Hao Zhou, Yin-fei Zheng, 2015. An efficient quadrature demodulator for medical ultrasound imaging. *Frontiers of Information Technology & Electronic Engineering*, **16**(4):301-310. [doi:10.1631/FITEE.1400205]

An efficient quadrature demodulator for medical ultrasound imaging

Key words: B-mode ultrasound imaging, Color flow imaging, Quadrature demodulation, Finite impulse response filter

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Introduction

- Quadrature demodulation is frequently used in medical ultrasound imaging.
- Quadrature demodulation consists of frequency mixing and low-pass filtering, and consumes much time.
- An efficient quadrature demodulator without frequency mixing has been presented in this work

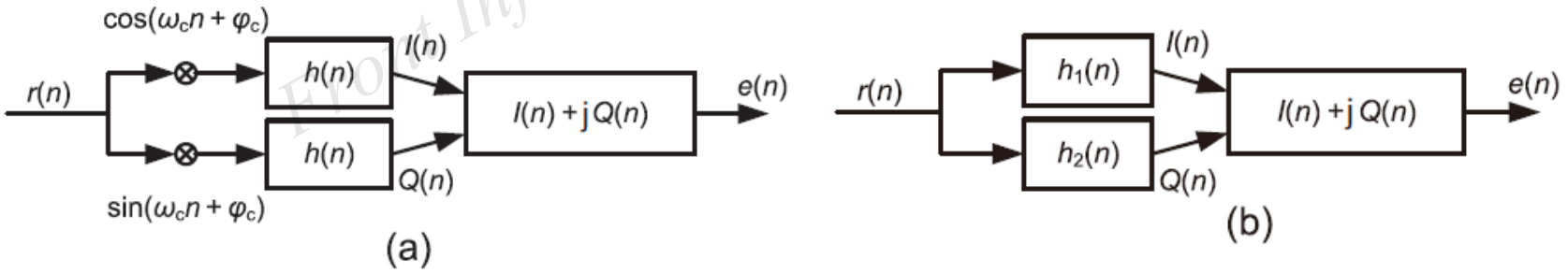


Fig. 1 Block diagrams of conventional quadrature demodulation (a) and the proposed demodulation (b). $\boldsymbol{h(n)}$ is the impulse response of the low-pass filter and $\boldsymbol{h_1(n)}$ and $\boldsymbol{h_2(n)}$ are the impulse responses of the proposed filters

