Study on Elevation Estimation of Low-Angle Target in Meter-Wave Radar Based on Machine-Learning

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Abstract. In these years, meter-wave radar has gotten more and more attention from the researchers all over the world for its advantages in anti-stealth. However, the beam width of meter-wave radar is wider because of the size of radar antenna's vertical aperture, and it makes the low-angle targets detecting and tracking more difficult, which has become one of the urgent problems in radar field. In this paper, the multipath effect in low-angle target detecting will be researched, and an elevation estimation algorithm of low-angle target in meter-wave radar based on machine-learning will be proposed.

Keywords: Elevation estimation · Meter-wave radar · Reflected echoes cancelling

1 Introduction

In recent years, with the rapid development of stealth technology, the ability of microwave radar to detect targets is declining day by day. Meanwhile, meter-wave radar has attracted more and more attention because of its advantages in anti-stealth. However, due to the long wave length, the beam width of receiving antenna is wider, which leads to the low elevation resolution of meter-wave radar. In the detecting and tracking low-angle targets, the reflected echoes from the ground or sea surface will enter the receiving antenna together with the direct ones, which cause the multipath effect, and seriously affects the targets real location estimation, resulting in the decline of radar elevation estimation and tracking performance [1, 2]. The multipath effect has become an important factor affecting the accuracy of elevation estimation of low-angle targets [3]. Nowadays, the problem of the multipath effect of low-angle targets has become an important issue in meter-wave radar field. In this paper, the elevation estimation algorithm which can effectively eliminate the influence of the multipath effect is studied, and the real elevation estimation of the target is obtained.

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2 The Multipath Effect Model

The elevation estimation of low-angle targets is influenced by multipath effect. So in order to solve the problem in elevation estimation of low-angle targets in meter wave radar, it is necessary to understand the cause of multipath effect, and the establishment of multipath model is a more effective means [4]. Therefore, when establishing the multipath effect model, the actual situation of the multipath effect should be reflected as much as possible, and give a model that can accurately describe the actual situation of the multipath effect.

Radar can detect, track and sometimes recognize targets because of the existence of the target's echoes. And the echo characteristics depend largely on the size and properties of the target surface exposed in the radar beam, and are sensitive to the changes of the target scattering characteristics. For the meter-wave radar, the geometric size of the aerial target (such as aircraft) is equivalent to the radar wavelength, which is usually of multiple wavelength orders of magnitude, so its scattering characteristics have resonance characteristics. In order to simplify the analysis, the total electromagnetic scattering of the target is simplified as the sum of the electromagnetic scattering of multiple isolated scattering centers. Therefore, the target in the multipath effect model is no longer a simple point target, but a set of equivalent multiple scattering centers. There are the direct echo path and the reflected echo path between each scattering center and the antenna, so the combination form of echoes is complex. Figure 1 shows the multipath effect model based on multiple scattering centers.

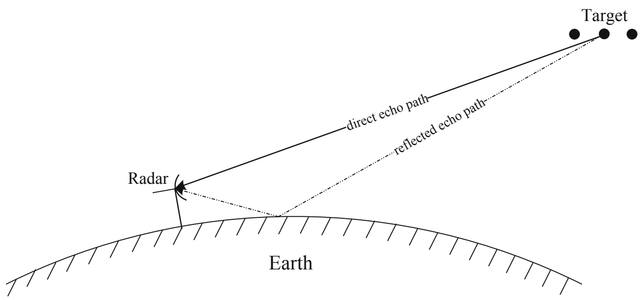

Fig. 1. The multipath effect model based on multiple scattering centers

In the Fig. 1, the distance of the direct path d_d and the distance of the reflection path d_f are respectively:

$$d_d = \sqrt{(r_{earth} + h_r)^2 + (r_{earth} + h_t)^2 - 2(r_{earth} + h_r)(r_{earth} + h_t)\cos(\beta_r + \beta_t)} \tag{1}$$

$$d_f = \sqrt{2\left(r_{earth}^2 + r_{earth} \cdot h_t\right)(1 - \cos\beta_t) + h_t^2} + \sqrt{2\left(r_{earth}^2 + r_{earth} \cdot h_r\right)(1 - \cos\beta_r) + h_r^2} \tag{2}$$

where, h_r is the height of the radar, h_t is the height of the target, r_{earth} is the radius of curvature of the earth's prime vertical circle, β_r is the sphere center angle between the radar and the ground reflection point, β_t is the sphere center angle between the target and the ground reflection point.

