OPTIMIZED RECEIVE FILTERS AND CODED PULSE SEQUENCES FOR CONTRAST AGENT IMAGING

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Motivation

Advantages of Amplitude- and Phase-Coded Pulse Sequences

- Full-bandwidth detection of harmonics
  - High resolution
- Low MI imaging, i. e. non-destructive
  - Real-time imaging
  - Longer sequences improve SNR
- Harmonic-specific sequences
  - Detect 1st harmonic generated by 3. order non-linearities
  - Suppress 2nd harmonic generated by nonlinear propagation in tissue

Challenges

- Transmitters do not reproduce pulse sequences with required accuracy
  - Incomplete cancellation
  - Pulse shaping is time consuming and may not be effective
- Depth dependent attenuation, variety of agents, different transducer etc.
  - Depth dependency requires extensive experimental studies

Proposed Solution

- 1 receive filter per pulse in sequence
- Automated filter optimization based on training data for 2 media

Expected Benefits

- No need for perfect transmitters
- Optimal differentiation between media
- Increased SNR

Introduction

Block Diagram

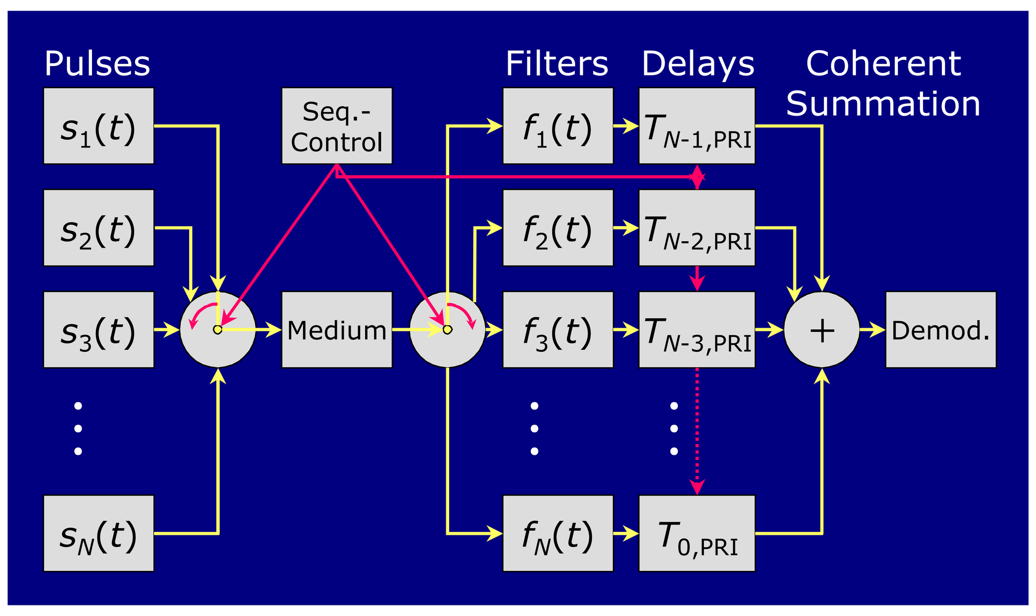

Fig. 1: Block diagram of an imaging system with 1 filter per pulse in the sequence.

Optimization Strategy

- FIR filters, typ. 16 – 128 taps
- Robust optimization criterion: Best contrast (energy ratio) between two media, e. g. contrast agent/tissue
- Training data: RF echoes representing the 2 media in the same depth range

Optimization

- Formulate the system in Fig. 1 by means of linear algebra
- Known: Training data
- Unknown: Filter coefficients

⇒ Solution of Eigenvalue problem yields filter coefficients

Experimental Results

Data Acquisition

- Tissue mimicking phantom with cylindrical hole
- Contrast agent: Definity
- 3.5 MHz curved array
- Siemens Sonoline Elegra
- pulse sequence: 0°-120°-180°-240°, 2 cycles at 2 MHz

