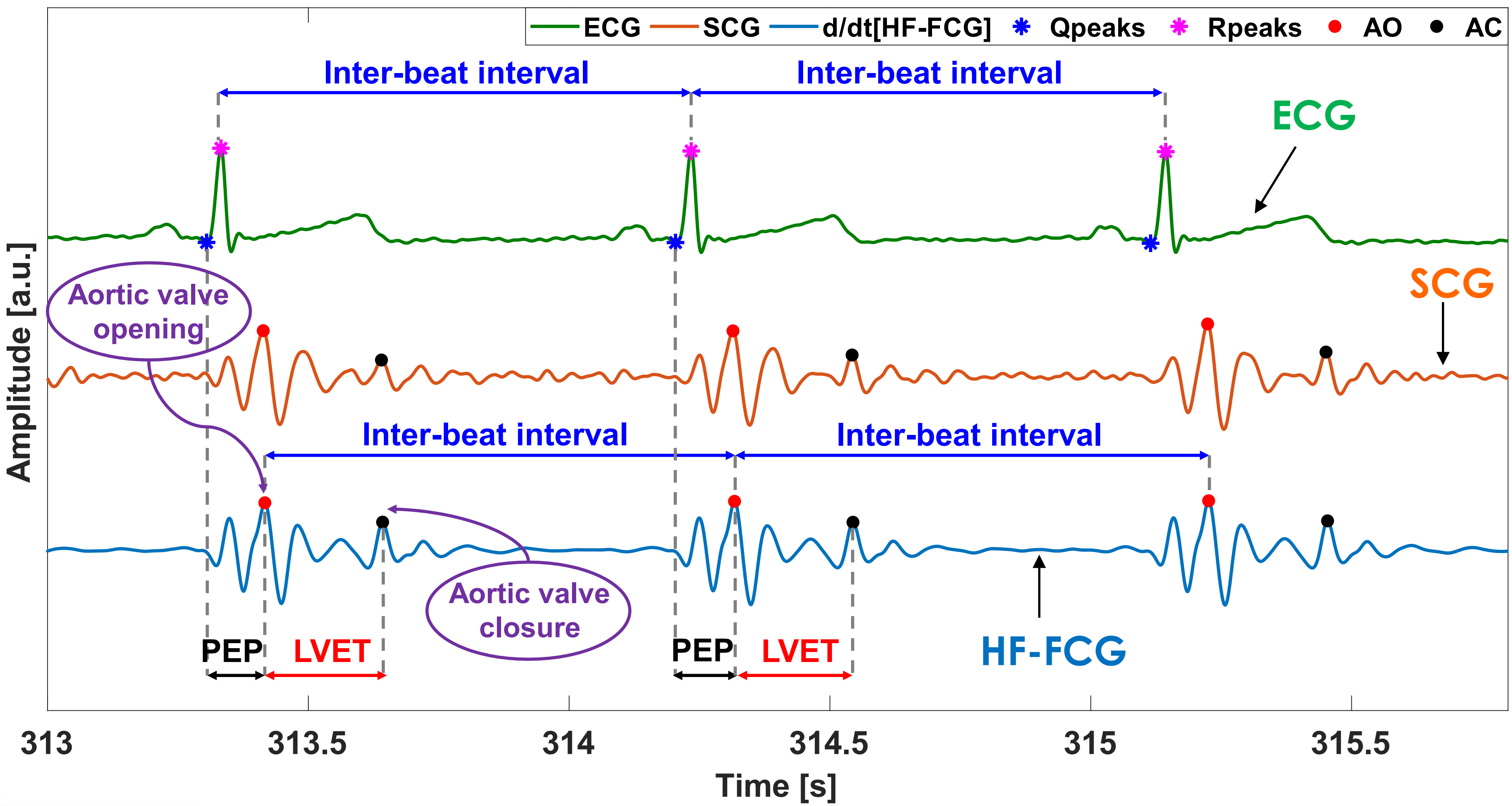


As opposed to the SCG signal,
the raw FCG signal can be split into
three cardiac components,
i.e., LF-FCG, HF-FCG and HS-FCG
by means of **simple filtering operations**.

