Performance Improvement in Target Detection Using Various Techniques in Complex Matched Filter in Radar Communication

Ajay Suri, Soham Gautam, and Ridhi Aggarwal

Abstract The term radar was coined in 1940 by the United States Navy and is derived from three terms, radio detection and ranging. Radar transmits electromagnetic (EM) waves of radio frequency (RF). Radar is also helpful in classifying targets as known or unknown; a known target may be monitored to check the progress of the respective target. An unknown target may be a theft unit; it may or may not be with the intentions of causing harm. Radar also faces interferences while its operation, namely clutter or some intentional/unintentional jammers (Han C et al, Multimed Tools Appl 1–16, 2018 [Han C, Guangyu G, Yu Z (2018) Real-time small traffic sign detection with revised faster-RCNN. Multimed Tools Appl 1–16]). Moreover, radar also faces obstruction by its own thermal noise. Nowadays, radar is advanced enough to implement the two-dimensional and three-dimensional mapping. Radar is also widely used for collision avoidance and earth resource monitoring (Hu et al, IEEE Sens J 18:3152–3162, 2018 [Hu et al. in IEEE Sensors J 18:3152–3162, 2018]).

Keywords Clutter · Jammers · Thermal noise · Mapping · Monitoring

1 Introduction

The evolution of radar system has been tremendous since its early days when it was just limited to functions such as target range detection and target detection. The term radar was coined in 1940 by the United States Navy and is derived from three terms, radio detection and ranging. The main objective of this project is to understand radar from its basics, the functionalities, and develop an understanding to be able to know its operations and analysis. This project focuses on the main issues in radar design, its operation and calculation. It also focuses on the received radar data and its processing. It gives an idea about the signal processing basic terms, signal detection techniques and clutter rejection in signal detection. To add on, it gives meaning to the terms such as data acquisition and digitization, also the concept

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of discrete Fourier transform analysis, having windowing and interpolation methods. Other parts included the important digital filters like matched filter concepts and its relation to data integration. Furthermore, resolution of range targets was enhanced by pulse compression, which was vital in range detection. Target speeds were offered with the help of Doppler concepts, through which the velocities of targets were accurately measured and reported further to classify them as friendly or foe. Radar cross section is also considered while discussing radar received power strength. Finally, the Doppler shifts were measured for the targets so as to classify them as stationary or moving targets, with their respective distances from the radar [1]. Doppler processing means Doppler shift information to attain two certain goals. The first one is to enable detection of targets in environment having clutter in it. Other is to measure Doppler shift, in general radial velocity of targets. Now, we will discuss: moving target indication (MTI) and pulse Doppler processing. MTI processing is used to achieve first goal; but pulse Doppler processing works for both the goals to accomplish. Now to understand clutter when signal returns by reflecting targets, the clutter signals act as echoes of external objects present in the surroundings, thus increasing radar power which ultimately does not improve the signal-to-clutter ratio (SCR) because it is caused in the signal-to-clutter form of the given radar range equation. Doppler processing is the principal means of improving SCR. Doppler effect in radar systems is observed by pulsed radar.

Our main aim here is to detect the moving targets along with its range by using various filters and analysis techniques. Apart from that, ambiguity resolution and blind zones are also included.

2 Literature Review

Complex matched filter is used for data processing for dealing with real as well complex data for getting the distance, direction and velocity of the target. Methods like windowing for reducing relative side lobe level that are unwanted and often not needed signal and pulse compression for finer resolution are used for generating accurate results. For further improvement, the Doppler concepts are also used which are known for improving the resolution of the range. Hence, it produces less ambiguity and losses.

2.1 Doppler Shift

Whenever a transmitted wave is reflected of a target which is radially in motion to the radar, be it in opposite direction or the same direction, there is always a difference in the frequency of the transmitted wave and the received wave. If the target is moving radially away from the receiver, then there is a decrement in the frequency hence negative Doppler frequency, while if the target is moving toward the radar, there is an increment in frequency, hence positive Doppler frequency [2].

2.2 Clutter

A return of a non-target from the radar is which is legitimate but is unwanted in the received radar data is called clutter. In other words, unintentional and unwanted but unwanted return from the receiver of radar is clutter. Among the three noises that we discussed earlier, clutter plays a dominant rule and is by far the most difficult to remove [3].

Noise in the atmosphere is at a set threshold and can be removed by increasing the threshold above that threshold noise power, but such is not the case with clutter which has variable power at different Doppler frequency levels [4]. The Doppler output of the receiver signal is all the combination of all the above-mentioned noises. Among all, there is white noise spread across all of the range bins. This white noise is of varying amplitude and is of non-uniform power [5].

