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Study of Different Radar Waveform Generation Techniques for Automatic Air Target Recognition

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ABSTRACT

Target recognition is the most challenging problem for missile defense. For accurate target recognition discriminant features must be extracted from the target signature. To extract suitable features an optimized waveform is needed which can be generated using pulse compression techniques. Pulse compression is a technique which can be generally used for achieving the benefits of short pulse rather than long pulse while we considering the peak power limitation. Pulse compression radar using the short pulse for detecting the target, has an advantage of achieving better range resolution. The survey presents the comparative study of different waveforms using pulse compression technique for extracting the features of target and simultaneously to achieve the high range resolution (HRRP), angular resolution, radar cross section (RCS) with the proper maintenance of SNR.

Keywords

High Range Resolution Profile (HRRP), Radar Cross Section (RCS)

I INTRODUCTION

The radar target classification is an important and challenging problem in radar applications. In radar target classification methods, the main goal is to distinguish targets by using similarities between the features of test target and known targets. These features are generally obtained by processing scattered signals from targets in noncooperative target recognition [Skolnik, 2001; Tait, 2009].For attaining the better range resolution (HRR) stepped frequency waveform would be transmitted over the target. Stepped-Frequency (SF) waveforms are the most popular waveforms used to achieve wide or ultra-wide bandwidth in radar applications [1]–[4]. Because of their effectiveness in achieving high-range resolution (HRR), SF waveforms are widely used for remote sensing [5] or inverse synthetic aperture radar (ISAR) and noncooperative target recognition (NTR).The most generic waveform used to maintain the optimum SNR and doppler tolerant is the LFM chrip signal while considering side lobe reduction NFLM chrip signal can be used to transmit over the target. However, the scattered signal from a target is highly dependent on operating frequency, polarization and aspect angle; therefore, a designed classification method should be independent of these parameters. Besides, additional random noise makes the classification problem more complicated and reduces the accuracy rate of the methods. In order to minimize adverse effect of the noise an intelligent classifier is needed. Decision speed is to be fast in order to be convenient for real time applications. Decision of a target type can be made by matching the received signal with the predefined target signal. This method is used together with different time-frequency distributions or using dynamic time wrapping techniques. The advantage of this approach is that only a small amount of information is lost during the transformation.

A. RANGE RESOLUTION

There are two categories in resolution; range resolution and bearing resolution. Range resolution is nothing but the ability of a radar system to resolve two or more targets on the same bearing but at different ranges. The range resolution mainly depends on the width of the transmitted pulse, the sizes and types of targets, and the efficiency of the receiver and indicator.

B. ANGULAR RESOLUTION

Angular resolution is the minimum angular separation at which two equal targets can be separated when at the same range. It can be determined by the antenna beam width represented by the -3dB.

C. RESOLUTION CELL

The range and angular resolution lead to the resolution cell. Shorter the pulse width and narrower the aperture angle, the smaller the resolution cell and higher the interference immunity of the radar station.

II RADAR AUTOMATIC TARGET RECOGNITION

There have been many approaches to radar ATR. Common inputs to classification algorithms are high range resolution (HRR) profiles, objects selected from synthetic aperture radar (SAR) and ISAR images, and a target’s μ-DS. A potential benefit of μ-DS based ATR is reduced processing overhead, since features are typically extracted using the highly optimized fast Fourier transform algorithm; in this study μ-DS recognition is performed in the time domain, keeping signature preprocessing to a minimum. Once the input to the ATR system has been chosen, the method of recognition must be decided on. The most common radar ATR methods are decision-theoretic/parametric classification, nonparametric classification, and supervised learning classifiers. Decision-theoretic classifiers require parametric models of each potential target to be recognized; inputs are classified by finding which model makes the input data most likely. Supervised learning routines have two modes: a training mode and an operational mode. During training, a series of reclassified inputs are used to train the classifier, so that during operation it may identify unclassified inputs. Artificial neural networks (ANN) and HMM are both forms of supervised learning classifiers. Nonparametric classification relies on the comparison of an unclassified input with a pre classified reference library for each recognition. Such techniques are simple to implement since they do not require a mathematical model of the potential radar targets, nor do they have a network topology that must be optimized as is the case for ANNs and HMMs. However, these methods are limited by the number of computations they require. For each classification, a comparison must be made between the input and every entry of the reference library. A trade must be made between completeness of the library and classification speed. Selection of the reference library is therefore critical to classifier performance.