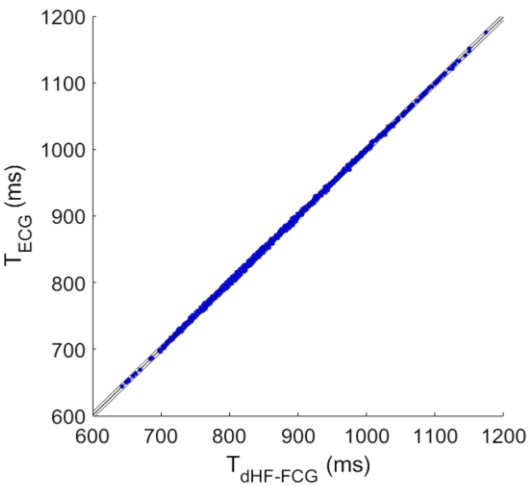


CARDIO-RESPIRATORY MONITORING VIA FORCECARDIOGRAPHY

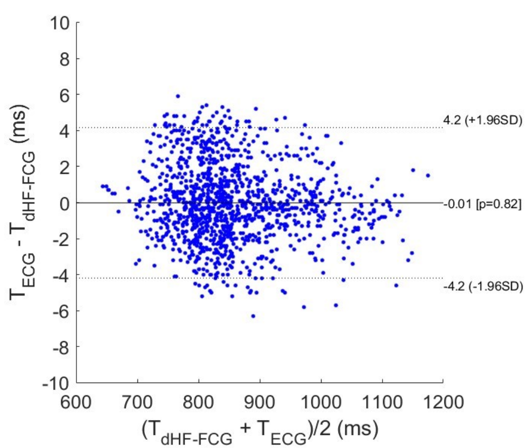
The HF-FCG showed a very high similarity with the SCG and provided accurate timings of aortic valve opening and closure events and estimates of **inter-beat interval**, **pre-ejection period (PEP)** and **left ventricular ejection time (LVET)**.



HF-FCG vs ECG
Inter-beat intervals

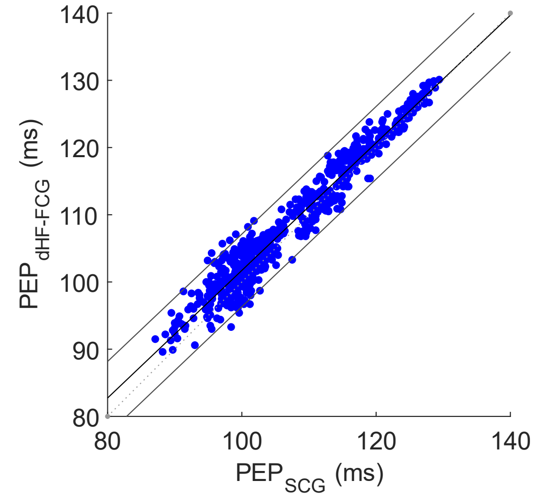


Slope > 0.99
($R^2 > 0.99$)

