

Adaptive Angular-sector Segmentation Radar Target Recognition based on Grey System

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Abstract

The aspect sensitivity of high-resolution range profile (HRRP) leads to the anomalous change of the HRRP statistical characteristic, which is one of inextricable problems on the target recognition based on HRRP. Aiming at the HRRP statistical characteristic, an adaptive angular-sector segmentation method is proposed through based on the grey relational mode. Comparing to the equal interval angular-sector segmentation method, the new method improves the recognition performance. And these simulation results of five kinds of aircraft targets HRRPs prove the feasibility and validity.

Keywords: grey system; adaptive angular-sector segmentation; radar target recognition; grey rational analysis

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1. Introduction

RTR (Radar Target Recognition) is a kind of radar data processing technology. It has very important application value and research significance in civil and military field. The process is to first receive the target returned echoes, and then to extract the target characteristics, and finally to identify the target category and its type [1]. With the development of science and technology, the current radar system, especially the wideband radar, can obtain more and more information about the radar target, which guarantees the development, research and application of RTR technology. Compared with SAR/ISAR, HRRP is another kind of the wideband radar target echo, and is easy to gain and process. In addition, HRRP reflect the target structure characteristic information. So the RTR based on HRRP has been widely researched and applied [2-5].

At present, the key technical problems of RTR based on HRRP are shift, azimuth and amplitude sensitivity. For the shift sensitivity, the correlation alignment, absolute alignment and translation invariant feature extraction algorithm are commonly used methods [6,7]. The amplitude normalization method is used to solve the amplitude sensitivity [8]. The method of solving the azimuth sensitivity is mainly divided into the kernel method [4], [9,10] and angular-sector segmentation method [11-14]. Thereinto, the angular-sector segmenting method consists of the equal angular-sector segmentation and adaptive angular-sector segmentation. The equal angular-sector segmentation divides equally the angular sector without the migration through range resolution cell(MTRC) and is the common method for the simple implementation and clear physical concept, but there are mismatches which affect the recognition performance. While the adaptive angular-sector segmentation adopts a certain criterion and segments adaptively the angular sector according to the specific target HRRP or the classifier, so it can improve the recognition performance [12-14]. In the previous research, combined with the grey system theory, the equal angular-sector segmentation author based on the grey system is proposed [15]. In this paper, aiming at the azimuth sensitivity, a further study is carried out, and the adaptive angular-sector segmentation based on the grey system is put forward.

2. Azimuth Sensitivity of HRRP and Equal Angular-sector Segmentation

2.1. Azimuth Sensitivity of HRRP

The azimuth sensitivity of the radar target during the optical zone can be analyzed by the scatterer model. The target returned echoes of the m -th azimuth angle in the n -th resolution range are:

$$x_n(m) = \sum_{i=1}^N \alpha_{n,i} \exp[-jd_{n,i}(m)4\pi/\lambda - j\theta_{0,n,i}] \quad (1)$$

Where j is the imaginary symbol, λ is the radar signal wavelength, N is the total number of target scatterers; $d_{n,i}(m)$, $\alpha_{n,i}$ and $\theta_{0,n,i}$ is respective the radial distance, the returned echo amplitude and the initial phase between the i -th scatterer and the radar.

The sub returned echo phase of each a scatterer in the expression (1) is:

$$\phi_{n,i} = -d_{n,i}(m)4\pi/\lambda - \theta_{0,n,i} \quad (2)$$

Then the power of HRRP used in the target recognition is:

$$|x_n(m)|^2 = x_n(m)x_n^*(m) = \sum_{i=1}^N d_{n,i}^2 + 2 \sum_{i=2}^N \sum_{k=1}^{i-1} d_i d_k \xi_{nik}(m) \quad (3)$$

Where the symbol ‘*’ represents the complex conjugate. $\xi_{nik}(m)$ is:

$$\xi_{nik}(m) = \cos[\theta_{nik}(m)] \quad (4)$$

$$\theta_{nik}(m) = \phi_{n,i}(m) - \phi_{n,k}(m) = -\frac{4\pi}{\lambda} [d_{n,i}(m) - d_{n,k}(m)] + (\theta_{0,n,i} - \theta_{0,n,k}) \quad (5)$$

Where θ_{nik} is the phase difference between the (n,i) scatterer and the (n,k) scatterer.

