Evaluation of Chirp and Binary Codes based Excitation Pulses for 3D USCT

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Background

- at Forschungszentrum Karlsruhe we are developing a new imaging method for early breast cancer detection: 3D ultrasound computer tomography (3D USCT)


Figure 1: Current status of the aperture of the 3D USCT demonstrator of 2nd generation, right-bottom: 2nd generation prototyp transducer

USCT concept

- 3D SAFT with unfocussed spherical waves emitted and received by single transducers.
- multistatic ellipsoid aperture 17cm x 12cm x 12cm, lift- and rotatable
- aperture walls lined with hundreds of transducers
- transducers with resonance frequency of 2.8 MHz and an opening angle of ± 23° at -6dB

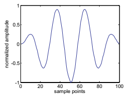

Figure 2: Emitter excitation pulse damped sinoid pulse

Challenge: low signal SNR

- unfocused emission and reception
- long traveling distances in 3D aperture
- for wide opening angle of transducers small active transducer area
- in designated medical application strong frequency damping

Approach

- advanced coded excitation techniques known from radar
- basic idea: prolonging the excitation pulse for higher energy, followed by pulse compression
- matched filtering (optimal filter) for pulse compression
- usage of frequency modulated chirps
- usage of phase encoded binary codes: Barker codes
- usage of complementary binary codes: Golay codes

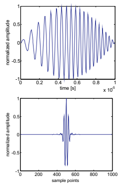

Figure 3: Chirp: top an linear frequency modulated chirp pulse, bottom the time compressed matched filtered pulse

Length	Code	PSL [dB]
2	+ +	-6.0
3	+ + -	-9.0
4	+ - + +	-12.0
5	+ + + - +	-14.0
7	+ + + - - + -	-16.9
11	+ + + - - - + - - + -	-20.8
13	+ + + + + - - + + - + +	-22.3

Table 1: Barker binary codes of various lengths, on the right is given the nominal peak-sidelobe level (PSL)

Length	A (A*)	B (B*)
2	+ + (+ +)	+ - (- +)
4	+ + - + (+ - + +)	+ + + - (- + + +)
8	+ + + - + + - + (+ - + + - + + +)	+ + + - - + - (- + - - - + + +)
16	- - + - - - - + - + + + + - + - - (- - + - + + + + - + - - - - - + - -)	- - + - - - - + + - - - + - + + (+ + - + - - - + +- - - - + - -)

Table 2: Golay complementary binary codes of different lengths, A and B as signal sequence and A* and B* as corresponding matched filters

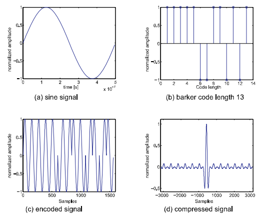

Figure 4: Barker binary code: (a) damped sine base pulse, (b) Barker of length 13, (c) convoluted pulse, (d) time-compressed by matched filtering

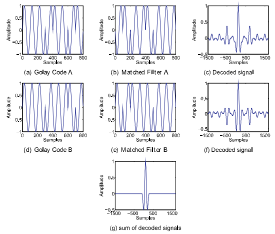

Figure 5: Golay complementary binary codes of different lengths, A and B as signal sequence and A* and B* as corresponding matched filters

Methods

Measurement setup

- water filled container (45x30x30cm³)
- 3D USCT 2nd generation prototype transducer with 2.8 MHz resonance frequency and 2 MHz (-6 dB) bandwidth
- 3D movable hydrophon-arm (Onda HNC-400)
- LabWindows based DAQ and control-software
- PC based Gage digitization card (20MHz)
- Tectronix AWG 2021 (arbitray-wave-generator)

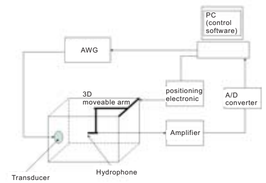

Figure 6: Schematic of measurement setup

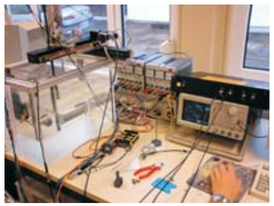
Figure 7: Measurement setup. Left: water container with hydrophone arm moveable by three axes. Right: AWG (arbitrary wave generator).


Figure 8: castor oil phantom

Empty measurement

- to simulate the multistatic 3D USCT aperture and evaluate signal processing and transducers
- measurement was done for varying angular position of the hydrophone

Phantom measurement

- breast tissue mimicking phantom
- consist of a bottle (wall thickness < λ/4) with dimensions 34cm x 8cm x 8cm filled with castor oil, frequency damping 0.72 dB/(MHz*cm)

Evaluated pulses

- sinoid pulse and linear chirp pulse
- Barker of length 13 and Golay of length 16, both convoluted with the sinoide pulse

Results

Evaluation

- applicability to the USCT setup and designated medical application is evaluated with well-established metrics SNR, GSNR, PSL, and ISL:

$$SNR_{out} = 10 \cdot \log_{10}(\frac{P_s}{P_e})$$

$$P_e = MSE = \frac{1}{N_e}\sum_{n=0}^{N_e-1} e(n)^2$$

$$P_s = \frac{1}{N_s}\sum_{n=0}^{N_s-1} s(n)^2$$

$$GSNR = SNR_{in} - SNR_{out}$$

$$ISL = 10 \cdot \log(\frac{P_{sidelobe}}{P_s})$$

$$PSL = 10 \cdot \log(\frac{M_{sidelobe}}{M})$$

Empty measurement	Golay Code 16	Barker Code 13	Chirp Pulse	Sinoide Pulse
SNR [dB]	56	33	26	12
GSNR [dB]	31	30	16	31
PSL [dB]	-39	-20	-31	-
ISL [dB]	-14	-16	-17	-

Table 3: Scores for different excitation pulses and the empty measurement setup, signal center frequency 1 MHz and bandwidth 0.25 MHz, measurements were averaged 512 times

Phantom measurement	Golay Code 16	Barker Code 13	Chirp Pulse	Sinoide Pulse
SNR [dB]	42	26	19	6
GSNR [dB]	29	27	13	-
PSL [dB]	-28	-13	-21	-
ISL [dB]	-8	-0.5	-6	-

Table 4: Scores for different excitation pulses and phantom measurement setup, signal center frequency 1 MHz and bandwidth 0.25 MHz, measurements were averaged 512 times

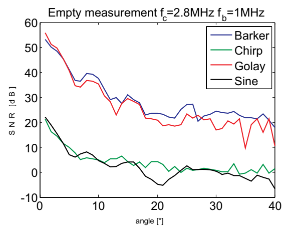

Figure 9: SNR for empty measurement for varying angular positions, center frequency 2.8 MHz and bandwidth 1.0 MHz, measurements were averaged 512 times

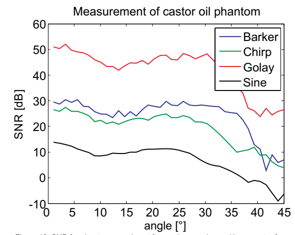

Figure 10: SNR for phantom experiment for varying angular positions, center frequency 1.0 MHz and bandwidth 0.25 MHz, measurements were averaged 512 times

Discussion

- techniques are suitable to the USCT setup and designated medical application
- Golay complementary code is a promising option for extending SNR, but downside doubled measurement time
- Barker is also a promising option without this downside

Outlook

- further evaluations are required for analyzing the tissue depended frequency dispersion

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