3 Elevation Estimation Algorithm

At present, in array signals processing, some classic techniques are usually used. Such as the super-resolution technology, it is very mature for array signal processing, and can obtain good angular resolution and estimation accuracy [5]. But this is based on the premise that the radar echoes only contains the direct echoes of the target, which is not for meter-wave radar. So this paper will analyze the characteristics of the reflected echoes, study the method of extracting the reflected components based on machine learning, and use the obtained reflected components to construct a cancellation vector to cancel the reflected echoes to eliminate the multipath effect, which lets the direct echoes dominate the whole echoes, makes the application of super-resolution algorithm possible, and the true elevation estimation of the target can be obtained.

3.1 Preprocessing of Elevation Estimation Credibility

For the meter-wave radar, due to the influence of multipath effects, the angle estimation of the low-angle targets is neither credible nor accurate. The meter-wave radar echoes of the low-angle target is actually the composite echoes of the direct ones and the reflected ones reflected by the ground. Among them, the direct ones is no longer dominant in the whole echoes. The target elevation estimation is influenced by the multipath effects. However, the influence of the multipath effects on elevation estimation presents a credibility phenomenon, that is, when the estimation is within a certain range, the credibility is very high, and it can be used as a true estimation, while it is incredibility in some range, and the estimation needs to be corrected. Therefore, after receiving the echo data, it is necessary to preprocess the elevation estimation credibility of the data by the elevation estimation interval.

In the process of space propagation, electromagnetic wave is blocked by undulating terrain surface and ground obstacles, forming terrain blind area, resulting in electromagnetic wave cannot be transmitted. In the evaluation credibility prediction process, if the elevation estimation obtained falls in the terrain blind area, the evaluation estimation credibility is lower, so the estimation should be corrected for the multipath effects.

For a radar, the terrain blind area is mainly related to the position of setting up the antenna and the terrain undulations within the radar coverage. Without considering its propagation influence, the radar's coverage blind area is mainly determined by the earth curvature blind area and terrain blocking blind area. The relationship between blind angle α_z and terrain is as follows:

$$\alpha_z = \cos^{-1}\left(\frac{d^2 - 2h \cdot r_{earth} - h^2}{2d \cdot r_{earth}}\right) - \frac{\pi}{2} \tag{3}$$

where, d is the distance of undulating terrain, h is the height of undulating terrain, r_{earth} is the radius of curvature of the earth's prime vertical circle where the radar is erected.

The flow chart of the calculation of terrain blind area is shown.

Firstly, according to the performance index of radar, the azimuth, elevation coverage and elevation resolution of the radar are input.

Secondly, a certain elevation value is set which needs to be calculated, and calculate the effective coverage distance d after propagation attenuation according to the working parameters and environmental parameters of the radar.

Thirdly, the latitude and longitude range of the radar coverage is calculated according to the latitude, longitude and altitude information, azimuth β, elevation α and coverage distance d. According to the latitude and longitude information, the terrain data of coverage area is indexed, and the effective elevation α' and its corresponding effective distance d' are calculated when the coverage distance is d and the azimuth is β.

Then, compare the values of α and α', if the former is greater than the latter, it means that there is terrain occlusion, at this time d is updated to d'; otherwise, d does not need to be updated.

Finally, traverse all the ranges of the elevation, and the output d is the coverage distance under the specified azimuth.

3.2 The Elevation Estimation Algorithm Based on the Reflected Components Cancellation

Therefore, the key to improving the elevation estimation performance of the targets is to eliminate the influence of the reflected echoes. To eliminate the reflected echoes, the prerequisite is to accurately grasp the reflected echoes components information. Therefore, the acquisition of the reflected components is very important. According to the multipath effect model of complex targets with multiple scattering centers, the target should be regarded as a group of multiple scattering centers that obey a specific distribution. Since different types of targets have different distributions of multiple scattering centers and the scattering characteristics of each scattering center, and the target type cannot be known in advance in actual situations, the data classification method can be used to extract the reflected echo vectors corresponding to each scattering center.

