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High-resolution range signature for coastal surveillance RADAR

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ABSTRACT

This paper mainly focuses on the signal processing techniques used on the coastal surveillance radar. As the radar is used to guard the coastal stretch of the Indian subcontinent, the target environment is dense. To satisfy this criterion wide band signal processing scheme is used. With the help of the wide band signal processing the high-resolution range signature for coastal surveillance radar is obtained using MATLAB

Keywords: *Range signature, Range profile, Wideband signal processing.*

1. INTRODUCTION

Coastal Surveillance Radar forms the main component of Surface Search Radars. Search radars scan a wide area with pulses of short radio waves. They usually scan the area two to four times a minute. The waves are usually less than a meter long. Ships and planes are metal and reflect radio waves. The radar measures the distance to the reflector by measuring the time of the round-trip from the emission of a pulse to reception, dividing this by two, and then multiplying by the speed of light. To be accepted, the received pulse has to lie within a period of time called the range gate. The radar determines the direction because the short radio waves behave like a search light when emitted from the reflector of the radar set's antenna.

Coastal Surveillance System is a highly sophisticated, multi-layer system employing advanced surveillance from autonomous, remotely operated sites. These sites feature long-range coastal surveillance radar synchronized with a long-range day-night video surveillance system. Each site is a self-sufficient unit, in terms of power, communication, site security, and processing. This enables independent deployment of sites in stages. The system is remote-controlled from a central control room. All the data from the sites is routed to the central control room via wireless, fiber-optic, or other existing communication infrastructure, where it is processed and displayed.

Major functions of CSR are Detection & Tracking of Sea Surface Targets for Various the Sea States, 24 X 7 Unmanned Operation, Operation for Clear & Inclement Weather Conditions, High Resolution for Dense Multi-target Environment, High Networking Capability.

2. ADVANTAGES

- High probability of detection, identification & classification of maritime targets and low-altitude aircraft (by radars and EO sensors)
- Advanced functions for evaluating and analyzing tactical information
- Fast and robust processing to allow handling of high-density environments
- Fast, wide and reliable method of collection and distribution of information among physically scattered decision makers
- Minimum work force – high level of automation i.e. its Cost effective - easy to operate and maintain, Flexible design for configuration changes.

The core of this system is comprised of:

- High performance, long-range coast surveillance radar, specially adapted to coastal and sea environments (clutter and sea environment)
- High-quality long-range day or night or laser observation systems, employing third-generation thermal imagers
- Observation towers complete with their own power unit, perimeter fence, and site security

- Wide-band wireless communication modules for each coastal surveillance site
- Optional mobile surveillance vehicles for coverage of areas not covered by the towers
- Personal surveillance sensors, such as hand-held third-generation thermal imagers, night vision goggles, and personal equipment
- Digitized control center facilitating coastal surveillance and management software, large LCD displays, digital maps and high tech control console for the operators.[4]

3. PROBLEM DEFINITION

A high-resolution range profile is a one dimensional signature of an object. It's a representation of the time domain response of the target to a high-range resolution radar pulse. In each high-resolution range cell, the amplitude of the signal is measured giving the strength of the return at that time delay. It generates high-resolution range profile of the target like ships, aircraft etc along Radar LOS, where the amplitude in each range gate is proportional to the superstructure RCS of each section of the ship, aircraft etc observed. Since the target heading is given by the tracking, the range profile aids in getting the estimate of the length of the ship, aircraft etc. The following images display one-dimensional signature, high-resolution gates of targets like aircraft, ships etc.

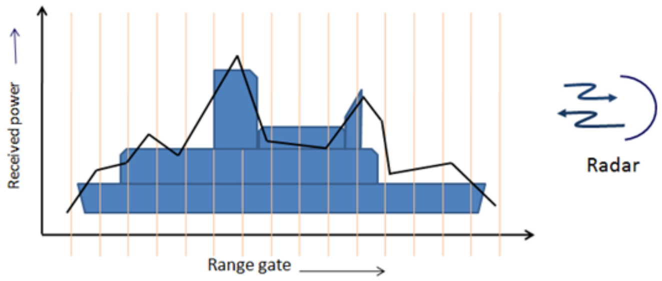


Figure 1: Different parts of the aircraft and ship appear in each range gate as the aspect angle to the radar changes