2.3 Pulse Compression

As we are aware that the major function of the radar is to detect the radar range detection. This is one of the most important features of the radar. So to get a finer resolution of range bins from the radar, we implement pulse compression. Originally, the radar received signal comprises the high power response of the whole CPI, but this is not the case in pulse compression [6]. Pulse compression is carried out by using the matched filter technique. The matched filter technique is used to essentially increase the SNR of the target's range bin so as to differentiate the specific range bin of the specific dwell that corresponds to the target echo. The matched filter technique is actually the correlation of the received radar data with the transmitted data. The received radar data is nothing but the delayed version of the same transmitted signal, with attenuated amplitude but with only linearly shifted phase, and hence, when a time shifted signal is auto-correlated to its own self, we receive a peak at a delay sample of the signal. This is the principle of using matched filtering, to get finer resolution in the range bin spectra of the analysis [7].

2.4 Windowing

Windowing is a method to suppress the relative side lobe level of the signal. The main lobe of the signal carries the desired response of a signal, while the side lobe level is made up of undesired response. This undesired side lobe level when competes with main lobe level can lead to incorrect results. So, the difference between the main lobe level and side lobe level is enhanced by using the windowing technique [8]. The windowing is in fact the gain introduced in a filter to maximize the central response and deplete the side levels of the filters [9]. There are many windows that can be used that give different responses, but custom Chebyshev window of 50 dB relative side lobe level has been used in the signal processing of this project were overcome in the pulse Doppler processing.

Although the clutter is dominant at range bins that are closer to the radar due to high clutter power that competes with the target echo power. It was also observed that pulse Doppler processing is difficult when the target has velocities corresponding to zero Doppler shifts due competition with the clutter's Doppler response, hence velocity detection is difficult in that case [10].

2.5 Matched Filter

Matched filter (MF) is conception based on the waveform of the sender radar signal. When the white noise is present, it gives maximum SNR. With MF, we can attain very thin pulses from low power long signals. As not all signals have achieved faithful matched filters, new waveform designs were created. Based on the requirement and nature of clutter noise, the waveform design must follow certain requirements. Also, correlation function between the senders and receivers signal can be utilized in place of MF. This filter is inactive in colored-noise. Thus, when colored-noise is present, a whitening filter has to be applied before the matched filter or you can say the correlation function, to reduce the spectrum of noise and avoid mismatch between the signals. Integration is a subpart of matched filter process which is used in radar signal processing (RSP) to improve the SNR of the output echo. The integrator used in this stores the energy of consecutive echo pulses which are reverted by the same target. At the IF stage of the output, pre-detection integration occurs that gives improved SNR in comparison with post-detection integration [11].

2.6 Doppler Processing

The process of Doppler processing of radar signals is used to set aside the unmovable objects and effectively increase the signal-to-clutter ratio (SCR). In recent times, there are two main techniques to boost the SCR in radar, i.e., moving target indication (MTI) for short pulses in radar and moving target detection (MTD) for pulse Doppler. Suppose the wavelength of signal is λ, the frequency shift will be the received from a target which is moving with a relative velocity (v_r). An MTI filter unstays the blind speeds issue with the help of a staggered PRF, in place of using the common PR. Now, the chances of a target moving with blind speeds will eventually reduce [12]. In case of pulse Doppler, a bank of filters is made into use to get larger dynamic range in the

Doppler frequency domain. This whole process avoids filtering out moving targets due to blind speeds and reduces errors to the least when the velocity is measured.

2.7 Drawbacks of the Existing System

- It does not do pulse compression.
- No function for windowing.
- They handle only real data.
- Not using Doppler concepts for accuracy.

3 Proposed Architecture

- Resolution of range targets was improved with Doppler concepts.
- It is a complex matched filter for complex data processing.
- More accurate results were produced.
- Here, one filter is overlapping two other filters. So, it produces less ambiguity and losses.
- Windowing is also done to suppress the relative side lobe level of signal.
- We will be concluding that when velocity corresponds to zero Doppler shifts, then velocity detection is difficult.

4 Results

4.1 Radar Range Plot

Radar Position = [0; 0; 0;] in x, y, z coordinates, respectively.

Target Positions:

1st target = [10,000 m; 0; 0;] which corresponds to 334th bin (=30 m) after the pulse transmission bins, i.e., 120, so the target echo is received at 120 + 334 = 454th range bin at a power of 70.81 dB.

2nd target = [16,000 m; 0; 0;] which corresponds to 654th range bin at a power of 74.15 dB.

3rd target = [22,000 m; 0; 0;] which corresponds to 854th range bin at a power of 76.8 dB.

Radar Range Plot with Clutter:

Due to clutter, the peak power of range bins 120–1000 is higher than the case of without clutter.

Radar Position = [0; 0; 0;] in x, y, z coordinates, respectively.

Target Positions:

1st target = [10,000 m; 0; 0;] which corresponds to 454th range bin at a power of 70.81 dB.

2nd target = [16,000 m; 0; 0;] which corresponds to 654th range bin at a power of 74.15 dB.

4.2 Complex Bandpass Filter

Ten complex bandpass filters used with relative side lobe level of 50 dB. This side lobe level is achieved by using a custom Chebyshev window. Figure 1 shows the ten filters with equally spaced central frequencies, ranging from-to frequencies (in radians).

