2P2-13

Coded Signal Scanning Acoustic Microscopy

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1. Introduction

Scanning Acoustic Microscopy (SAM) has emerged as a powerful tool for non-destructive imaging and characterization of materials at the microscale [1)]. It is extensively used in biomedical research for detailed microscopic imaging of biological samples and in industrial quality testing of materials [2-5)]. In high-frequency SAM imaging, the quality of the generated images depends on several factors, including noise level, resolution, pixel size, type of excitation signal, and other parameters. As the excitation frequency increases in SAM imaging, spatial resolution improves. However, this rise in frequency also leads to higher attenuation, reducing the depth of penetration. To address this limitation, one can compensate by either increasing the excitation voltage of the ultrasonic transducer or extending the length of the transmit waveform. Therefore, the performance of SAM relies significantly on the selection of the excitation signal. To achieve high excitation energy without damaging the transducers, signal energy must be distributed over time. Standard excitation methods can't do this without compromising temporal resolution. Therefore, coded signals are used. Coded excitation sends a longer ultrasound pulse than traditional methods[6)]. Coded (chirp) excitation has been a fundamental technique in radar technology for over 70 years [7)]. The long-standing use of chirp excitation in radar underscores its effectiveness in improving signal-to-noise ratio and target resolution, making it a crucial component in the development of advanced radar systems.

Despite the extended duration, coded excitation techniques preserve the spatial resolution of an ultrasound image by using matched or mismatched filters during signal processing. Coded signals reduce measurement time, improve the signal-to-noise ratio (SNR), and enable bandwidth tuning [8)]. One example is the chirp-coded wave, where the frequency varies continuously over time. Unlike constant-frequency waves, chirp waves exhibit either linear or nonlinear frequency modulation, with the instantaneous frequency changing smoothly or following a specific pattern. Ramp chirp waves are a specific type of chirp signal characterized by a linear frequency increase or decrease over time. Unlike nonlinear chirp signals that follow a curved frequency trajectory, ramp chirps have straight-line frequency modulation. Chirp waves effectively reduce measurement time (eliminating the need for averaging), significantly enhance the signal-to-noise ratio (SNR) and facilitate bandwidth tuning. In this study, we investigate the impact of input signal selection and image formation technique on the quality of images obtained through SAM. A comparative analysis is performed on images produced using three different input signals: Ricker waves, ramp chirp waves, and chirp waves. This analysis aims to determine how the choice of input signal influences the resultant image quality in terms of resolution, signal-to-noise ratio (SNR), and overall clarity.

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2. Experimental setup

In this article, we focus on using the reflection mode for scanning samples in SAM. A commonly employed method involves using a concave spherical sapphire lens rod to concentrate acoustic energy through a coupling medium, typically water.

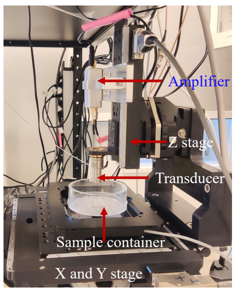

Fig. 1: The figure represents the SAM experimental setup for the sample imaging[9)].

Fig. 1 provides a detailed representation of the configured setup for the SAM used to images of the coin. This setup illustrates the components and configuration necessary for utilizing different types of excitation signals. Ultrasonic signals, generated by a signal generator, are directed toward the sample. When these signals reflect off the sample's surface, the reflected waves are captured and converted into a digital signal, known as an A-scan or amplitude scan. To generate a C-scan image of the sample, this process is repeated at various positions within the XY plane, integrating A-scans in two dimensions. We employed a 40 MHz PVDF-focused Olympus transducer with specifications, including a 6.35 mm aperture and a 12 mm focal length.

3. Results and discussions

The transducer was excited with a centre frequency of approximately 40 MHz. Fig. 2 demonstrates the different types of time-domain input signals used for acoustic imaging. To ensure optimal imaging performance, the excitation frequencies for all three signals were tuned to around 40 MHz, matching the transducer's centre frequency.

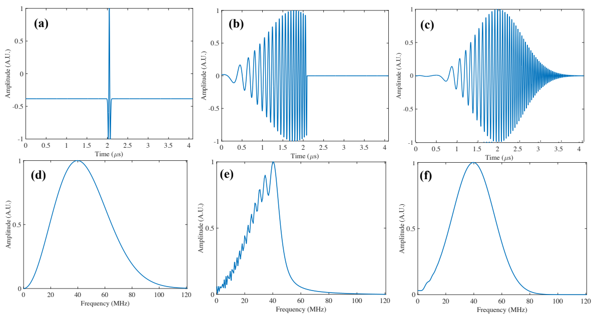

Fig 2: It illustrates the different time-domain input signals used for acoustic imaging: (a) a time domain Ricker wavelet, (d) its Fast Fourier Transform (FFT), (b) a ramp chirp coded signal, (e) its FFT, (c) a ramp chirp signal, and (f) its FFT.

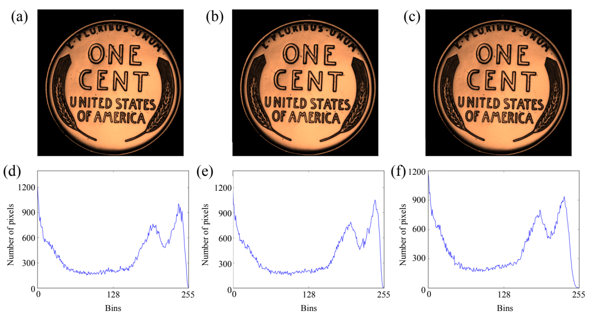

Fig. 3: Image created by taking the power of the (a) chirp signal, (b) ramp chirp signal and (c) Ricker signal. Histogram illustrating the distribution of pixel intensities in the image developed by (d) chirp (e) ramp chirp, and (f) ricker.

This study presents a comprehensive framework for analyzing data from three input signals: chirp, ramp chirp, and Ricker. To assess image quality, we utilized three metrics: sharpness, BRISQUE (for overall visual quality), and NIQE (for similarity to natural scenes). The images formed by different signals are shown in Fig. 3 and the corresponding evaluation metrics values are reported in Table 1.

Table. 1: Evaluation metrics (i) Sharpness, (ii) BRISQUE score and (iii) NIQE index for the image created by taking the power of the (a) chirp signal, (b) ramp chirp signal and (c) Ricker signal.

Signal type	Sharpness	BRISQUE	NIQE
Chirp	1.014	29.39	7.89
Ramp Chirp	1.006	31.40	9.08
Ricker	0.992	55.17	9.76

The results from Table 1 confirm that the images formed by the chirp signal are sharper and had better BRISQUE and NIQE score which made it more suitable signal for microscopy imaging.

4. Conclusion

This study presents initial findings on high-frequency acoustic imaging using various excitation signals. A comparison of coded signal excitation and traditional methods in acoustic microscopy is provided. Results demonstrate the potential of coded excitation for high-frequency imaging. To optimize image quality with chirp signals, pulse selection and coding parameters must be carefully chosen to suit the specific application.

Acknowledgment

A.A. acknowledges FRIPRO Young (project # 345136) funding from Research Council of Norway.

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