4. METHODOLOGY

Range resolution for given radar can be significantly improved by using very short pulses. Unfortunately, utilizing short pulses decreases the average transmitted power, which can hinder the radar's normal modes of operation, particularly for multi-function and surveillance radars. Since the average transmitted power is directly linked to the receiver SNR, it is often desirable to increase the pulse-width (i.e., increase the average transmitted power) while simultaneously maintaining adequate range resolution. This can be made possible by using pulse compression techniques. Pulse compression allows us to achieve the average transmitted power of a relatively long pulse while obtaining the range resolution corresponding to a short pulse. In this chapter, we will analyze analog and digital pulse compression techniques. Two LFM pulse compression techniques are discussed in this chapter. The first technique is known as "correlation processing" which is predominantly used for narrow band and some medium band radar operations. The second technique is called "stretch processing" and is normally used for extremely wide band radar operations. Here in this report, we will discuss stretch processing technique because coastal surveillance radar has wide bandwidth requirements.

Stretch processing is a way of processing large bandwidth waveforms using narrow band techniques. For our present purposes, we want to look at stretch processing as applied to LFM waveforms. Stretch processing relieves the signal processor bandwidth problem by giving up all-range processing to obtain a narrow-band signal processor. If we were to use a matched filter we could look for targets over the entire waveform pulse repetition interval (PRI). With stretch processing, we are limited to a range extent that is usually smaller than an uncompressed pulse width. Thus, we couldn't use stretch processing for search because search requires looking for targets over a large range extent, usually many pulse widths long. We could use stretch processing on track because we already know range fairly well but want a more accurate measurement of it. One of the most common uses of wide bandwidth waveforms and stretch processing is in discrimination, where we need to distinguish individual scatterers on a target. Another use we will look at is in SAR (synthetic aperture radar). Here we only try to map a small range extent of the ground but want very good range resolution to distinguish the individual scatterers that constitute the scene.[3]

Stretch Processor

Stretch processing, also known as "active correlation" is normally used to process extremely high bandwidth LFM waveforms. This processing technique consists of the following steps: First, the radar returns are mixed with a replica (reference signal) of the transmitted waveform. This is followed by Low Pass Filtering (LPF) and coherent detection. Next, Analog to Digital (A/D) conversion is performed; and finally, a bank of Narrow Band Filters (NBFs) is used in order to extract the tones that are proportional to the target range, since stretch processing effectively converts time delay into frequency. All returns from the same range bin produce the same constant frequency. Fig. 2 shows a block diagram for a stretch processing receiver. The reference signal is an LFM waveform that has the same LFM slope as the transmitted LFM signal. It exists over the duration of the radar "receive-window" which is computed from the difference between the radar maximum and minimum range. Denote the start frequency of the reference chirp as f_r.[1]

Consider the case when the radar receives returns from a few close (in time or range) targets, as illustrated in Fig. 2. Mixing with the reference signal and performing low pass filtering is effectively equivalent to subtracting the return frequency chirp from the reference signal. Thus, the LPF output consists of constant tones corresponding to the targets' positions. The normalized transmitted signal can be expressed by

$$s_1(t) = \cos(\, 2\pi\, (f_0 t + \frac{\mu}{2} t^2)\,) \qquad 0 \le t \le \tau'$$

Where $\mu = B/\tau'$ is the LFM coefficient and f_0 is the chirp start frequency. Assume a point scatter at range *R*. The signal received by the radar is

$$s_r(t) = a\cos\left[2\pi\left(f_0(t-\Delta\tau) + \frac{\mu}{2}\ (t-\Delta\tau)^2\right)\right]$$

Where a is proportional to target RCS, antenna gain, and range attenuation. The time delay is $\Delta\tau$