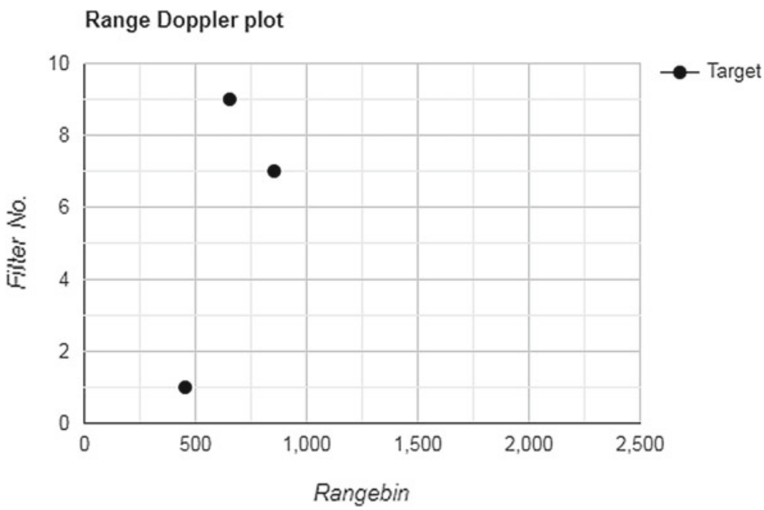

Fig. 1 Range doppler response

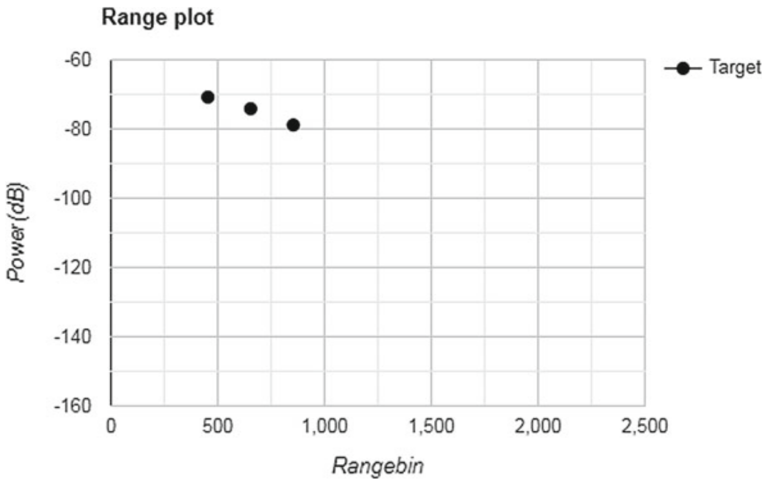

Fig. 2 Radar range plot

4.3 Range Doppler Response

As discussed above, the range of the targets is plotted according to their respective range bins. Targets 1, 2 and 3 having velocities in x, y, z coordinates as (100 m/s, 0, 0), (125 m/s, 0, 0) and (112 m/s, 0, 0), respectively, have been detected at 1st, 9th and 7th filter, respectively, and hence, there doppler frequencies have been calculated.

Range Doppler Response with Clutter:

As seen above in the range Doppler plot without clutter, the targets were detected with relative ease. Such is not the case in presence of clutter, especially when the clutter power competes with the target echo power. This happens in the range bins following the transmission of radar pulse. In other words in presence of clutter, the targets having near zero Doppler shifts are hard to detect using pulse Doppler processing (Fig. 2 and Table 1).

5 Conclusion

The range detection and Doppler shift calculated with the pulse radar processing technique have been duly verified with the theoretical results. The pulse Doppler processing model accurately fits the results of the actual target functions such range and Doppler shift, which in turn is used to calculate the speed of the target. Effects of clutter were duly considered for both range detection and Doppler measurement and were overcome in the pulse Doppler processing. Although the clutter is dominant at range bins that are closer to the radar due to high clutter power that competes with

Table 1 Comparison between the existing models and the proposed model based on several parameters

S. No.	Parameters	Existing method	Proposed method
1	Works on	Only real data [6, 10]	Real as well as the complex data
2	Clutter	The peak power of range bins is 120–1000 is higher. Also, unwanted distortions can occur in the results [5]	The peak power of range bins is correct. No distortions are present
3	Accuracy	Theory and practical results vary with each other [1, 2, 7]	The practical and theoretical results are identical
4	Side lobe level	Side lobe level of the signal was comparable with the main lobe [10]	Ten complex bandpass filters used with relative side lobe level of 50 dB achieved by using a custom Chebyshev window
5	Resolution	Standard resolution [9]	Improved by taking suitable pulses

the target echo power. It was also observed that pulse Doppler processing is difficult when the target has velocities corresponding to zero Doppler shifts due competition with the clutter's Doppler response, hence velocity detection is difficult in that case.

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