It can be seen that the power of HRRP is composed of two parts according to the expression (3). The first part is known as the scatterer auto-term (SAT), which is the sum of the scatterer energy in the resolution range. The second part is called the scatterer cross-term (SCT), which is the result of phase interference among the scatterers in the resolution range. When the target posture changes, the number of the scatterers will increase or decrease with the MTRC, and then the total scattering characteristics will also change. The SAT has nothing to do with the azimuth without the MTRC. And it is a stable feature of the power of HRRP, but the change of the relative distance $d_{n,i}(m) - d_{n,k}(m)$ among these scatterers causes the change of the phase difference so that the echo amplitude happens to the fluctuation.

3.2. Equal Angular-sector Segmentation

The HRRP target posture sensitivity mainly is composed of the pitch sensitivity and azimuth sensitivity. This paper researches on the RAR method of the aircraft target. And the aircraft target is mostly flat, so changes of the pitch angle tend to be small. Therefore, the research of the posture sensitivity aims at the azimuth sensitivity. The equal angular-sector segmentation is generally divided into two steps. The first step is to divide equally the target angular sector, and the second step is to make statistical analysis of the angular partition, to extract the feature and to establish the HRRP template model in turn.

Figure 1 shows respectively the results of the mutual Deng-Si degree of grey incidence (DGI) model, degree of grey slope incidence (SGI) model and type-B degree of grey incidence (BGI) model between the adjacent HRRP, which is sampled at 0.1° azimuth interval from the full azimuth turntable simulation data of five aircraft targets (Su27, F16, M2000, J8II and J6). These data all include 128 resolution ranges provided by the Target Characteristic Research Center of Nanjing University of Aeronautics and Astronautics, and they are done the normalization and alignment pretreatment so as to solve the amplitude sensitivity and shift sensitivity. The step frequency of the signal radiated by the radar is 4MHz, and then the effective bandwidth of the

signal is 512MHz. So the unambiguous range R_u is 37.5 meter, and the range resolution R_r is 0.3 meter. As known from Figure 1, the azimuth sensitivity is also different in some same azimuth angle intervals for these different targets. So these different targets should correspond to different segmentation intervals. And the azimuth sensitivity is different while the azimuth angle is different for each target, that is, there are some adjacent HRRPs which are poor incidence, so these HRRPs cannot be divided into the same segmentation frame. But in the positive line of sight which the azimuth angle is about 90° , these five aircraft targets also have the strong azimuth sensitivity, so these HRRPs should be considered separately.