A. MICRO-DOPPLER EFFECT

The micro-Doppler effect is nothing but, if the target or any structure on the target has mechanical vibration or rotation in addition to its bulk translation, it might induce a frequency modulation on the returned signal that generates sidebands about the target’s Doppler frequency shift. Return signals from a target includes vibrating or rotating structures, such as rotors of a helicopter, propellers of a fixed-wing aircraft, or the engine compressor and blade assemblies of a jet aircraft, that may contain micro-Doppler characteristics related to these structures. The micro-Doppler effect helps us to determine the dynamic properties of the target and it also provides a new approach for the target signature analysis. The micro-Doppler effect can be used to identify specific types of vehicles, and determine their movement and the speed of their engines. Vibrations induced by a vehicle engine can be determined by radar signals returned from the surface of the vehicle. From micro-Doppler modulations in the engine vibration signal, one can determine whether it is a gas turbine engine of a tank or the diesel engine of a bus.

B. TARGET ENGINE RECOGNITION BY MICRO DOPPLER EFFECT

Radar targets comprised of several moving components such as wheels, rotor blades, caterpillar tracks, etc., impart an intricate frequency modulation on the backscatter signal known as the micro-Doppler signature. When soldiers listen to the audio output of battlefield radar to identify a target, it is this signature they hear, and they are performing μ-DS classification. There are anecdotal reports of such an approach being used in early CW airborne surveillance radar: operators were able to identify the targets' jet engine modulation (JEM) or propeller engine modulation (PEM) by listening to audio outputs. Depending on a human operator for target recognition has two key drawbacks: the operator may become tired and make errors, and each operator will require substantial practice before their identifications can be trusted. An automated approach potentially overcomes both of these problems. Frequency modulation of the backscattered radar signal resulting from propellers and jet engines (JEM and PEM) was identified early in the development of radar. Mathematical models for the return signal have been developed, leading to a comprehensive understanding of the phenomenology. With increased dynamic range and improved signal-to-noise ratio, it is possible to detect weaker components of the return signal. Frequency modulations from target micro-motions such as vibrations become visible and, together with the original JEM and PEM, these modulations comprise the micro-Doppler effect.

C. SIDE LOBE REDUCTION BY NLFM

In general, side lobe suppression can be achieved in pulse compression radar by using the nonlinear frequency modulation signal (NLFM).Most of the pulse compression radars suffer from range side lobes which cause energy from strong reflections to leak into adjacent range cells. High level of side lobes suppression is not required in some other non-meteorological radar, but is important for meteorological radar, because weather phenomena can have significant reflectivity gradients, and ground clutter echo can be between 35-55 dB much larger than medium rain. Furthermore, the side lobes of strong signal will be falsely recognized as existence of small target. Therefore, range side lobes must be suppressed by at least 60 dB to prevent contamination in adjacent range cells. There isn't an easy way to overcome the dilemma that reduces the side lobes energy while decreasing the system bandwidth. It is necessary to consider a scheme that integrates kinds of methods such as amplitude tapering, mismatched filter, NLFM, etc. Nonlinear FM (NLFM) signals represent an important class of continuous phase modulation waveforms with applicability inside pulse compression radar systems. They have been claimed to provide a high-range resolution, an improved SNR, low cost, good interference mitigation. In pulse compression radar theory, there are many interesting research works which have been done to investigate and design optimal (as sidelobe level) NLFM signals.

