Non-Uniform Temporal Alignment for Heartbeat Characterization in Doppler Radar Monitoring

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Aims. Remote heart rate monitoring using Doppler radar is challenged by heart rate variability (HRV), respiratory motion and low Signal-to-Noise Ratio (SNR) dominated by close-in phase noise. This work investigated the enhancement of cardiac component extraction through a non-uniform temporal alignment algorithm designed to compensate for HRV.

Methods. Measurements were conducted on seven adults (N=7) employing a 2.4 GHz Continuous Wave Doppler radar alongside a Pulse Oximeter (PO) as reference. Applying a band-pass filter, the algorithm extracted the instantaneous cardiac phase of each recording via the Hilbert transform, resampling the Doppler data onto a phase-uniform grid to enforce the periodicity of heartbeat cycles. Two recalibration configurations were assessed: a PO-aided mode and a fully autonomous blind mode. Each was then evaluated under both voluntary apnoea and free-breathing conditions.

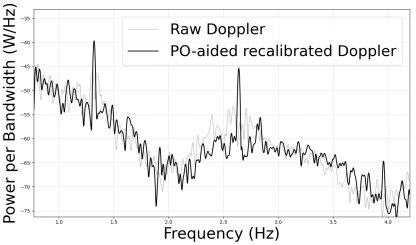

Figure 1. Recalibrated PSD (breathing)

Results. Under apnoea, cardiac energy was shifted into a narrower frequency band, revealing higher-order harmonics previously masked by noise. The blind mode achieved a heart rate root mean square error of 5.1 beats per minute relative to the PO reference. During free-breathing, PO-assisted alignment recovered cardiac harmonics that remained undetectable in raw signals. The power spectral density (PSD) was computed to highlight PO-aided recalibration. Conversely, the performance of the blind approach degraded due to unreliable cardiac phase estimation.

Table 1. Pulse Extraction Evaluation

Condition	Alignment	SNR Gain (dB)	
		Mean	Max
Apnoea	Blind	+3.7	+5.7
Breathing	PO-aided	+7.1	+12
Breathing	Blind	N/A	+3.8

Conclusion. Non-uniform temporal alignment effectively restores the cardiac harmonic structure in Doppler radar sensing. While robust during apnoea and PO-aided cases, autonomous extraction under free-breathing remains an open challenge. These findings identify parametric respiratory modelling as the key remaining challenge for fully autonomous blind separation.