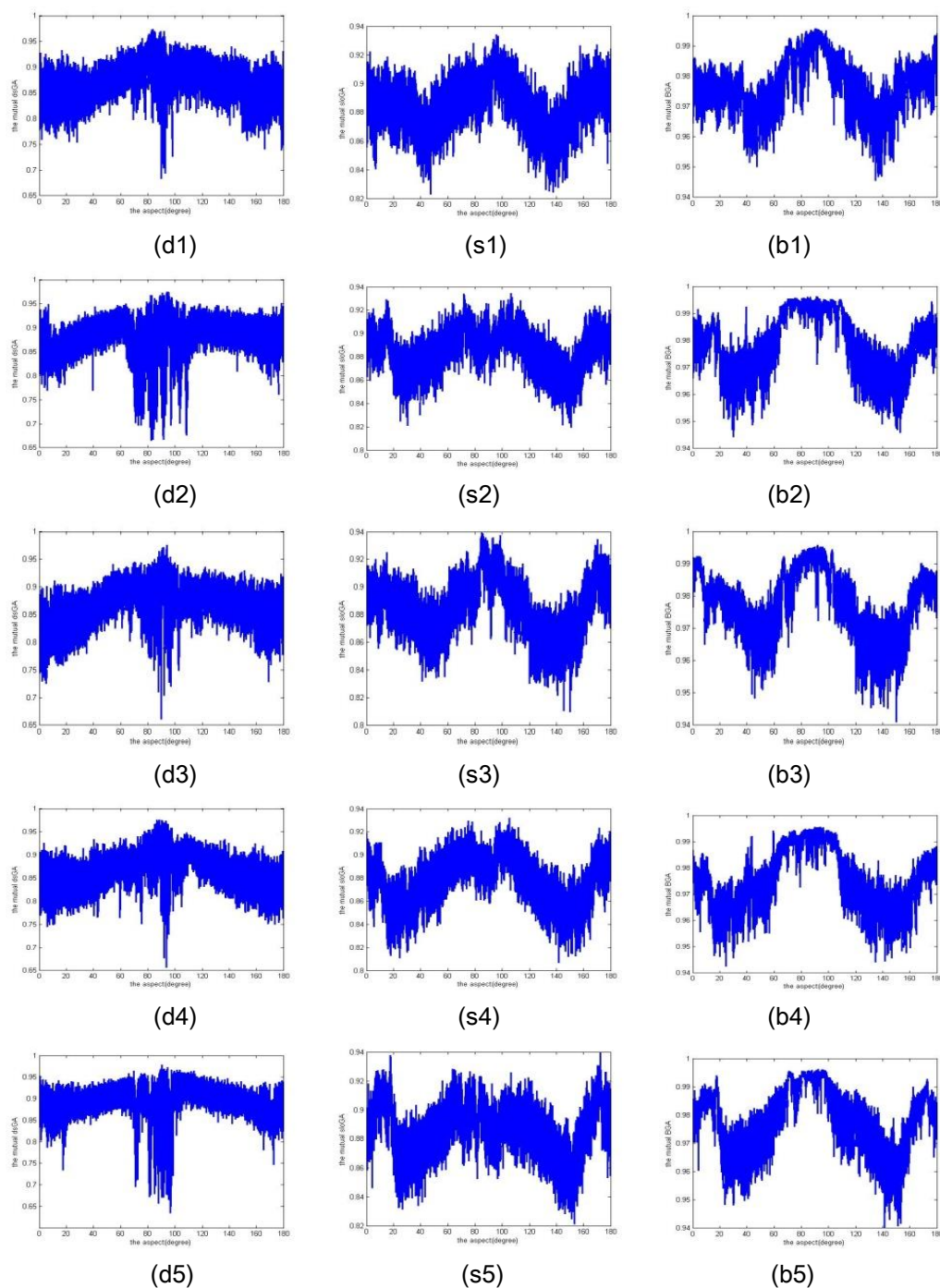


Figure 1. the mutual relational degree between the adjacent HRRP samples of full azimuth of five aircraft targets

3. Adaptive Angular-sector Segmentation Based on Grey System

It is seen from the upper section that it causes the mismatch between the data and the model when the equal angular-sector segmentation is adopted. So the angular-sector should be segmented according to the specific distribution of HRRP. For these strong azimuth sensitivity or easy misjudgment sector, the azimuth interval should be smaller, while for these poor azimuth sensitivity sector the interval should be bigger in order to reduce calculations and save storage spaces. For this reason, on the basis of the previous research results [15], the adaptive angular-sector segmentation based on the grey incidence analysis (GIA) model is researched. That is to say, the angular-sector is adaptively segmented according to the mutual grey incidence value of the adjacent HRRPs. The specific process is as follows:

Step 1. Assume that the target A contains N HRRP training samples, calculate the mutual grey incidence value of each training sample with its adjacent HRRP sample, and get the grey incidence value array $a = [a_1, a_2, \dots, a_{N-1}]$;

Step 2. In the light of the distribution of $a = [a_1, a_2, \dots, a_{N-1}]$, set these angular-sector regions $[\theta_{i1}, \theta_{i2}]$, $i = 1, 2, \dots, Y$ which needs to be segmented meticulously (where Y is the number of these regions), the maximum initial angular-sector segmentation number N_{\max} and the final angular division K_{\max} ;

Step 3. According to these settings of the Step 2, give the mutual grey incidence value threshold μ_1 of $[\theta_{i1}, \theta_{i2}]$, $i = 1, 2, \dots, Y$ and the remaining region threshold μ_2 , where $\mu_1 < \mu_2$;

Step 4. Compare the grey incidence value array a with μ_1 and μ_2 , put the HRRP training sample where the grey incidence value is below two thresholds as the breakpoint, divide unevenly these HRRP training samples, and gain the initial angular-sector segmentations;

Step 5. Calculate the azimuth interval of these segmentations obtained by the Step 4, in accordance with φ_{MTRC} separate evenly these segmentations whose azimuth interval is far greater than φ_{MTRC} , where φ_{MTRC} corresponds to the azimuth interval where MTRC does not occur.

Step 6. Delete less sample segmentations including these segmentations near 90° azimuth, because the SCT of the average HRRP cannot be weakened effectively for the segmentations whose amount of the HRRP sample is smaller;

Step 7. Calculate each segmentation template according to (6), get M templates;

$$x = \frac{\left[\sqrt{\frac{1}{L} \sum_{l=1}^L |x_l(1)|^2}, \sqrt{\frac{1}{L} \sum_{l=1}^L |x_l(2)|^2}, \dots, \sqrt{\frac{1}{L} \sum_{l=1}^L |x_l(128)|^2} \right]^T}{\left\| \left[\sqrt{\frac{1}{L} \sum_{l=1}^L |x_l(1)|^2}, \sqrt{\frac{1}{L} \sum_{l=1}^L |x_l(2)|^2}, \dots, \sqrt{\frac{1}{L} \sum_{l=1}^L |x_l(128)|^2} \right]^T \right\|_2} \quad (6)$$

Where L is the sample number of the segmentation, and $\|\cdot\|_2$ is the 2-norm calculation of the vector.