NLFM waveforms can be designed by various ways a) designing of pseudo-NLFM waveforms which are in fact, LM signals predistortioned on short intervals (e.g., at the pulse ends) into temporal domain or corrected into spectral domain; b) designing of NLFM waveforms using usually, iterative methods, stationary phase principle, Zak transform, suitable weighting/convolutional functions, explicit functions cluster algorithm or marginal Fisher's information-based techniques etc. It offers the advantage that a pure matched filter gives low sidelobes. The NLFM signals also assure better detection rate characteristics, and they are more accurate in range determination than other processing methods (e.g., dual apodization (DA), spatially variant apodization (SVA), leakage energy minimization (LEM) etc.). The main drawback of NLFM waveforms is their Doppler intolerance. All pulse compression radars suffer from range side lobes which cause energy from strong reflections to leak into adjacent range cells. High suppression of side lobes is not required in some other non-meteorological radar, but is important for meteorological radar, because weather phenomena can have significant reflectivity gradients, and ground clutter echo can be between 35-55 dB much larger than medium rain. Furthermore, the side lobes of strong signal will be falsely recognized as existence of small target. Therefore, range side lobes must be suppressed by at least 60 dB to prevent contamination in adjacent range cells. There isn't an easy way to overcome the dilemma that reduces the side lobes energy while decreasing the system bandwidth. It is necessary to consider a compromise scheme that integrates kinds of methods such as amplitude tapering, mismatched filter, NLFM, etc.

III PULSE COMPRESSION

The desired range resolution as well as the SNR (signal to noise ratio) can be achieved in radar, sonar and echography by Pulse compression technique. It can be achieved by modulating the transmitted pulse and then correlating the received signal with the transmitted pulse. Pulse compression can be used to explain a waveshaping process that can be produced as a propagating waveform which is modified by the electrical network properties of the transmission line. The pulse is modulated in phase or in frequency, which helps to resolve targets which may have overlapping returns. Temporal compression can be used to amplify the transmitted impulse power in pulse compression technique. It is a method through which the high energy of a long pulse width with the high resolution of a short pulse width can be combined. The older type requires a high pulse power to achieve the desired range. These radars are able to produce and emit the total transmit power in just a few micro- or even nanoseconds. The modulation or coding can be either

- FM (frequency modulation)
  - * Linear (chirp radar)
  - * Non-linear
  - *Time-frequency-coded waveform (e.g. Costas code) or
- PM (phase modulation).

A. STEPPED FREQUENCY WAVEFORM

Because of the technology and the flexibility associated with the SFWF, many systems are using this process to achieve high- and ultra-high-range resolution, although they are mainly used as experimental radars, because of the long time needed to take one profile. The difference between this kind of synthetic pulse compression system and a “traditional” system is that the requirements to obtain the same resolution are less restrictive in the first case because of the extremely high power required for a short pulse radar to achieve a conventional maximum range. For example, a system with uncompressed pulses requires a pulse width of 1 nanosecond to obtain a range resolution of 15 centimeters and an instantaneous receiver bandwidth of 1 Gigahertz (1/pulse width), whereas the SFWF-processed resolution may be 15 centimeters with instantaneous pulses of some Megahertzs, being the final synthetic bandwidth the one required to comprise 1 GHz [6]. However, the SFWF process is not a single-look process, because it requires the transmission and reception of multiple pulses. The traditional stepped-frequency waveform is shown in Figure 1 and consists of a series of bursts of narrowband pulses, where each burst consists of n pulses shifted in frequency from pulse to pulse by a fixed frequency step size Δf, and the distance between two pulses is usually constant and equal to PRI [1]. Thus, in every burst, the first pulse will be sent at a frequency f0 and the i-th pulse at fi, where fi is given by:

$$fi = f0 + \Delta f \qquad (1)$$

Thus, the expression for each pulse of amplitude Bi, at frequency step i, is expressed as

$$xi(t) = Bi \cos(2\pi fit + \theta i), \; iT2 \le t \le iT2 + T1$$
$$= 0 \qquad \text{otherwise} \qquad (2)$$

where θi is the relative phase at frequency step i. Nowadays, especially in LPI (Low Probability of Interception) radars, SFWFs with apparently random frequency hops among each pulse are used. Each sub pulse is assigned a unique frequency, uniformly distributed across a bandwidth B, and the sub pulse frequency order determines the ambiguity properties of the complete pulse. When the frequency of each pulse is monotonically increasing (or decreasing), the waveform can also be analyzed as an approximation of a chirp by a CW pulse train. Although one of the advantages of the SFWF is the high stability of the phase.