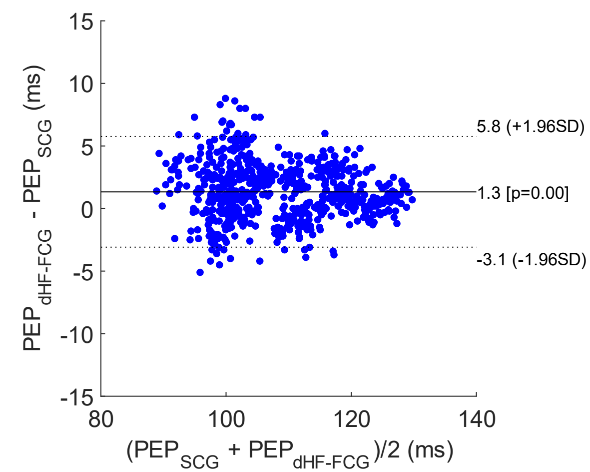


Limits of agreement = ± 4.2 ms

HF-FCG vs SCG
Pre-ejection period estimates



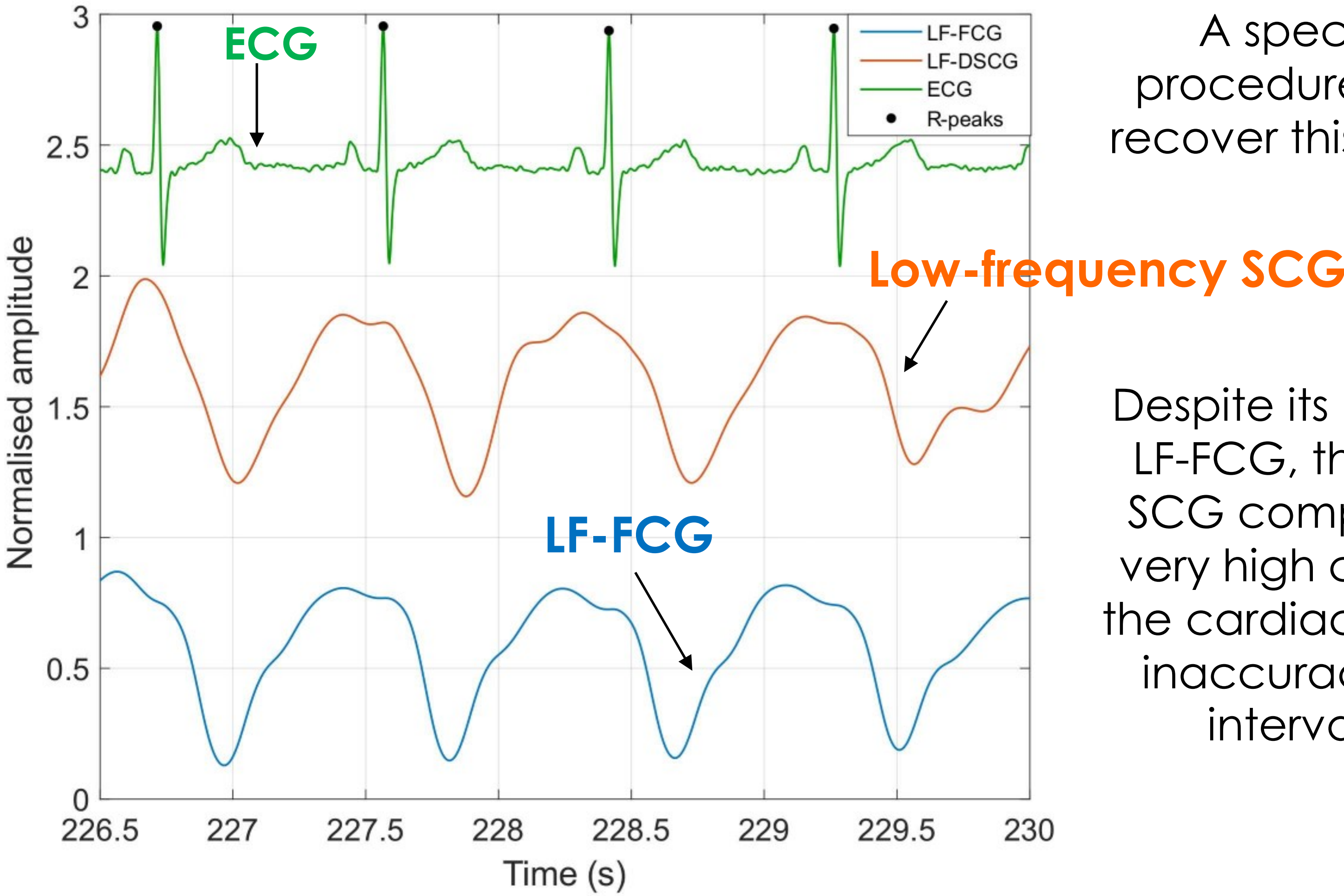
Slope = 0.95
($R^2 = 0.95$)