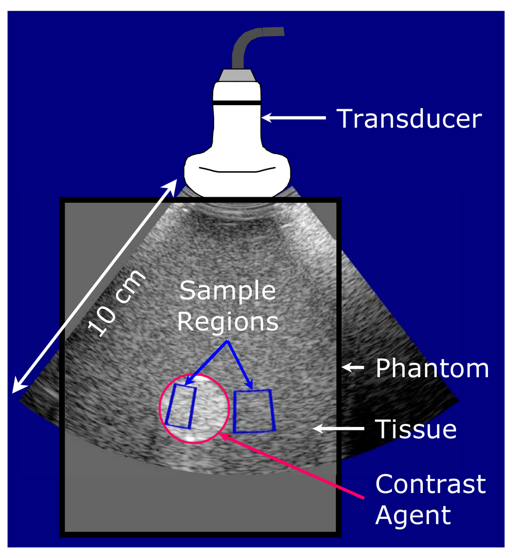

Fig. 2: Experimental setup.

Results

B-Mode (Fig. 3, Fig. 4)

- Contrast agent creates shadowing
- Contrast agent and tissue can hardly be distinguished

1-tap Filter (Fig. 5, Fig. 6)

- Optimal weighted summation
- Contrast is improved
- Poor SNR, without receive filter

64-tap Filter (Fig. 7, Fig. 8)

- Almost perfect separation of the media, classification error < 3.5 %
- Filters suppress noise, since noise decreases contrast

Discussion

Findings

- Optimized receive filters can greatly improve image contrast (Fig. 3, Fig. 5, Fig. 7)
- Transducer passband most important for image contrast (Fig. 9, Fig. 11)
- Filters introduce phase shifts to enhance image contrast (Fig. 10)
- 2nd harmonic degrades contrast and is suppressed (Fig. 9, Fig. 11)
- Sub-harmonics important for some agents and if SNR is poor (not shown)

Conclusion and Outlook

- Optimized receive filters clearly enhance pulse sequence-based imaging
- Harmonic-specific imaging modes for contrast agent and general non-linear imaging will be investigated
- Dynamic, i. e. depth dependent, filters will be developed

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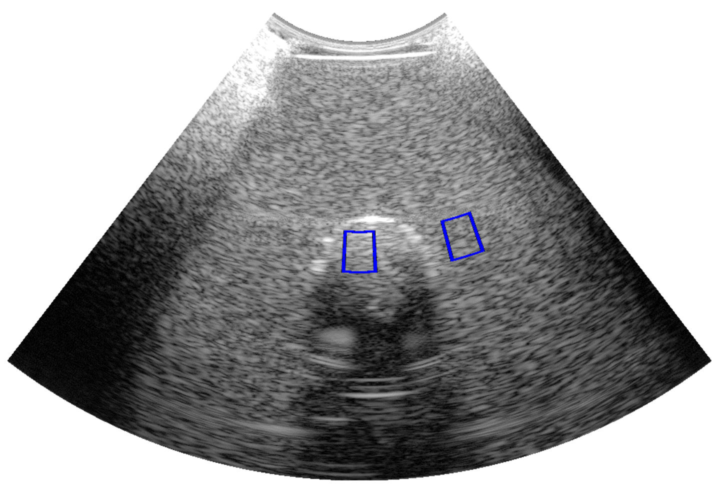

Fig. 3: B mode image of the contrast agent phantom. Dynamic range: 55 dB. Boxes: sample regions for filter optimization (left: contrast agent, right: tissue).