Step 8. If $M > K_{\max}$, calculate the mutual grey incidence value of each HRRP template with its adjacent HRRP template and get the mutual grey incidence value array $b = [b_1, b_2, \dots, b_M]$, merge these HRRP templates which the grey incidence value is larger according to a certain proportion, such as $M \cdot 5\%$;

Step 9. Return to the Step 8 until $M \leq K_{\max}$, calculate the normalized average HRRP for each HRRP template.

After the target A finishes the above algorithm, the angular-sector segmentation number and their normalized average HRRP will be obtained.

4. Experimental Simulation

4.1. Experimental Process

These HRRP data are sampled with the 0.1° interval from the full azimuth turntable simulation data of five aircraft targets. So these data contain various azimuths. One half of them are used as the training samples, and the other half of them are used as the testing samples. After the HRRP samples preparation, the experiment is done according to the following algorithm.

Step 1. Execute the adaptive angular-sector segmentation method based on the GIA model in the above section. Some frames and their corresponding normalization average range profiles are gained. And they are matching templates. The number of frames is supposed to $K_{i-\max}, i \in [1, 5]$.

Step 2. Calculate the degree of grey incidence $r_{i,k}$ between the testing sample x and the template x_{ik} which is the k -th segmentation of the i -th target according to the GIA model. Then the degree of grey incidence matrix which is degrees of grey incidence between x and the whole template library.

$$R = \begin{bmatrix} r_{1,1}, r_{1,2}, \dots, r_{1,K_{1-\max}} \\ r_{2,1}, r_{2,2}, \dots, r_{2,K_{2-\max}} \\ \dots \\ r_{5,1}, r_{5,2}, \dots, r_{5,K_{5-\max}} \end{bmatrix} \quad (6)$$

In the actual segmentation, the number of frames are not necessarily equal for five aircraft targets. So the matrix cannot be formed, five degree of grey incidence arrays are obtained.

Step 3. Search the maximum degree of grey incidence for each a testing sample. The line corresponding to the maximum degree of grey incidence is the category of the testing sample x .

Step 4. Do statistics the number of the testing samples judged by the recognition decision for a certain target and divide it by the total number of the test samples extracted from the target. The recognition rate and the average rate of recognition both can be gotten. That is:

$$avg = num / N_{total} \quad (7)$$

Where avg is the recognition rate of a certain target, num is the number of the testing samples judged by the recognition decision for the target, N_{total} is the total number of the test samples extracted from the target.

4.2. Result Analysis

Figure 2 shows the comparison of the recognition rate for six different methods aiming at the Su27, F16, M2000, J8II and J6 in different SNR. The six different methods are respective the DGI, SGI, BGI and three adaptive angular-sector segmentation based on three GIA models. These three adaptive methods are abbreviated as ADGI, ASGI and ABGI. Among them, the sub graph (a), (b), (c), (d) and (e) are corresponding to the Su27, F16, M2000, J8II and J6 aircraft target. And then Table 1 is the recognition rate of these methods at $SNR=20dB$. In the simulation, ρ is the coefficient of the DGI model and is set to be 0.5 according to the principle of minimal information.

As can be seen from these recognition results, these adaptive angular-sector segmentation methods are better than these equal angular-sector segmentation methods. ABGI considers the mean information, the first order changes slope information and the second order changes slope information on the basic of SGI and ASGI which consider the change rate in each a resolution range, so the recognition rate of ABGI is the best.

Table 1. Recognition results of several methods (percent, $SNR=20dB$)

	Su27	F16	M2000	J8II	J6	Avg
DGI	85.83	80.58	84.53	76.36	87.22	82.91
ADGI	88.91	83.66	87.49	79.29	90.26	85.92
SGI	88.25	84.86	83	75.19	77.81	81.82
ASGI	91.33	87.79	86.02	78.16	80.79	84.82
BGI	93.44	82.61	90.14	82.94	86.08	87.04
ABGI	96.45	85.54	93.15	85.9	89.01	90.01
MCC	92.94	80.14	89.31	81.11	80.89	84.89