Method: quadrature filter design

1. Design a linear phase low-pass FIR filter with proper characteristics for conventional quadrature demodulation.

2. Multiply the coefficients of the derived FIR filter with reference sine and cosine waveforms (using Eq. (10)).

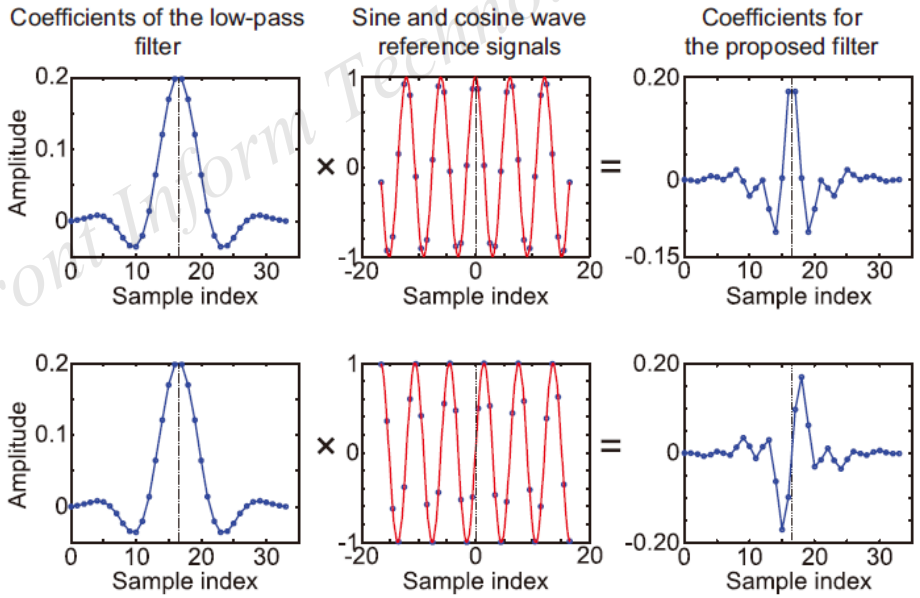


Fig. 2 Diagrammatic explanation of designing the proposed demodulation filter

Result: B-mode simulation

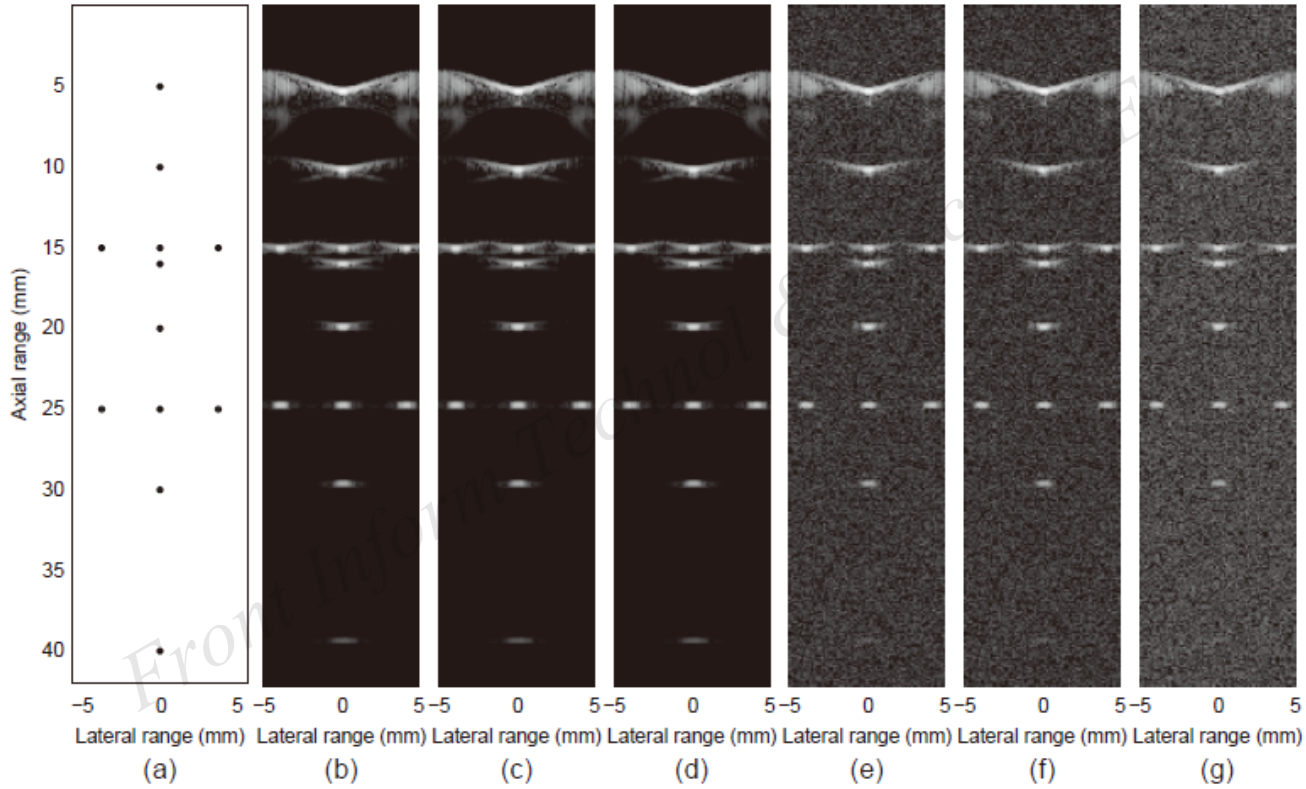


Fig. 3 Simulation results of the B-mode images: (a) 12-target array model; (b) B-mode image without noise and envelope detected by the proposed method; (c) B-mode image without noise and envelope detected by the conventional method; (d) B-mode image without noise and envelope detected by the Hilbert transform method; (e) B-mode image with SNR=20 dB and envelope detected by the proposed method; (f) B-mode image with SNR=20 dB and envelope detected by the conventional method; (g) B-mode image with SNR=20 dB and envelope detected by the Hilbert transform method