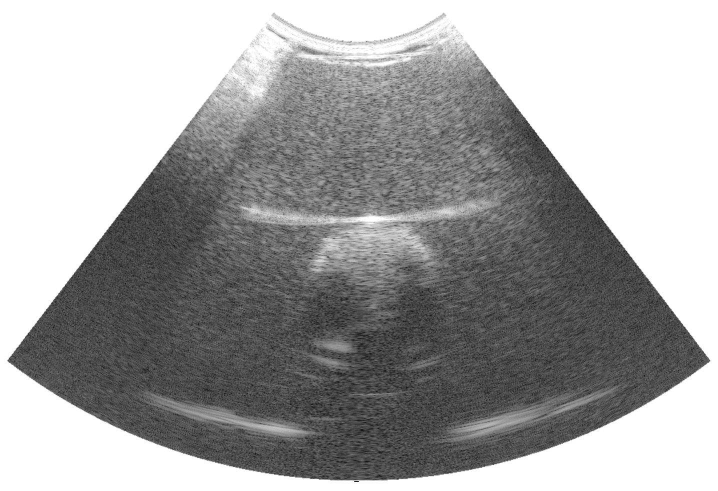

Fig. 5: Demodulated image after optimized 1-tap filtering. Dynamic range: 55 dB.

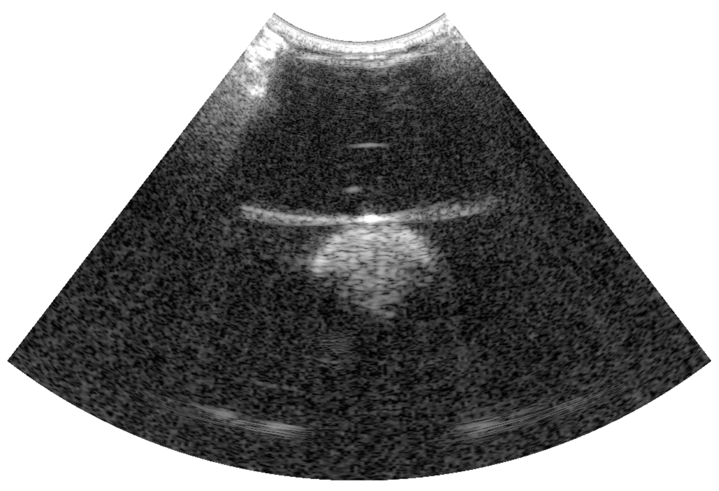

Fig. 7: Demodulated image after optimized 64-tap filtering. Dynamic range: 55 dB.

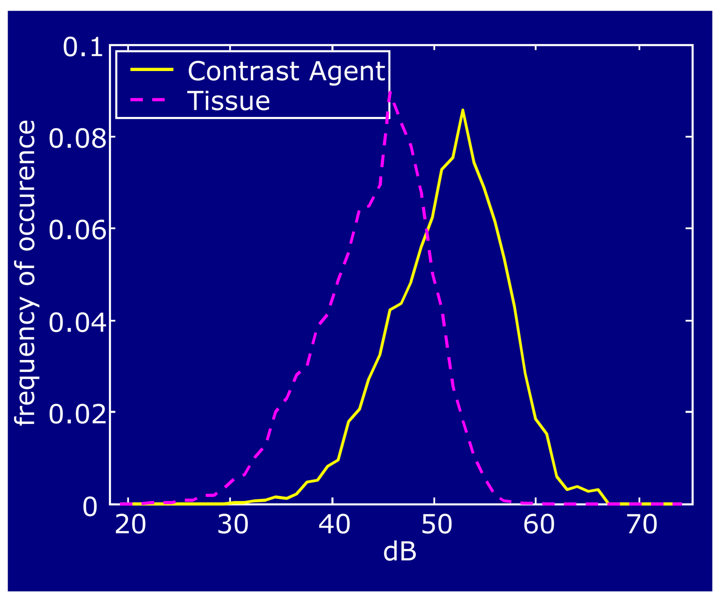

Fig. 4: Normalized histograms for the representation of contrast agent and tissue in the image shown in Fig. 3.