B. LINEAR AND NON LINEAR FREQUENCY WAVEFORM

The output of the matched filter is the autocorrelation function of the given input signal. Also well known is that the autocorrelation function is the Fourier Transform of the signal's Power Spectral Density (PSD)[4]Matched filter exhibits the maximum Signal to Noise Ratio at the peak of its autocorrelation function. In general, commonly used waveform is the Linear FM signal. Mainly this type of waveform can be generated by variety of technologies and it is easily processed by variety of techniques.LFM waveform can generate the rectangular PSD and its autocorrelation function produces a sinc() function shape. Reducing the sidelobes of the Matched Filter output (actually increasing the peak to sidelobe ratio) is typically accomplished by linear filtering the output, most often by applying window functions or data tapering. This additional filtering method makes the Matched Filter result to reduce sidelobes as desired. The cumulative filtering is not matched to the signal precisely; it necessarily reduces output SNR as well, typically by 1-2 dB. By generating the Non-Linear FM (NLFM) modulation, it can form the PSD so that autocorrelation function exhibits reduced sidelobes. NLFM chirps are more difficult to design, produce, and process. Amplitude tapering is the alternative to NLFM modulation for shaping the PSD, are not viable since typically efficient power amplification of the waveform necessitates operating the hardware in a nonlinear manner, e.g. operating the amplifiers in compression. This can reduces the ability to maintain precision amplitude tapering. Waveform phase remains unaffected by operating amplifiers in compression.

C. PHASE CODED STEPPED FREQUENCY WAVEFORM

By combining intrapulse phase and interpulse frequency modulations, the PCSF technique enables larger frequency step sizes than SF processing-system effective bandwidth is traversed more quickly, allowing shorter burst times while decreasing Doppler sensitivity. The PCSF framework and corresponding HRR simulation results for complex targets are shown in et al., K.L. Sitler [2002] with the ideal SF response and demonstrate Doppler sensitivity reduction. Radar effective bandwidth is a primary factor limiting range resolution. Ideally, pulse compression techniques increase the effective bandwidth and improve range resolution without sacrificing maxi- mum detection range or Doppler sensitivity. High range resolution (HRR) techniques commonly use either intrapulse (within the pulse) or interpulse (pulse-to-pulse) phase or frequency modulation to increase bandwidth e.g. the stepped-frequency (SF) waveform expands system bandwidth using interpulse frequency variation. The phase- coded stepped-frequency (PCSF) waveform with synthetic HRR processing combines intrapulse phase modulation with SF interpulse modulation. This provides greater sub pulse bandwidth than equivalent SF processing (identical bandwidth) and interpulse frequency step size (Δf) becomes a function of compressed sub pulse width.

PCSF waveform design: The PCSF waveform combines intrapulse phase and interpulse frequency modulations to increase bandwidth while reducing burst times and providing reliable HRR performance. Intrapulse phase modulation involves dividing each sub pulse into K equal length time intervals of sub pulse width, and coding each with a phase offset relative to the carrier. By phase coding SF sub pulses, both Δf and coarse-range sample spacing become functions of sub pulse width [1]. In addition, sub pulse bandwidth increases by a factor of K compared to an equal width uncoded pulse. Thus for a given bandwidth a larger Δf may be used and burst time is reduced. PCSF processing differs slightly from SF waveform processing in that phase-coded sub pulse returns may be processed with quadrature detection to simultaneously remove phase coding and carrier modulation.

IV CONCLUSION

One of the challenging problems of missile defense is the radar target recognition. Both target classification and recognition are required in the defense for predicting the target whether it is friend or foe. Doppler signature along with RCS and HRRP may be used for the accurate classification of target. Due to the micro doppler effect , the system can forecast whether the particular target have any rotating blades or it may identify any special vehicles and determines their movement and speed of the engine. Along with this the pulse compression techniques can be used to achieve the benefits of short pulse rather than using the long pulse, so that we can obtain the better range resolution. The survey represents the comparative study of different waveforms along with the pulse compression techniques for getting the high range resolution, radar cross section and target recognition.

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