Result: NRSS of B-mode image

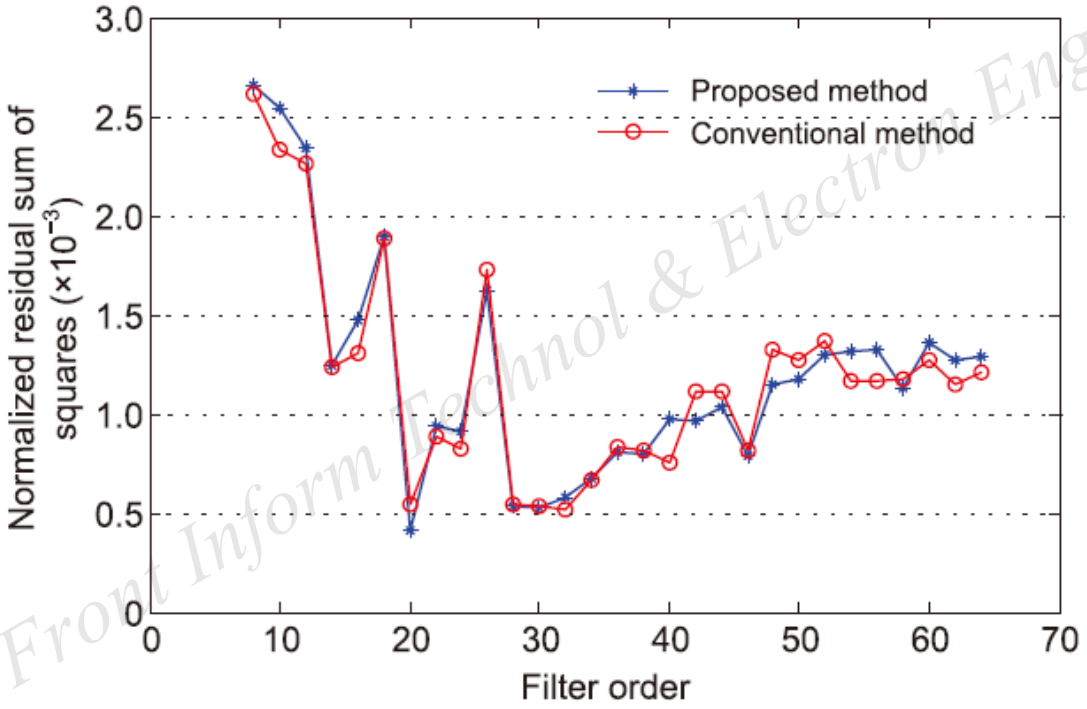


Fig. 4 Normalized residual sum of squares (NRSS) of the proposed method and the conventional quadrature demodulation method (the number of bits of the filter coefficients is 10)