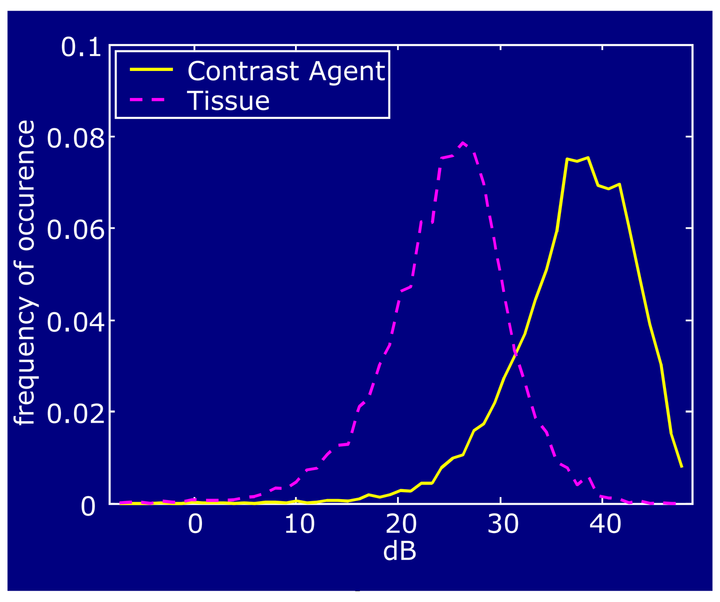

Fig. 6: Normalized histograms for the representation of contrast agent and tissue in the image shown in Fig. 5

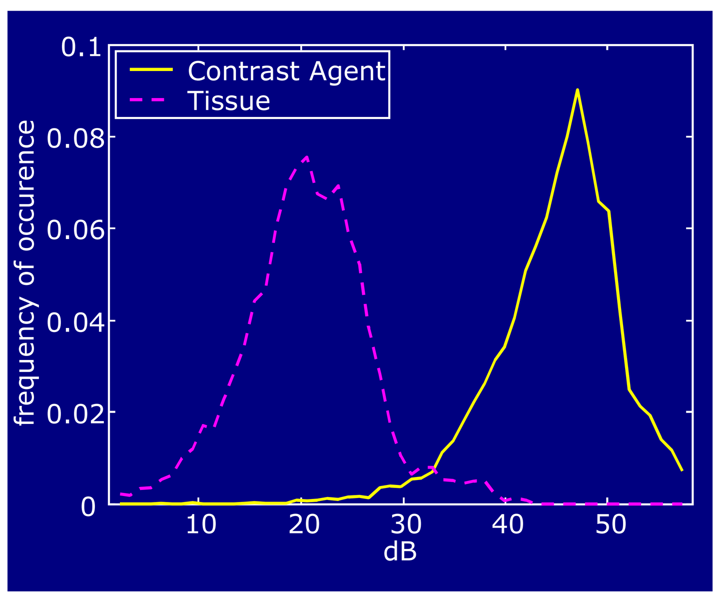

Fig. 8: Normalized histograms for the representation of contrast agent and tissue in the image shown in Fig. 7

