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Multimodal Sensing For AI-Assisted Diagnoses of Heart Failure

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Extended Abstract

Motivated by the challenge of finding a screening-compatible method for early detection of heart failure (HF), we have revised polycardiography using the modern sensing technology. Polycardiography is a multimodal measuring technique based on the synchronous noninvasive recording of the electrical and mechanical parameters of the cardiovascular system [1]. Our prototype polycardiograph simultaneously acquires an electrocardiogram (ECG), phonocardiogram (PCG), seismocardiograms (SCG) and photoplethysmograms (PPG) [2]. It provides a direct access to electro-mechanical biomarkers of HF with reduced ejection fraction (HFrEF), notably the systolic-time intervals such as left ventricular ejection time (LVET) and the pre-ejection period (PEP). Moreover, there are strong indications that it can provide a sufficient set of biomarkers for conclusive diagnostics of HF with preserved ejection fraction (HFpEF). We are currently performing a clinical study SensSmart at the University Clinical Centre of Serbia, in which we are testing the non-inferiority of the HF diagnosis by polycardiography with respect to the echocardiography. Preliminary results of AI-based classification preformed on the median heartbeats from a set of 100 HF patients and controls, indicate a possibility to diagnose both HFrEF and HFpEF. At the conference, we will present the interim AI-based results and the study of the significance of particular noninvasively accessible features to HF classification.

The clinical study SensSmart was preceded by a validation study SensSmartTech performed on healthy volunteers. Besides the technical validation of the prototype, its goal was detection of the HF biomarker (LVET, PEP, EF) dependence on heart rate (HR). Thus, the volunteers were measured before and after running on a treadmill, producing consistent heart relaxation signals over a wide range of HRs. The SensSmartTech database provides the valuable information on the complex nonlinear heart relaxation post-exercise dynamics and is made available on PhysioNet [3, 4]. It contains 338 30-sec signals, represented by ten channels each: 4 ECG, 4 PPG, 1 PCG and 1SCG. They were obtained from 18 females and 14 males with an average age of 34.6 ± 9.1 years. HRs were in the range of 58-170 bpm, rendering a total of 17817 heartbeats. Taking the ECG as a reference, the HR was estimated with 2 bpm root mean square error (RMSE) from PPG and 3 bpm RMSE from SCG [2]. LVET, PEP and EF dependences of HR were derived and compared to the literature. The dependences were used in estimation of STIs in the analysis of the clinical study data. Finally, we note that this direction of research is in line with the European Society of Cardiology guidelines that the assessment under stress may help clarify the HF diagnosis, in particular in HFpEF patients [5].

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References

[1] A. M. Weissler, W. S. Harris, and C. D. Schoenfeld, “Systolic Time Intervals in Heart Failure in Man,” Circulation, vol. 37, no. 2, pp. 149–159, 1968.

[2] Jovana Petrović, Marija D. Ivanović, Vladimir A. Atanasoski, Aleksandar Lazović, Maša Tiosavljević, P. Tadić, Ljupčo R. Hadžievski, Arsen Ristić, Vladan Vukčević, “Validation of Heart Rate Estimation from Photoplethysmograph and Accelerometer Recordings During Post-Exercise Relaxation,” in Proc. 2024 11th Int. Conf. Electr., Electron. Comput. Eng. (IcETRAN), Niš, Serbia, 2024, pp. 1–5, doi: 10.1109/IcETRAN62308.2024.10645151.

[3] A. Lazović, P. Tadić, N. Đorđević, V. Atanasoski, M. Tiosavljević, M. Ivanović, L. Hadžievski, A. Ristić, V. Vukčević, and J. Petrović, “SensSmartTech database of cardiovascular signals synchronously recorded by an electrocardiograph, phonocardiograph, photoplethysmograph and accelerometer (version 1.0.0),” PhysioNet [Online]. Available: https://doi.org/10.13026/fy9p-n277, 2024.

[4] A. L. Goldberger, L. A. N. Amaral, L. Glass, J. M. Hausdorff, P. C. Ivanov, R. G. Mark, J. E. Mietus, G. B. Moody, C.-K. Peng, and H. E. Stanley, “PhysioBank, PhysioToolkit, and PhysioNet: Components of a new research resource for complex physiologic signals,” Circulation, vol. 101, no. 23, pp. e215–e220, 2000.

[5] T. McDonagh, M. Metra, M. Adamo, R. S. Gardner, A. Baumbach, M. Böhm, H. Burri, J. Butler, J. Čelutkienė, O. Chioncel, J. G. F. Cleland, A. J. S. Coats, M. G. Crespo-Leiro, D. Farmakis, M. Gilard, S. Heymans, A. W. Hoes, T. Jaarsma, E. A. Jankowska, M. Lainscak, C. S. P. Lam, A. R. Lyon, J. J. V. McMurray, A. Mebazaa, R. Mindham, C. Muneretto, M. F. Piepoli, S. Price, G. M. C. Rosano, F. Ruschitzka, A. K. Skibelund, “2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure,” Eur. Heart J., vol. 42, no. 36, pp. 3599–3726, 2021.