Limits of agreement = ± 4.6 ms

CARDIO-RESPIRATORY MONITORING VIA FORCECARDIOGRAPHY

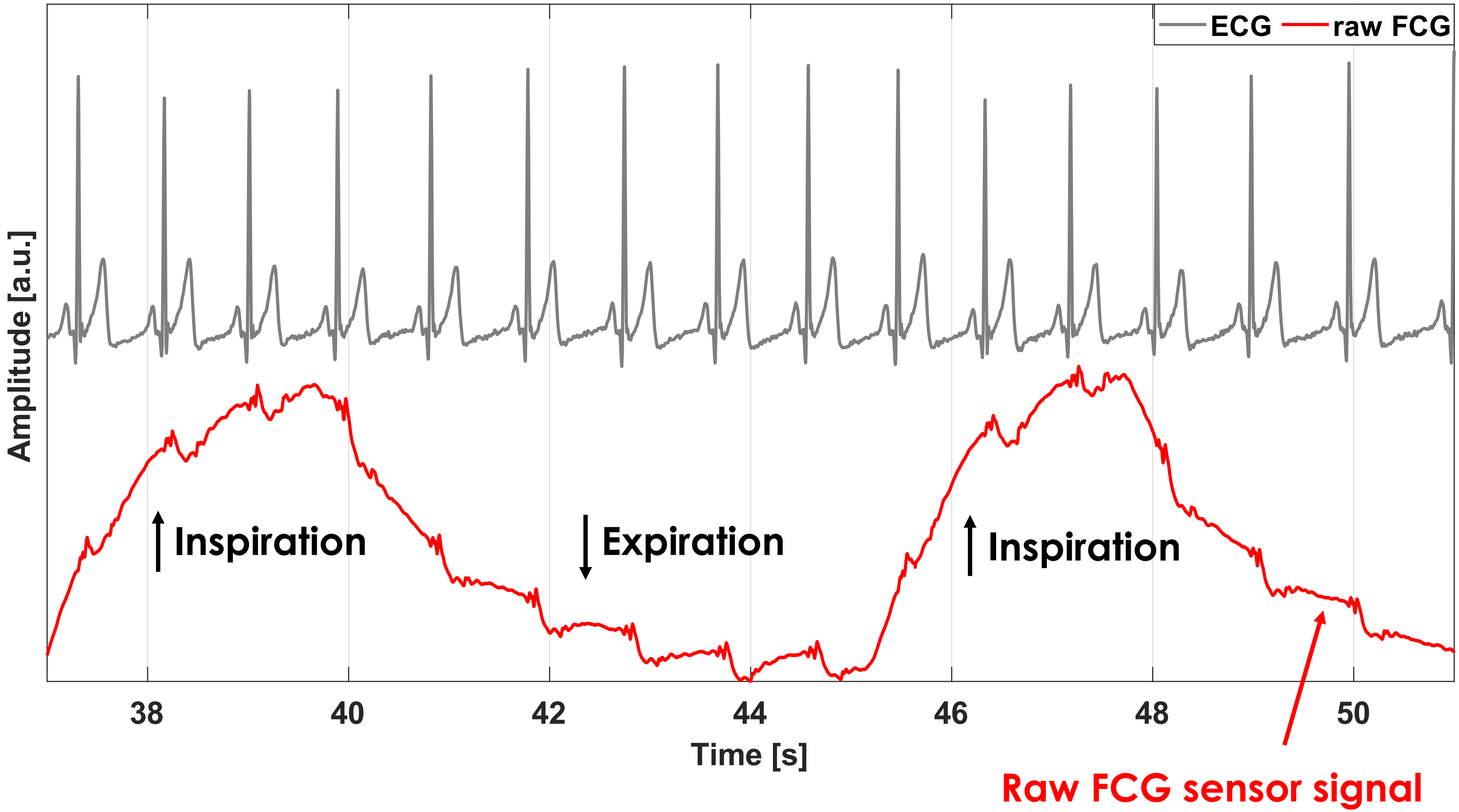
The LF-FCG reflects heart walls motion, thus potentially carrying information on ventricular volume variations. This low-frequency component is not visible in SCG signals, nor it can be extracted by simple filtering.