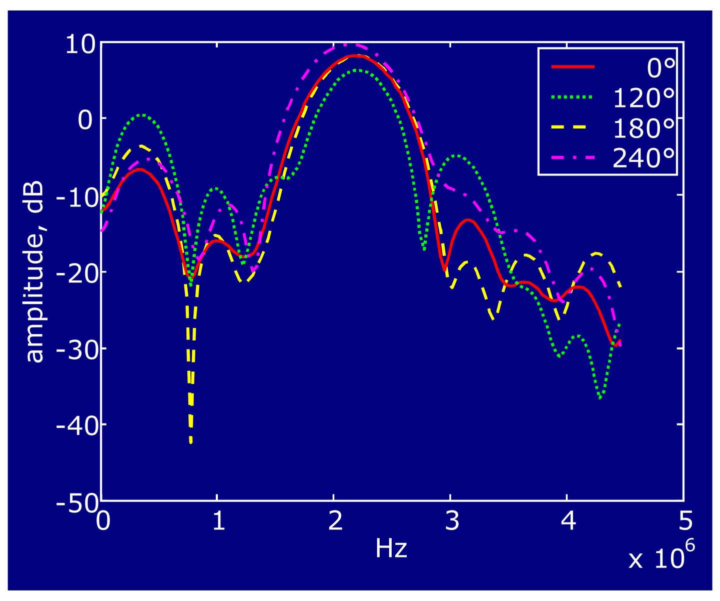

Fig. 9: Amplitude spectra of the 64-tap filters. Note that spectral components in the passband can still be canceled out in the summation.

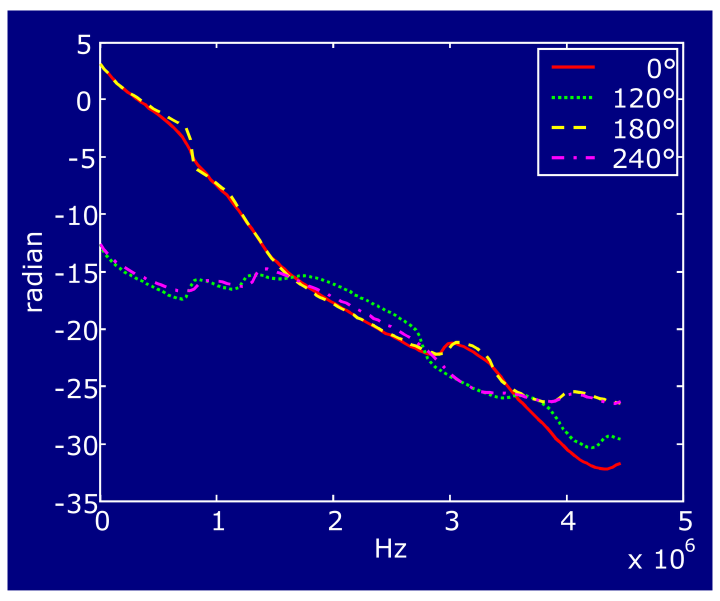

Fig. 10: Phase spectra of the 64-tap filters. Note the symmetry of the filters for the 0°, and 180° pulses and the phase shifts for the 120° and 240° pulses.

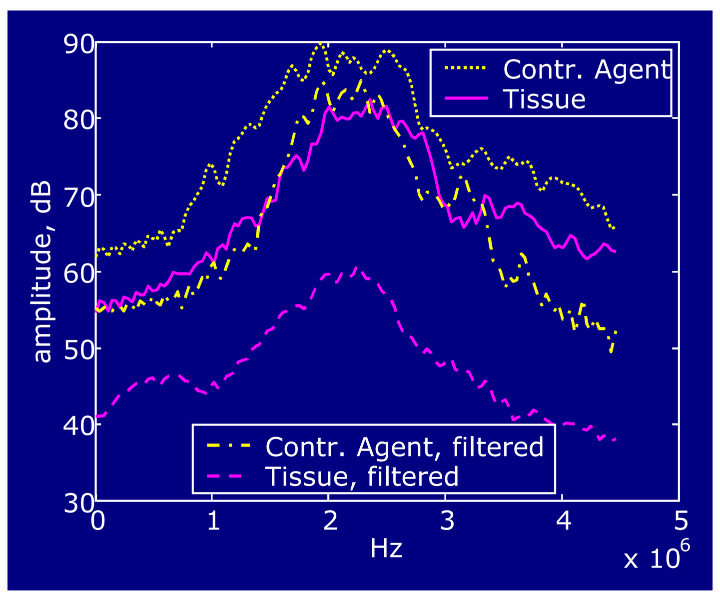

Fig. 11: Amplitude spectra for tissue and contrast agent before and after filtering and summation.