EDUCATIONAL MODEL OF SYNTHETIC APERTURE SONAR USING RANGE-DOPPLER ALGORITHM

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Abstract: This paper deals with synthetic aperture imaging techniques in ultrasound spectrum. The paper provides description of Synthetic Aperture Sonar (SAS) experiment with low-cost components in laboratory environment. The Range-Doppler Algorithm for signal processing, which is one of the imaging algorithm, is also depicted in this paper. The theoretical resolution is compared with that of the experimental results.

Keywords: Experiment, SAS, RDA

1. INTRODUCTION

The technique known as synthetic aperture sonar (SAS)/radar (SAR) belongs to remote sensing systems, which can produce high-resolution images by moving a single sensor past a scene of interest along a track. SAS is based on SAR, which were developed and used earlier on spaceborn platforms. The basic difference between SAS and SAR is a type of wave (acoustic/electromagnetic) and from that reason speed of propagation in a given environment, carrier frequency, beam width or dimensions of transducer [1].

The fundamental principle of image reconstruction in the SAS/SAR system is based on post-processing of pulse responses which are digitized and stored in a memory. More often used SAS/SAR post-processing algorithms are range Doppler algorithm (RDA) [2], chirp scaling algorithm [2] and omega-K algorithm [2]. The RDA is presented in this paper. It has been selected for the multi-purpose SAR platform design due to its advantageous characteristics like a block processing efficiency.

Post-processing was realized in MATLAB. It was also used for defining the output signal which goes through a transducer. .

2. THE INSTRUMENTS

The main laboratory sonar parts and instruments characteristics are summarized here. The entire experiment system is based around a PC and external sound card and MATLAB, which depicts Figure 1. The sonar transmitted a LFM pulsed signal with a currier frequency 40 kHz with bandwidth 4 kHz. A propagation speed is approximately 340 m/s in air which causes quite a big limitation for defining Pulsed Repetition Frequency (PRF) – one of the most important SAS/SAR parameter.

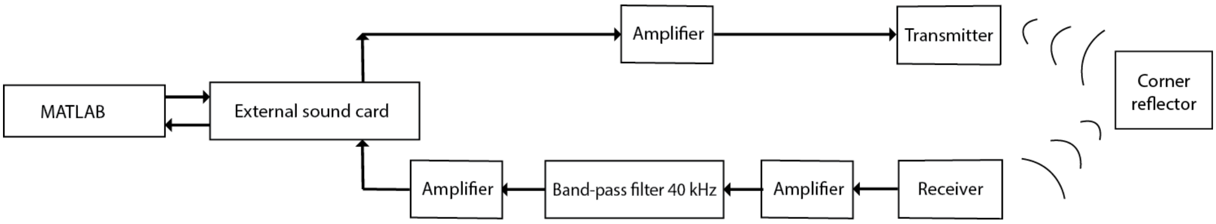

Figure 1: Block scheme

In MATLAB environment is defined LFM pulse with carrier frequency f_0 40 kHz, bandwidth B_0 4 kHz and pulse duration T_p 1 ns. MATLAB function `audioplayer` creates audio object for generating output signal from the sound card. Function `audiorecorder` solves inverse action for acquisition echoed signal. Both functions provide possibility to choose appropriate parameters such as given signal, sample rate or ID outputs and inputs.

The transmitter channel provides accurate amplification of the transmitted signal. It is composed of low noise JFET dual operational amplifiers TL072. Amplified signal is fed to transmitter transducer.

Echoed signal is received and modified in receiver channel. The band-pass filter with cutoff frequency 40 kHz is composed of two active low-pass filters and one band-pass filters. There are also amplifiers which increase Signal-Noise resolution. The attenuated signal by propagation and reflection is approximately amplified more than 1000 times.

For our experiment was used an external sound card Icon Cube because integrated sound card has not appropriate parameters. This card has 192 kHz sample rate, and its frequency response has been extended until 50 kHz by change of capacitors in output channel.

3. THE POST-PROCESSING

As was mentioned above, for the signal post-processing was chosen RDA, which was also created in MATLAB. Figure 2 illustrates the flowchart of the RDA process.

3.1. RANGE COMPRESSION

Compression of the echoed signal s_{rc} in the range direction is the first step of the RDA and this process can be described by:

$$s_{rc} = \text{IFFT}\{S_r(f_\tau, \eta) S_0(f_\tau\}, \quad (2)$$

where S_r is received signal in frequency domain and S0 is reference signal. Both signals are knocked under Inverse Fast Fourier Transform (IFFT). Increasing resolution in range can be gained by using of conventional windowing functions (Hann, Kaiser, etc) in addition to the rectangular envelope. The frequency matched filter is applied for each range line of received signal matrix.