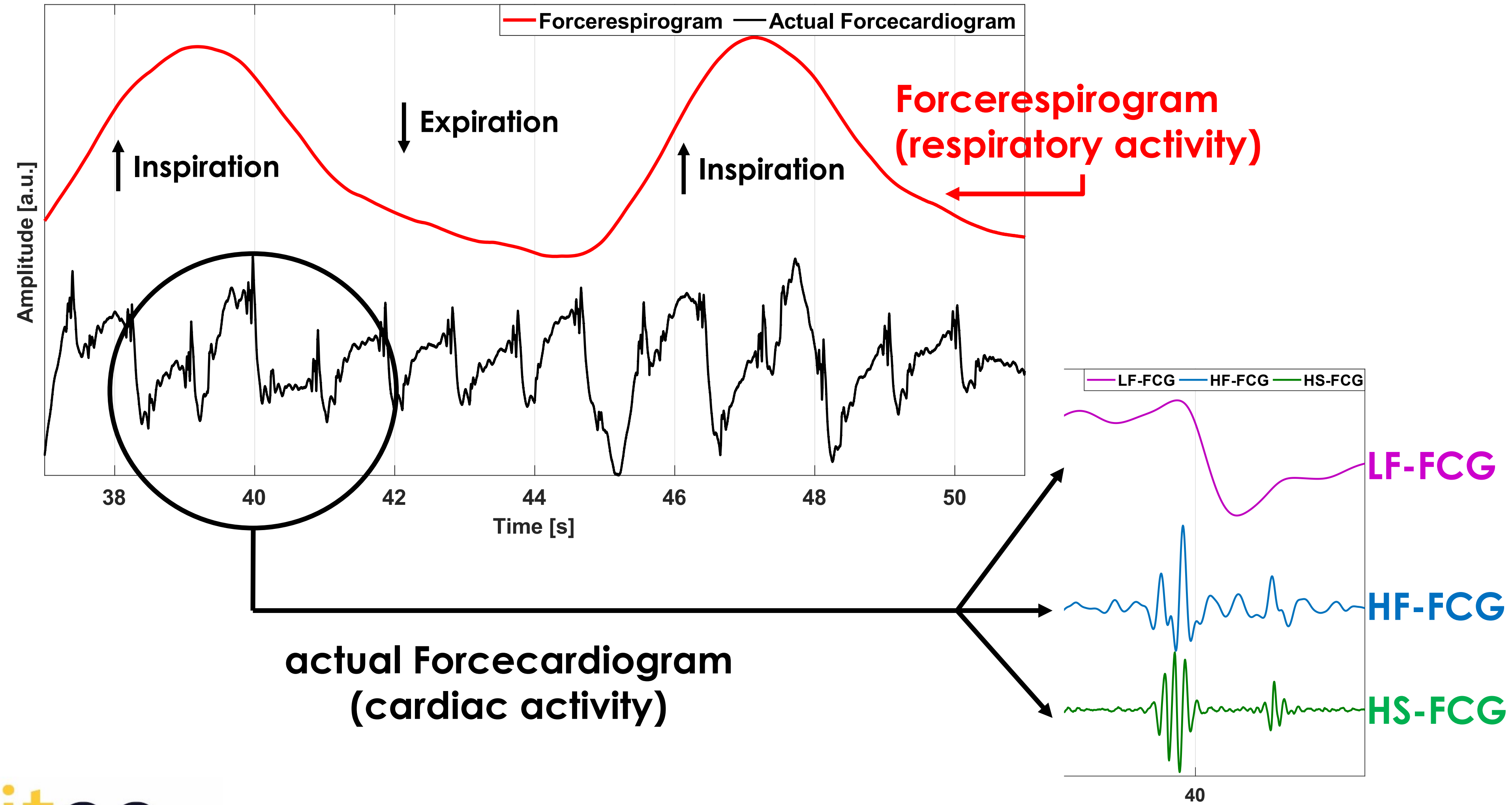
A specific numerical procedure was devised to recover this information from SCG.