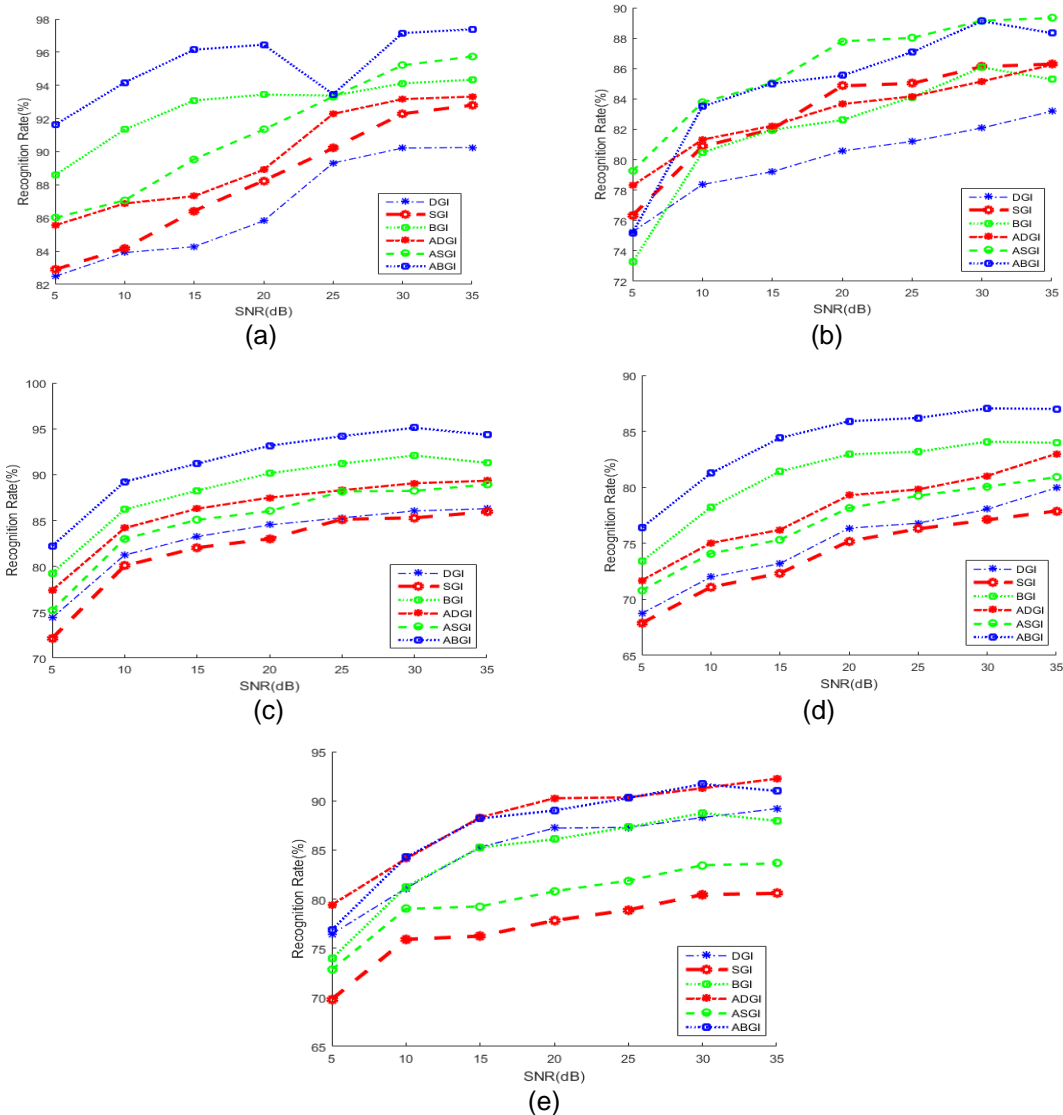


Figure 3. The recognition rate of five aircraft targets under different SNR, (a) the recognition rate of Su27 (b) the recognition rate of F16, (c) the recognition rate of M2000 (d) the recognition rate of J8II, (e) the recognition rate of J6

5. Conclusion

In this paper, the grey system theory is applied to the RTR based on HRRP, and an adaptive angular-sector segmentation method based on the gray incidence analysis model is proposed to solving the azimuth sensitivity of HRRP. These experiments of full azimuth angle turntable HRRP data of Su27, F16, M2000, J8II and J6 five fighter models have shown that the new method can improve the recognition performance. So the method has a practical

significance in target recognition applications. At the same time it should be noted that the angular-sector segmentation number, these angular-sector regions which needs to be segmented meticulously, and these thresholds are predetermined. The determination of these parameters is the compromise between the template number, computational workload and the recognition performance.

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