According to the multipath effect model of the multi scattering centers, the echoes of the low-angle target in meter-wave radar are composed of two parts: the direct echoes which returns to the receiving antenna after the target scattering and the reflected ones arriving at the receiving antenna after the ground reflection. Echoes received at the radar antenna $E(t)$ shall be expressed as:

$$\begin{aligned} E(t) &= \sum_{k=1}^{K} E_{dk}(t) + \sum_{k=1}^{K} E_{fk}(t) \\ &= \sum_{k=1}^{K} A_{dk} e^{j\phi_k} + \sum_{k=1}^{K} A_{fk} e^{j\varphi_k} \end{aligned} \tag{4}$$

where, $E_{dk}(t)$ and $E_{fk}(t)$ are the direct echoes and reflected echoes generated by the k^{th} scattering center of the target, A_{dk} and A_{fk} are the amplitude of direct echoes and reflected echoes from the k^{th} scattering center respectively, and φ_k and ϕ_k are the phases of direct echoes and reflected echoes respectively.

Among them, reflected echoes are the main reason for inaccurate measurement of low-angle target in meter-wave radar. Therefore, the key to solve the problem of the elevation estimation of low-angle target is how to eliminate the influence of reflected echoes. According to the influence of each equivalent reflection components on the estimation results, the most appropriate combination of reflection echoes cancellation components is extracted based on machine-learning feature matching. Then, according to the statistics and analysis of the cancellation results of different combinations, which is the estimation is classified, and then the estimation results of different combination cancellation are mapped into the classes one by one, and the estimations in one class are combined, and the target track and target motion trend information are combined to obtain the more accurate target elevation estimation.

Through the analysis of the multipath effect model, it is known that each reflected component corresponds to a phase and amplitude. Therefore, searching for the reflected component is actually to search for the phase and amplitude of the reflected component.

Therefore, the steps for searching the reflected components are as follows:

1) The amplitude of the reflected component is set, and then the angle of the reflected component is adjusted to construct the cancellation vector phase.
2) After cancellation, the cancellation result is judged, and those that meet the judgment conditions are output as the extraction result.
3) By adjusting the amplitude of the reflected component, the phase search is carried out again, and finally a set of cancellation components is obtained.

In the process of searching cancellation components, how to determine the cancellation components is an important part. Through the analysis of the cancellation results, it can be found that the peak energy of super-resolution spectrum after cancellation is higher than that corresponding to the adjacent search phase when the reflected components extraction is more accurate. The reason is that the cancellation components is sensitive to the phase, and some difference in the phase will lead to different cancellation results. Once the phase is aligned, the cancellation result will be significantly improved compared with that without alignment, and the reflected components will be restrained to some extent, thus the super-resolution spectrum energy will be improved. At the same time, because the search step is very small, many cancellation vectors with small phase difference often obtain similar cancellation results, which makes the same reflected components be extracted many times, resulting in overlapping of extracted reflected components. Therefore, the validity of the reflected components can be judged and extracted according to the cancellation result of the reflected components. The extraction of the reflected components can be equivalent to the two-classification problem of the good or bad cancellation effect of the reflected components. In this paper, BP neural network is used to extract the characteristic samples of the reflected components with prior information to train the network, so as to realize the classification and extraction of the reflected components.

The specific steps of cancelling component extraction based on BP network are as follows:

1) Continuous weight/threshold initialization, using a small random number for assignment, and the weight and threshold cannot be equal to avoid network errors.
2) Provide the training samples, test samples and the network parameters of the reflected cancellation component to the neural network for normalization preprocessing.
3) Each sample in the training set is calculated: the output of each neuron in the hidden layer and output layer is calculated in the forward direction; the error between the expected output and the network output is calculated; the weights and thresholds of the modified network are calculated backward.