Despite its high similarity with LF-FCG, this low-frequency SCG component has not a very high consistency within the cardiac cycle, leading to inaccuracies in inter-beat intervals estimation.

FCG sensors can also monitor the forces impressed onto the chest wall by the expansions and consequent releases of the ribcage during breathing acts.



In addition to the cardiac activity (i.e., **the actual Forcecardiogram**), a large, very low-frequency component (within 0.6 Hz) related to respiration, namely **the Forcerespirogram (FRG)**, was observed in the raw FCG sensor signal.



CARDIO-RESPIRATORY MONITORING VIA FORCECARDIOGRAPHY

FRG signals were compared with those provided by an electro-resistive respiration band (ERB), which was assumed as the ground truth.

ECG-derived respiration (EDR) signals were also tested against the reference (i.e., ERB).

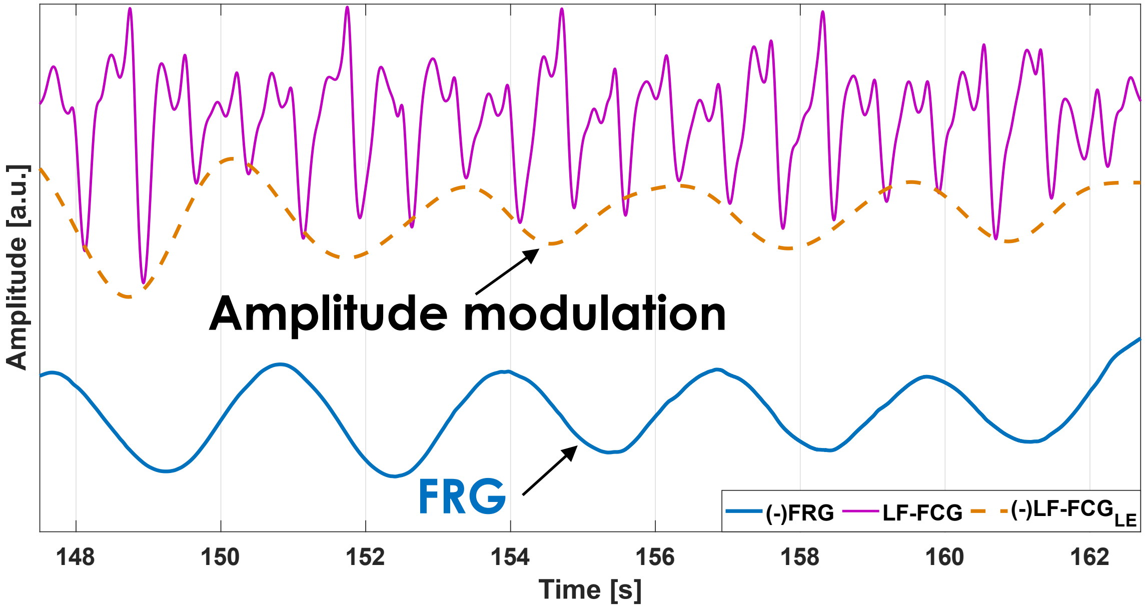
FCG sensors ensure a more sensitive and precise detection of respiratory acts than EDR,

	Sensitivity (%)	PPV (%)
FRG	100	98.9
EDR	95.8	92.5

as well as a superior accuracy and precision in inter-breath interval measurement.

	Slope	Intercept (s)	R^2	Bias	p-value	LoA (s)
FRG	0.99	0.026	0.98	0.0	0.87	± 0.61
EDR	0.98	0.11	0.88	Non-significant	0.11	(–1.4; +1.5)

