Sparse Transmission Strategy for Transverse Doppler Spectrum Estimation

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Introduction

Motivation

Spectral Doppler allows the visualization of blood velocities which is crucial for diagnosing many conditions such as blood clots, heart valve defects, cancerous tumors, etc. However, Doppler mode exhibits several major challenges:

- **Spectral Resolution** – Large number of Doppler transmissions is required.
- **Alternating Strategy** – Doppler and B-mode both must be displayed at the same time.
- **Frame Rate** – We need to identify rapid temporal variations in the blood flow and track tissue movement.
- **Lateral Velocity** – flow perpendicular to the beam is not usually measured.
- **Spatial Coverage** – In focused acquisition, velocity estimation can be performed only on points on the acquisition line.
- **Clutter Removal** – Reflections from the vessel walls degrade our estimation.

Main Goal

Recovering the blood spectrum while reducing the number of transmissions.

Key - Difference Array

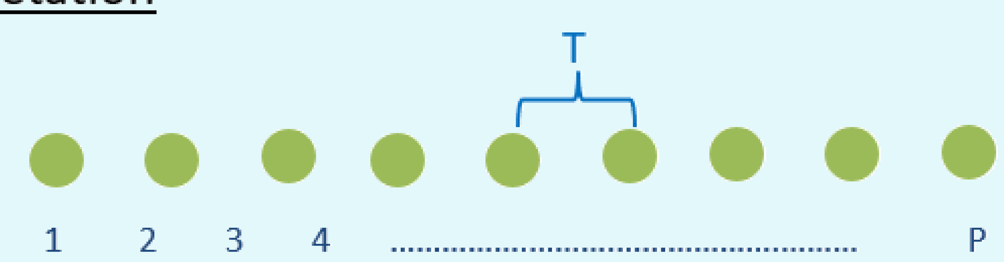
The blood spectrum is given by the Fourier transform of the signal autocorrelation:

$$S(f)=\mathcal{F}\{\boldsymbol{R}[d]\}(f).$$

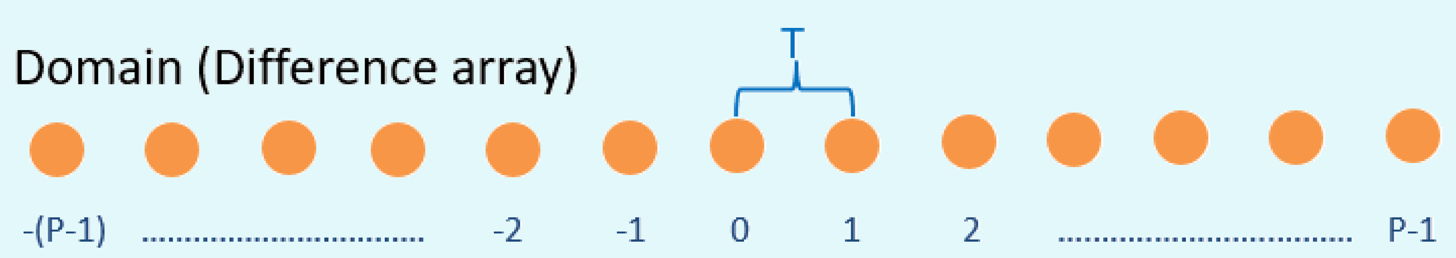
We exploit that the autocorrelation depends on **differences between samples**

$$\boldsymbol{R}[d]=E\Big[\boldsymbol{y}[p]\bar{\boldsymbol{y}}[p-d]\Big]$$

- Geometrical Interpretation
- Time Domain



- Correlation Domain (Difference array)



Sparse Doppler Transmission Strategy

Solution

We introduce a non-uniform stream of pulses based on the design of sparse arrays **whose difference coarray is full.** This allows to **recover the autocorrelation from fewer pulses.**

Proposed Sparse Arrays

$$U=[U_A\ \ U_B]\rightarrow U_A=\{1,...,A\},\quad U_B=\{n(A+1):\ n=1,...,B\}$$

where $P=(A+1)B$. **Difference co-array property:**

$$D=U-U=\{-(P-1),...,P-1\}.$$

Minimal Number of Transmissions

$$\min_{A,B} A+B \quad s.t.\ P=(A+1)B\rightarrow A=\sqrt{P}-1, B=\sqrt{P}$$

Recovery Methods

We present two reconstruction techniques:

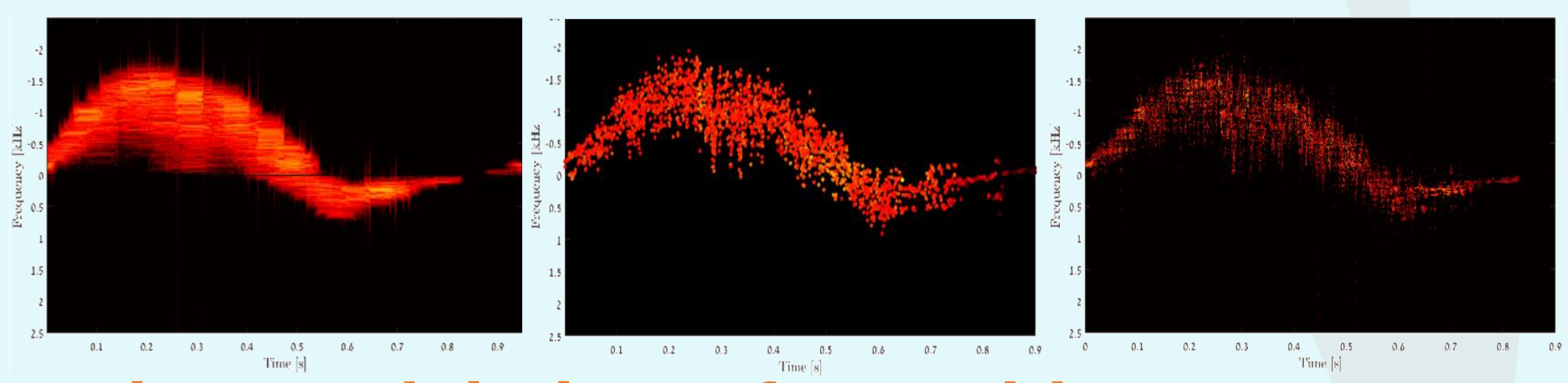
- **NEST** – performs **discrete recovery** of the Doppler frequencies.
- **NESPRIT** - performs **continuous recovery** of the Doppler frequencies.

Both methods utilize the non-uniform transmission strategy above to recover the spectrum from fewer pulses.

- **Significant transmission reduction.**
- **High spectral resolution**
- **Doppler gaps** which can be used for **B-mode to track movement** or for other Doppler sequence at different direction to **increase spatial coverage**.
- **Clutter Removal –** any existing technique can be used using this approach.
- Lateral Velocity - transvers oscillation (TO) can be easily integrated.

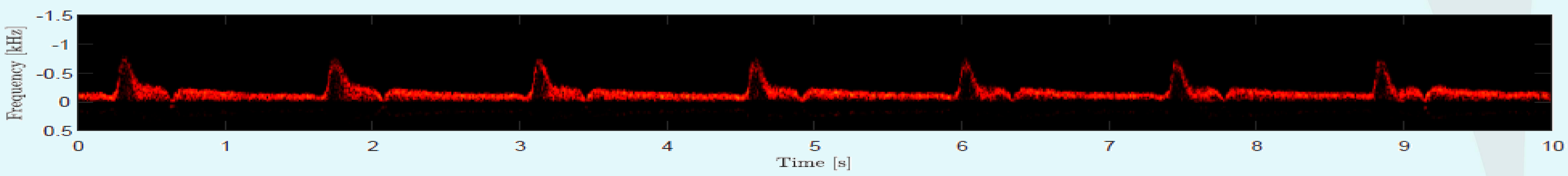
Field II – Transverse Flow

Welch – 256 Pulses | NESPRIT – 31 Pulses | NEST – 31 Pulses

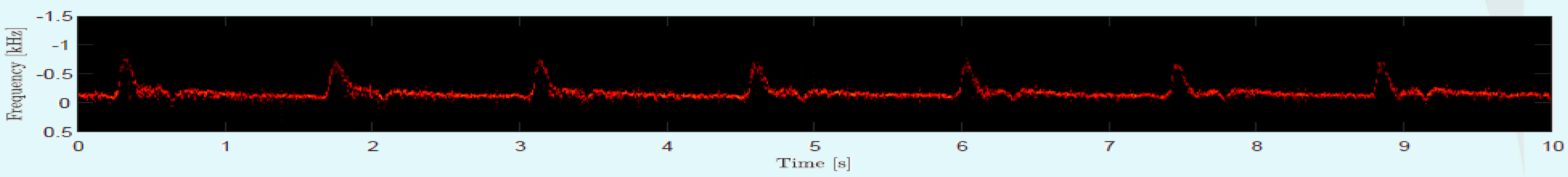


In-vivo Results – Axial Flow of Carotid Artery

Welch – 128 Pulses



NEST – 35 Pulses



NESPRIT – 35 Pulses