Result: color flow imaging simulation

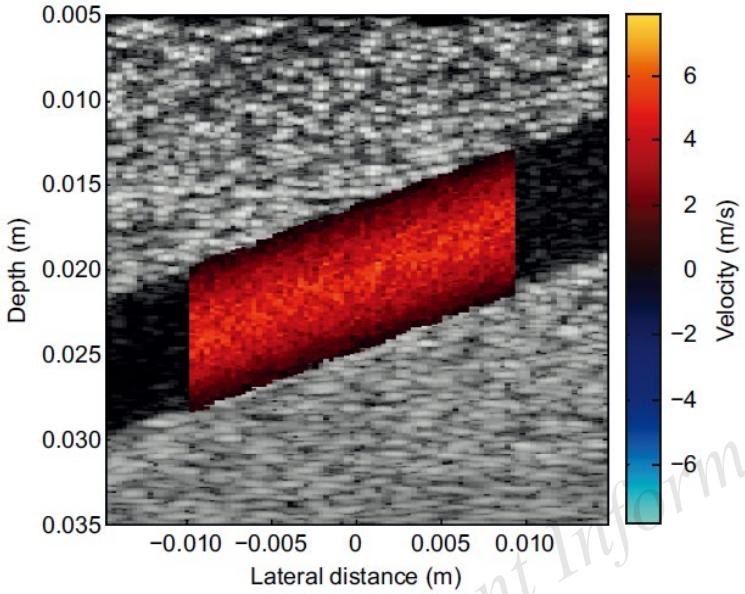


Fig. 5 Color flow map of the vessel model using the proposed demodulator

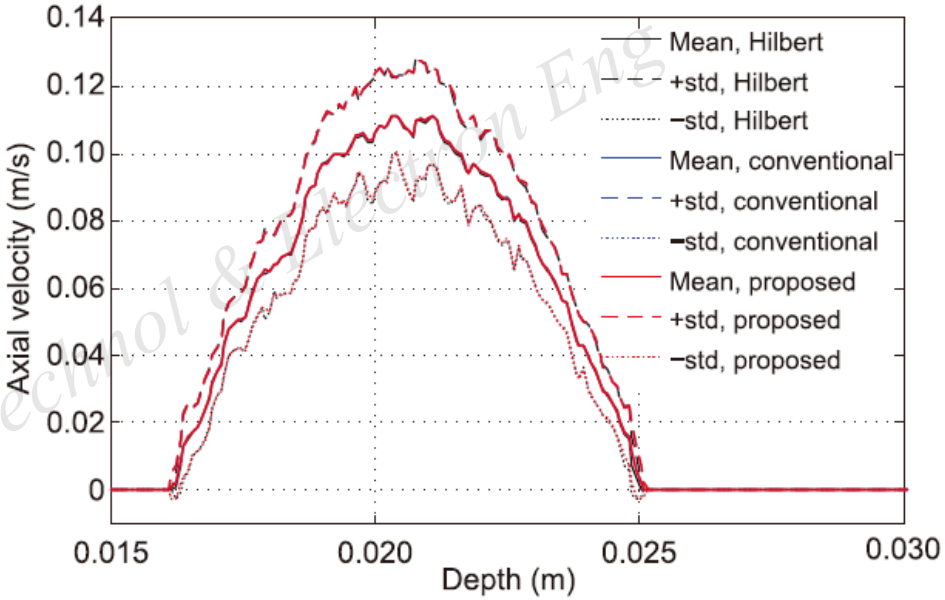
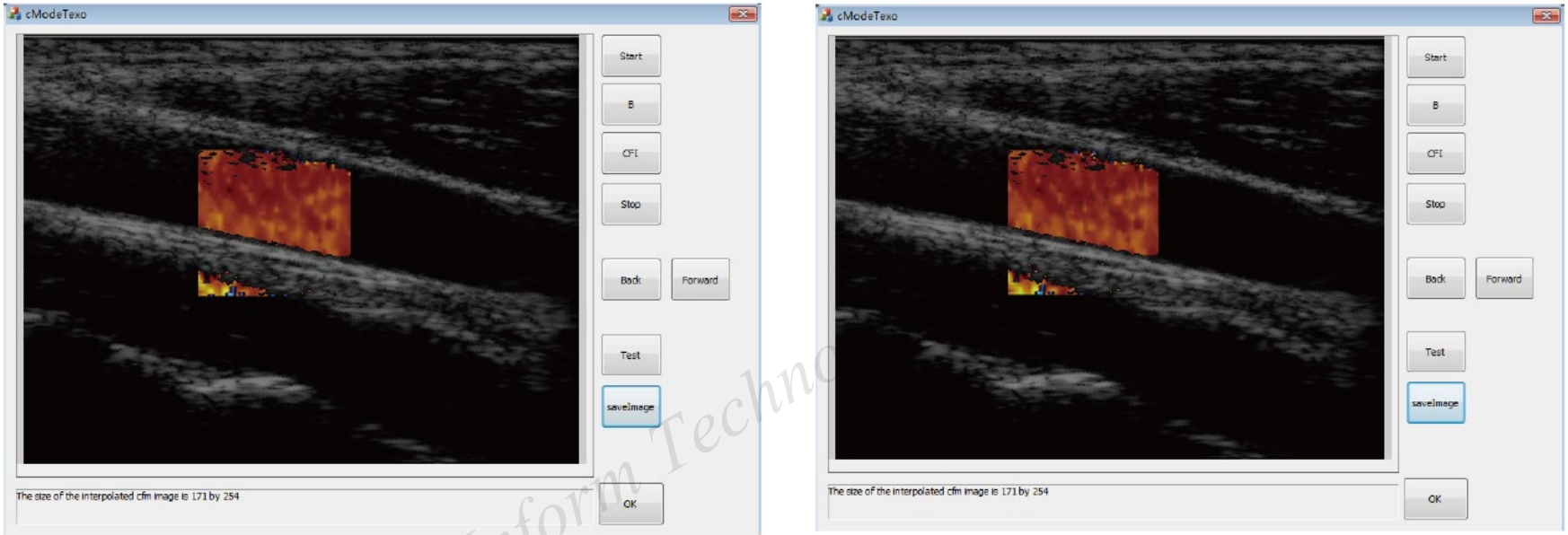