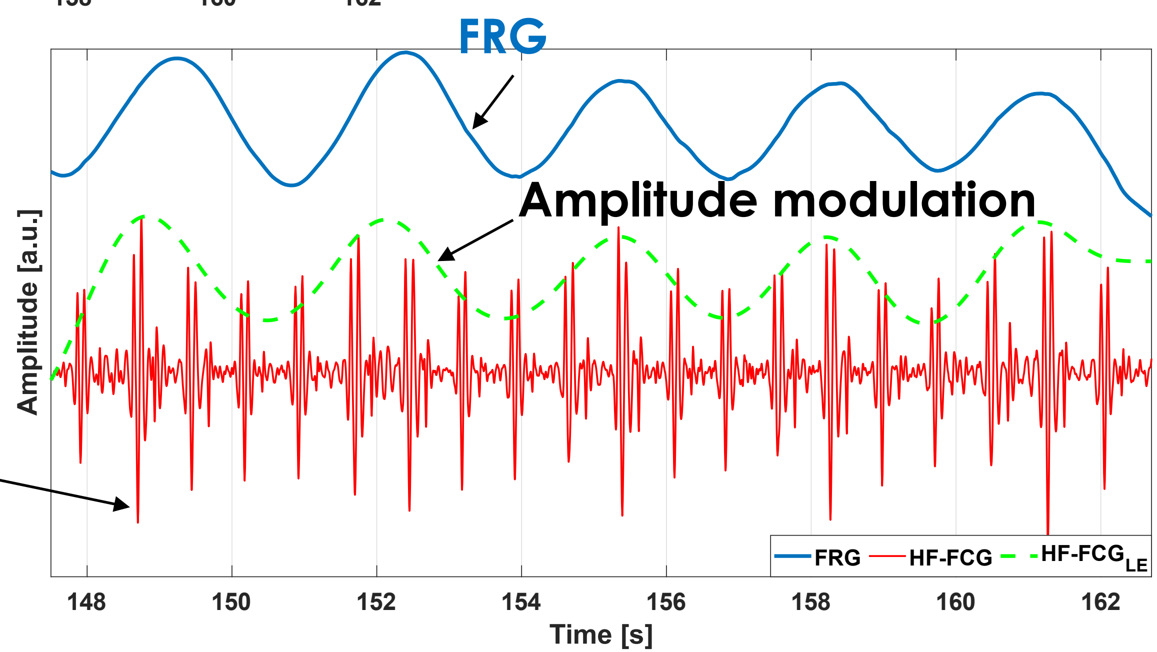
CARDIO-RESPIRATORY MONITORING VIA FORCECARDIOGRAPHY



Respiration causes amplitude modulations

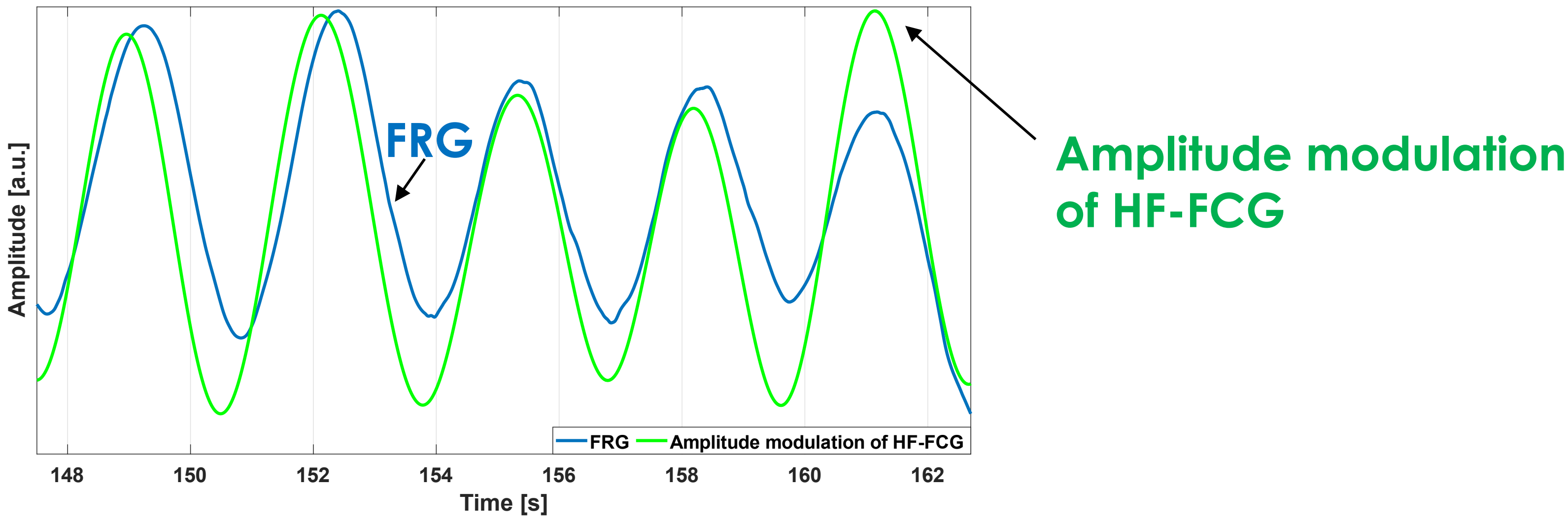
of **LF-FCG**…

…and **HF-FCG**.

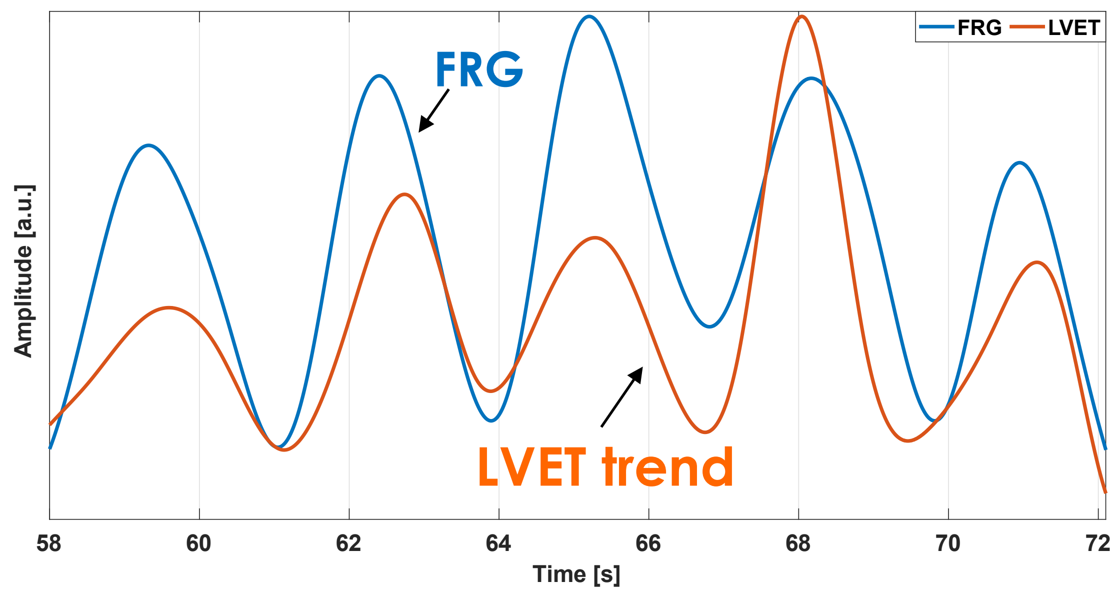


CARDIO-RESPIRATORY MONITORING VIA FORCECARDIOGRAPHY

In addition to the amplitude modulations of LF-FCG and HF-FCG…



…respiration also induces changes in various parameters of heartbeat morphology, e.g. the LVET.



CONCLUSIONS AND FUTURE PERSPECTIVES

- Forcecardiography (FCG) allows to acquire signals with much richer information content as compared to well-established cardio-mechanical monitoring techniques by means of a unique sensor.

- FCG could support pervasive wearable monitoring applications. It could be used for continuous, long-term monitoring of cardio-respiratory function in daily life environments, e.g., for early detection of heart and pulmonary diseases or management of chronic patients.

Future perspectives:

- experimental tests on a larger cohort, also including pathological subjects;
- FCG recordings acquired during physical activities and/or sport exercises;
- comparison with Echocardiography;
- multichannel measurements by using FCG sensor matrices.

THANK YOU
FOR YOUR KIND ATTENTION