3.3 The Solution of the Problem of Multi-value Suppression

In the process of meter-wave radar signal processing, since the elevation estimation is obtained by cancelling the searched reflected components, the cancellation results directly affect the estimation results. However, the reflection components used in the cancellation is obtained by searching, which cannot be completely equivalent to the real multipath effect. Therefore, there will be residual components after cancellation, which will produce multi value phenomenon in the estimation results. The multiple estimation generated are regarded as multiple observation values of the current batch. The plot-track association method based on data classification and recognition is used, and the training samples are obtained through the analysis of historical data, and the batch of plots containing multi-value information are input into the trained model for target association classification, so as to realize the association of target plots and tracks and solve the problem of multi value suppression.

The plot-track association algorithm based on data classification adopts the support vector machine (SVM) based on posterior probability. In the process of track association, the association threshold is set based on the previous batch of plots of the target's existing track, and the association area is established based on the threshold value. If the value of multiple estimates of the current batch falls within the association area, the estimation and the existing track of the target form an association hypothesis, And whether the hypothesis is true can be obtained by the classifier. When constructing the target track sample for training classifier, it is obtained by extracting the track data, including a specified number of batch data and error data affected by the multipath effect. The training data set **C** is composed of the classifier training samples whose characteristic parameters include information such as speed, acceleration, etc., which is obtained from each sample as features:

$$\mathbf{C} = \{(c_{11}, c_{12}, \cdots, c_{1j}), \cdots, (c_{i1}, c_{i2}, \cdots, c_{ij})\}, i = 1, 2, \cdots, M \quad j = 1, 2, \cdots, N \quad (5)$$

where, c_{ij} is the characteristic parameter of the sample, M is the number of samples in the training data set, N is the number of extracted features of each sample.

By inputting the characteristic parameters of the track association hypothesis sample into the trained posterior probability SVM classifier, the probability of

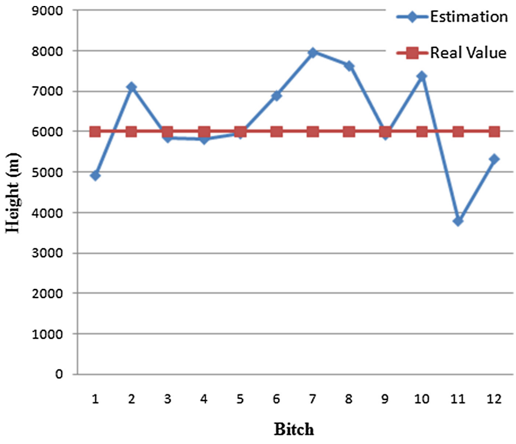

Fig. 2. Elevation estimation of target without reflected components cancellation

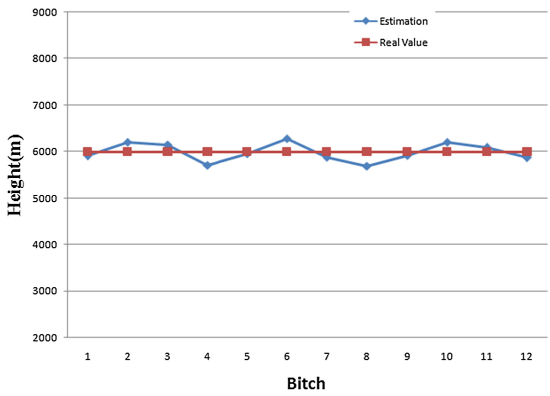

Fig. 3. Elevation estimation of target based on reflected components cancellation

interconnection between the associated track and the batch of plots can be obtained under the condition that the associated track in the current hypothesis which the characteristic parameters correspond to is tenable. After classification, the probability of each hypothesis can be obtained. Finally, the multi value problem is solved and the elevation of low-angle target is estimated correctly. Figure 2 and Fig. 3 show the processing results of elevation estimation of target without reflected components cancellation and based on reflected components cancellation, respectively.

4 Conclusion

In this paper, the elevation estimation algorithm of low-angle target in meter-wave radar based on reflected components cancellation is studied. The characteristics of multi scattering centers and the multipath effects are analyzed by establishing the multipath effect model of multi scattering centers. On this basis, a solution to the problem of low-angle target elevation estimation is proposed, which can better overcome the influence of the multipath effects, obtain more accurate target elevation information, and improve the performance of meter-wave radar low-angle target tracking.

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