Multi-Encoder Autoencoders for Unsupervised Separation of the Second Heart Sound: An Application to Pulmonary Hypertension Diagnosis

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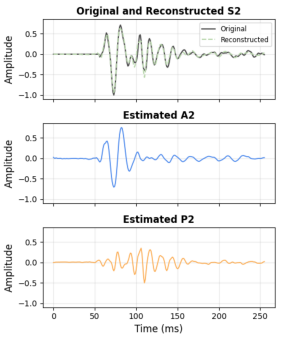
Aims: The second heart sound (S2) provides clinically relevant information for the diagnosis of pulmonary hypertension (PH) through the relative timing and amplitude of its aortic (A2) and pulmonary (P2) components. Algorithms for estimating these components traditionally rely on iterative optimization frameworks with predefined assumptions about their waveforms. This work proposes a data-driven alternative based on a multi-encoder convolutional autoencoder that learns to separate single-channel S2 mixtures in an unsupervised process, mitigating the need for ground-truth source signals or auxiliary physiological measurements.

Methods: The model comprises two parallel encoder branches sharing one single decoder, which processes the concatenation of all encoded representations. Each encoder is encouraged to specialize in one source subspace via a custom loss function and, during inference, A2 and P2 estimates are obtained by masking all encoders except the one of interest before decoding. The clinical utility of the model was assessed on a dataset of 12,831 real S2 sounds from 42 patients (13 without PH, 29 with PH) with reference pulmonary artery pressure obtained via right heart catheterization. After estimating the individual waveforms of A2 and P2 for each S2 sound, eight statistical features (derived from time split, energy ratio and peak-to-peak ratio) were extracted and aggregated per patient to train a linear SVM classifier under nested leave-one-out cross-validation.



Results: The PH classification task achieved an AUROC of 0.87 and an average precision of 0.93.

Conclusion These results suggest that deep learning-based blind source separation can extract clinically discriminative features from S2 sounds, thus providing valuable insight for the detection of pulmonary hypertension.