Sparse Transmission Strategy for Transverse Doppler Spectrum Estimation

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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:

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

We exploit that the autocorrelation depends on differences between samples

\[ R[d] = E[u[p]\bar{y}[p-d]]. \]

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

\[ \min A + B \quad \text{s.t.} \quad P = (A+1)B \rightarrow A = \sqrt{P} - 1, B = \sqrt{P} \]

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

**NEST** – 31 Pulses

**NESPRIT** – 31 Pulses

In-vivo Results – Axial Flow of Carotid Artery

**Welch** – 128 Pulses

**NEST** – 35 Pulses

**NESPRIT** – 35 Pulses