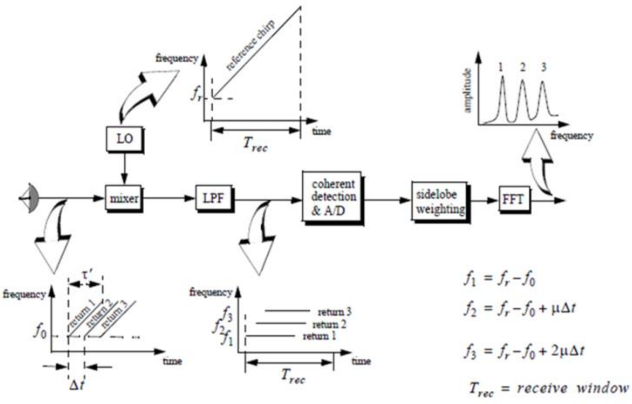
$$\Delta\tau = 2R/c$$

The receive window in seconds is

$$s_{ref}(t) = 2\cos(2\pi(f_r t + \frac{\mu}{2}\ t^2)) \qquad 0 \le t \le T_{rec}$$

The reference signal is

$$T_{rec}\ = \frac{2\ (R_{max} - R_{min}\ )}{c} = \frac{2R_{rec}}{c}$$



Stretch processing block diagram.

It is customary to let $f_r = f_0$. The output of the mixer is the product of the received and reference signals. After low pass filtering the signal is

$s_0(t) = a\cos(\ 2\pi f_0\Delta\tau +\ 2\pi\mu\Delta\tau t -\ \pi\mu\,(\Delta\tau)^2\ )$

Substituting and collecting terms yield

$$s_0(t) = a\cos\left(\left(\frac{4\pi BR}{c\tau'}\right)t + \frac{2R}{c}\left(2\pi f_0 - \frac{2\pi BR}{c\tau'}\right)\right)$$

The receive window in seconds is

$$s_{ref}(t) = 2\cos(2\pi(f_r t + \frac{\mu}{2}\ t^2)) \qquad 0 \le t \le T_{rec}$$

and since $\tau' \gg 2R/c$, Eq. is approximated by

$$s_0(t) \approx a\cos\left(\left(\frac{4\pi BR}{c\tau'}\right)t + \frac{4\pi R f_0}{c}\right)$$

The instantaneous frequency is

$$f_{inst} = \frac{1}{2\pi}\frac{d}{dt}\left(\left(\frac{4\pi BR}{c\tau'}\right)t + \frac{4\pi R f_0}{c}\right) = \frac{2BR}{c\tau'}$$

which clearly indicates that target range is proportional to the instantaneous frequency. Therefore, proper sampling of the LPF output and taking the FFT of the sampled sequence lead to the following conclusion: a peak at some frequency f_1 indicates the presence of a target at range

$$R_1 =\ f_1 c\tau'/2B$$

Assume close targets at ranges R_1, R_2 and so forth $(R_1 < R_2 < \ldots R_I)$. From superposition, the total signal is

$$s_r(t) = \sum_{i=1} a_i(t)\cos\left[\ 2\pi\ \left(f_0(t-\tau_i) + \frac{\mu}{2}\ (t-\tau_i)^2\right)\right]$$

where $\{a_i\,(t)\ ;\ i = 1,2,\ \ldots\ I\}$ are proportional to the targets cross sections, antenna gain, and range. The times $\{\ \tau_i\,(\ = (\ 2R_i\,/c\ )\ ;\ i = 1,2,\ \ldots\ I\}$ represent the two-way time delays, where τ_1 coincides with the start of the receive window. Using Eq. the overall signal at the output of the LPF can then be described by

$$s_0(t) = \sum_{i=1} a_i \cos\left(\left(\frac{4\pi B R_i}{c\tau'}\right) t + \frac{2R_i}{c}\left(2\pi f_0 - \frac{2\pi B R_i}{c\tau'}\right)\right)$$

And hence, target returns appear as constant frequency tones that can be resolved using the FFT. Consequently, determining the proper sampling rate and FFT size is very critical. The rest of this section presents a methodology for computing the proper FFT parameters required for stretch processing.