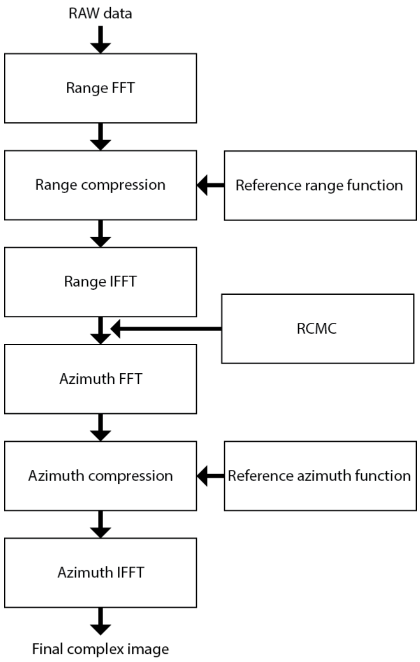

Figure 2: RDA diagram

3.2. RANGE CELL MIGRATION CORRECTION

Slant range $R_i(\eta)$ is changing due to movement of radar through synthetic aperture. This change causes additional Doppler shift. A hyperbolic form of instantaneous range (3) causes a phenomenon called range cell migration (RCM), which complicates the following signal processing.[2][3][4]

The contribution of RCM in frequency azimuth should be correct by:

$$\Delta R(f_\eta) = \frac{\lambda^2 R_0 f_\eta^2}{8V_r^2}, \tag{4}$$

where f_η is expressed as:

$$f_\eta = -K_a \eta, \tag{5}$$

and K_a is azimuth frequency rate, see (6). Note, the hyperbola (target trajectory) opens up with decreasing range in frequency domain, see (3)[2].

3.3. AZIMUTH COMPRESSION

After range compression and RCMC, the signal energy from target follows a trajectory in the two-dimensional matrix of echoed signal that depends on the changing range delay to the target as it passes through the antenna beam. In order to capture all signal energy from a point the target must be aligned in a signal range bin [2][3].

Azimuth compression is performed analogically to range compression. The difference is in the azimuth reference signal s_a:

$$s_a = exp\left\{-j\pi \frac{2V_g^2\eta^2}{\lambda R_0}\right\} \tag{6}$$

The platform velocity V_g causes the (parasitic) phase modulation. Signal s_a has LFM characteristic and its frequency rate K_a is expressed as [3]:

$$K_a \approx \frac{2V_r^2}{\lambda R_0}. \tag{7}$$

4. THE EXPERIMENT AND RESULTS

The experiment was realized in a soundproofed laboratory. Transducers were placed approximately two meters from two reflectors. Transmitter and receiver were mounted on a rail on which were assessed align the track. The transmission was realized every 1 cm along the track (1 meter) to simulate accurate PRF.

Figure 3 depicts matrix of echoed signals. Peaks represent each reflection. There was a complication with synchronization of an acquisition time base, because CPU time is changing during each transmission of a signal. This latency causes CPU, memory, sound card, audio drivers and others. The latency can reach in order of tenths of second, which correspond to dozens of meters. For this reason was necessary to synchronize time base before RDA processing which results in final image of a scene.

To align all echoed signals was used threshold, because relatively low noise and high sample frequency allowed this approach. For this purpose can be also used built-in functions based on cross correlation, but since echoed signals are pretty different, I decided to use first mentioned approach.

Figure 4 gives better preview on received signal in range domain. There are three main peaks. First peak represents transmitted LFM pulse, second and third peak are caused by reflection from above mentioned targets. Figure 4 is composed of these signals. Due to MATLAB processing time was necessary to set acquisition time (recording time) to 1s, which is disproportionate to our scene and was also necessary to crop redundant part of the echoed matrix. The delay between main peaks corresponds to a distance between transmitter and targets.