Fig. 6 Detected mean flow velocity and ±1 standard deviation of the center line of the simulation

Result: color flow imaging



(a) (b)

Fig. 7 GUIs using the proposed demodulation method (a) and the conventional quadrature demodulation method (b)

Result: computing time

- Computing time of the demodulation operation for each frame of duplex imaging (Fig. 7) was 5.66 ms and 3.36 ms for the conventional and the proposed method, respectively

- Computing time for generating a B-mode image was 30.77 ms and 27.88 ms for the conventional and the proposed method, respectively

- In B-mode imaging, 10% of frame rate improvement can be obtained using the proposed demodulator

Discussion: comparison of demodulation methods

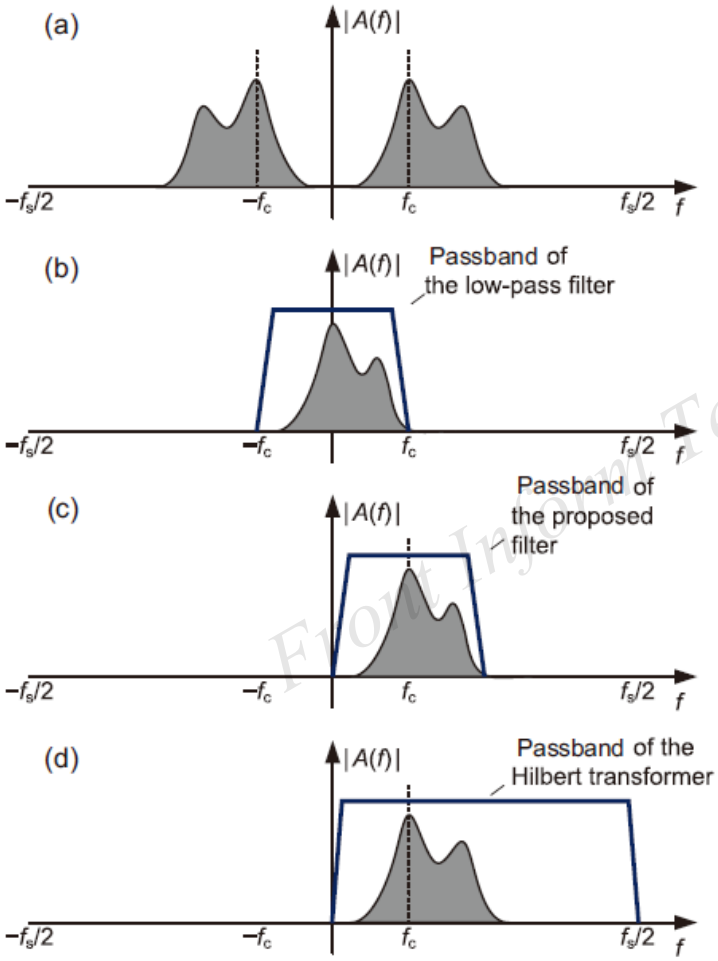


Fig. 8 Comparisons of the proposed method and conventional methods in frequency domain: (a) spectrum of the radio-frequency signal; (b) spectrum of the base-band signal after conventional quadrature demodulation; (c) spectrum of the complex signal obtained using the proposed method; (d) spectrum of the complex signal obtained using approximate Hilbert transform method

Conclusions

- The proposed demodulator is obtained by mixing the coefficients of low-pass filter with the reference signal to reduce the computational complexity of demodulation operation.
- The proposed demodulator can provide a similar accuracy to that of the conventional quadrature demodulator.