Assume a radar system using a stretch processor receiver. The pulse-width is τ' and the chirp bandwidth is B. Since stretch processing is normally used in extreme bandwidth cases (i.e., very large), the receive window over which radar returns will be processed is typically limited to from a few meters to possibly less than 100 meters. The compressed pulse range resolution is computed from Eq. Declare the *FFT* size to be N and its frequency resolution to be Δf. The frequency resolution can be computed using the following procedure: consider two adjacent point scatterers at range R_1 and R_2. The minimum frequency separation, Δf between those scatterers so that they are resolved can be computed from Eq. More precisely,

$$\Delta f = f_2 - f_1 = \frac{2B}{c\tau'}(R_2 - R_1) = \frac{2B}{c\tau'}\Delta R$$

Substituting yields

$$\Delta f = \frac{2B}{c\tau'}\frac{c}{2B} = \frac{1}{\tau'}$$

The maximum frequency resolvable by the FFT is limited to the region $\pm N\Delta f/2$. Thus, the maximum resolvable frequency is

$$\frac{N\Delta f}{2} > \frac{2B(R_{max} - R_{min})}{c\tau'} = \frac{2BR_{rec}}{c\tau'}$$

Using Eqs. and collecting terms yield

$$N > 2BT_{rec}$$

For better implementation of the FFT, choose an FFT of size

$$N_{FFT} \geq N = 2^m$$

m is a nonzero positive integer. The sampling interval is then given by

$$\Delta f = \frac{1}{T_s N_{FFT}} \rightarrow T_s = \frac{1}{\Delta f\, N_{FFT}}$$

5. EXPERIMENTAL OUTPUTS

The Outputs obtained after processing the codes derived from the stretch processing technique with the help of MATLAB is given below,

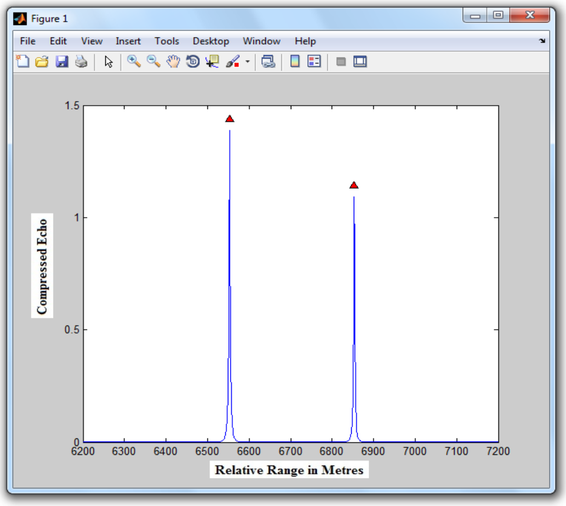


Figure 3: Target Peaks Obtained at 6553 m and 6853 m

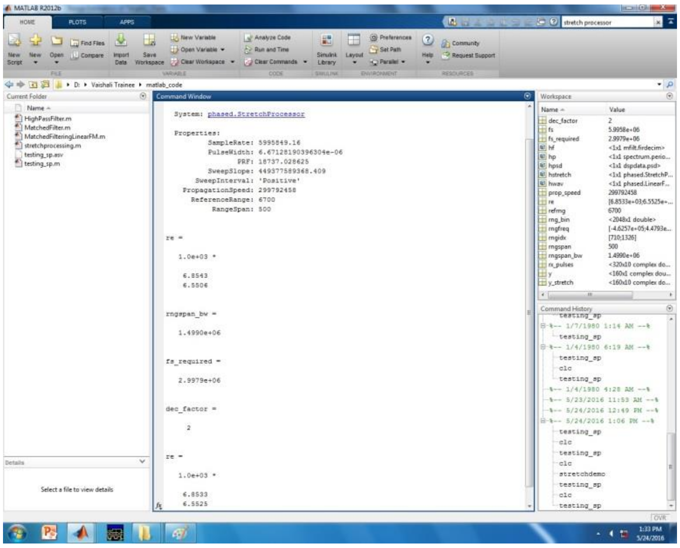


Figure 4: Snapshot of MATLAB function file

6. FUTURE WORKS

Stretch Processing method for coastal surveillance radar helps in the detection of targets in the coastal region. This technique is successful to obtain the location of the target, but it is unable to fulfill the target recognition process. With the help of data generated using this methodology, further processing can be done by various image processing methods. In future works, ISAR Image Processing Technique is used to recognize the targets obtained by Stretch Processing Methodology.

7. REFERENCES

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