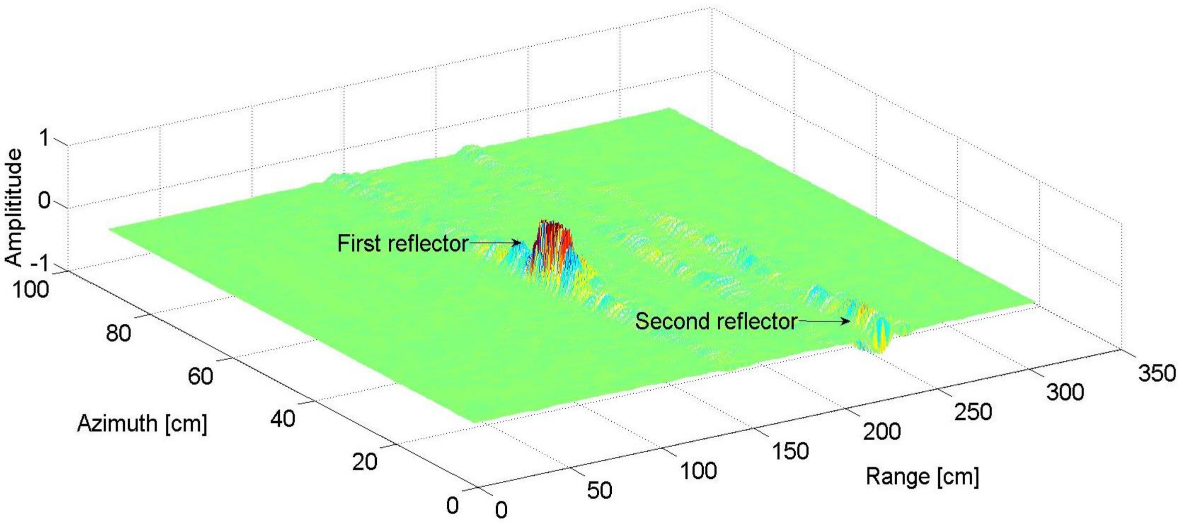

Figure 3: Echoed signals

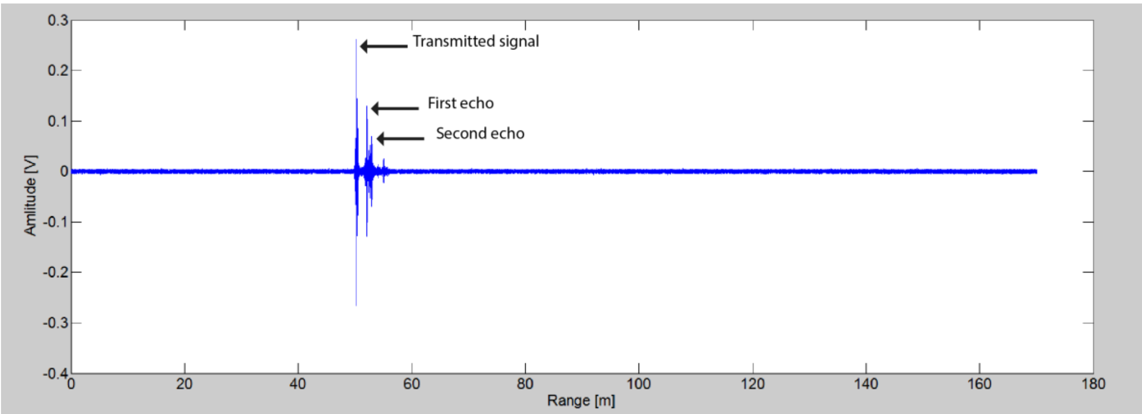

Figure 4: Received signal

5. CONCLUSION

Results show that the experiment confirms theoretical assumptions of the theme. The current phase of the experiment proves possibility to detect and resolve target in ultrasound spectrum. RDA was applied for the final image, which is discussed in third chapter. For the experiment, instruments used were described in second chapter. All measurements can be realized in Graphical Interface Unit in MATLAB, where a signal is generated and processed. Due to the difficult possibility of synchronization between generating and receiving time, input and output channel were operating simultaneously. Other task will carry out additional measurements, ideally outside in free space on bigger distances with metal scatters, which should ensure more transparent results. The final form of the laboratory model will be utilized for educational purposes.

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REFERENCES

[1] Wilkinson A. J., Mukhopadhyay P. K., Lewitton N., Inggs M. R. *Inverse Synthetic Imaging using a 40 kHz Ultrasonic Laboratory Sonar.* Grabouw, South Africa, 2004.

[2] Ouchi, Kazuo. *Recent Trend and Advance of Synthetic Aperture Radar with Selected Topics. Remote Sensing* [online]. 2013, DOI: 10.3390/rs5020716. ISSN 2072-4292

[3] Cumming, Ian G, Frank Hay-Chee Wong. *Digital processing of synthetic aperture radar data: algorithms and implementation*. Boston: Artech House, c2005, xxviii, 625 p. ISBN 15-805-3058-3.

[4] Shultz, Matthew. *Synthetic Aperture Radar Imaging Simulated in MATLAB*. San Luis Obispo, 2009. Master thesis. California Polytechnic State University.