Research on Background Knowledge Based Software Processing Method of Target Height Measurement for 3D Radar

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Abstract. The three-dimensional (3D) radar can detect 3D information of air targets, including range, azimuth and height. It is considered as an important equipment of the air defense detection system in various countries. The precision of target height measurement is the key challenge in radar detection due to the influences of the complex background environment of air targets. This paper considers the background knowledge during target detection. By using the background knowledge of radar position meteorological parameters and multi-dimensional radar position RAG maps etc., this paper proposes an integrated software processing method to improve the precision of target height measurement for 3D radar and designs a height confidence evaluation model to improve the fusion precision of height information in the superior command unit of the radar.

1 Introduction

In the modern warfare, diversified aviation weapons with high and low altitudes can carry out multi-directional, multi-level and three-dimensional attacks to implement strategic strike. Compared with the traditional 2D radar, 3D radar can simultaneously acquire the information of range, azimuth and height to perform three-dimensional coordinate positioning on air targets, which can effectively prevent various types of air attack targets. The height of the detected target is most important in 3D radar and its measurement precision plays a key role in the target positioning and tracking.

Shu et al. [1] propose a target height measurement method for ground-based air-surveillance radar applications via the robust beamspace transformation, considering that all diffuse reflected multipath signals are the interference signals and can be cancelled after beamspace transformation. Berube et al. [2] design a solution to measure target height using multipath radar reports over land, based on the principle that the target height can be estimated accurately with the known location and altitude of the point of reflection. Besides, Laribi et al. [3] utilize radar wave multipath propagation to height measurement in the FMCW automotive radar and propose a height measurement algorithm for objects in the vehicle's surroundings without requirement of multiple antennas at different heights. For wide illumination of wide-beam pulse radar altimeter, the traditional height measurement algorithm cannot be applied to the complex terrain area with large fluctuation. In order to solve the above problem, Zhang et al. [4] propose a new algorithm named average-height algorithm applicable to kinds of terrain. Lin et al. [5] analyze the height jumping problem of 3D radar from radar position, radar signal processing, data processing and radar monitoring system etc., and then give relevant software improvement measures to improve the precision of target height measurement.

The detection precision of target height by 3D radar is greatly affected by the background environment where the target is detected. Therefore, in the radar software implementation, the relevant process of the target height should be considered together with the radar position meteorological parameters, the radar position RAG maps of clutter area, defilade area, blind area and height measurable area, and other background knowledge. The comprehensive use of background knowledge improves the precision of target height measured by 3D radar. Besides, it is necessary to design a model to evaluate the height confidence of the detected target based on the background knowledge, since the height confidence level of the target is beneficial to improve the fusion precision of the height information of the same target reported by different radars in the superior command unit of the radars.

2 Radar Position RAG Map

The radar position RAG map is obtained by dividing the radar detection area from the two dimensions of range and azimuth. Radar position RAG maps include various types of RAG maps, such as RAG map of the clutter area, RAG map of the defilade area, RAG map of the blind area and RAG map of the height measurable area. The RAG map of the blind area refers to the near area from the radar less than a certain detection range threshold (e.g., the range within 5km from a radar is its blind area)
and the RAG map of the height measurable area is the area covered by the radar height-precision measurement (e.g., the range within 200km from a radar is its height measurable area).

In this paper, for a radar with the maximum detection range 400km, we divide the radar detection area into 256 azimuth units and 256 range units. Thus, each RAG map consists of 65536 sector grids in total, where the azimuth is 1.40625 degrees (1.40625*256=360) and the range is 1.6km (1.6*256=409.6~400, 409.6 is enough for the maximum detection range 400km) as shown in Figure 1. Similarly, we can construct the RAG map of the clutter area and the RAG map of the defilade area. By the radar display software, the user can fill the background of RAG maps by a larger zone instead of filling so many sector grids, if the user selects the “Zone” button. If the user wants to mask the specified sector grid, the user should click the “Mask” button and moves the mouse to the specified grid to finish masking process for the RAG map easily.

![Figure 1. Sector Grids of RAG Map.](https://via.placeholder.com/150)

In order to improve the precision of target height measurement, the 3D radar should have the function of correcting measured height based on the meteorological parameters. In the process of meteorological parameter correction, typical radars generally divide the vertical height dimension of radar detection airspace into several height layers and bind the meteorological parameters such as air temperature, atmospheric pressure and relative humidity etc., in each height layer. However, it is actually difficult to obtain meteorological parameters for each height layer, which demonstrates that it is not suitable for engineering implementation.

Therefore, we propose a multi-model meteorological parameter correction scheme to improve the precision of target height measurement. The user can use the software interface to select the meteorological parameters suitable for the approximate conditions of the radar position as shown in Figure 3. The commonly used correction models for meteorological parameters include the refractive index average gradient model and the hierarchical equivalent curvature radius model etc. Each model is approximated to the actual environment condition. If more meteorological parameters are given, the model is more accurate. The user can select a reasonable model for correcting the target height to improve the precision of target height measurement for 3D radar, according to the actual environment condition.

![Figure 3. Radar Position Meteorological Parameter Correction.](https://via.placeholder.com/150)

### 4 Height Confidence Evaluation

When the radar detecting target is at a case of long range, low elevation, or low signal to noise ratio, it will result in a poor precision of target height measurement. In this case, the radar position RAG maps of the clutter area, the defilade area, the blind area and the height measurable area, the center beam amplitude and the moving status of the target should be comprehensively utilized to evaluate the target height confidence level.

Based on the above background knowledge, this paper proposes a height confidence evaluation model to obtain the height confidence level information of targets. The model is implemented in the radar data processing software and the evaluation results are sent to the radar display software. The radar display software utilizes different colors to distinguish the height confidence levels of different targets. Therefore, the users can directly find the targets with low confidence level of height measurement and pay attention to them. Besides, the radar communication processing software reports the
height measurement confidence level information of targets to the superior command unit. The superior command unit may receive multiple different height values of the same target reported by different radars. In the fusion of the target information by the superior command unit, the information with higher height confidence level reported by some radar may be assigned with a larger weight coefficient to improve the fusion precision of the target detection information, especially helpful for the fusion precision of the height information.

The model of evaluating height confidence level of the target is shown in Formula 1. In Formula 1, the variable \( c \) represents the subordination degree of the clutter area, \( d \) represents the subordination degree of the defilade area, \( b \) represents subordination degree of the blind area, \( a \) represents subordination degree of the beam amplitude, \( h \) represents subordination degree of the height measurable area and \( m \) represents the subordination degree of target maneuvering.

\[
\varphi = c \times d \times b \times (a + h + m) \quad (1)
\]

Formula 2 shows how to get the subordination degree of the clutter area. By using the RAG map of the clutter area, if a target is in the clutter area, its track has a higher probability of error association to a wrong plot during its plot-to-track association process for the target. Therefore, the target in the clutter area has low confidence level of height measurement.

\[
c = \begin{cases} 
1 & \text{out of clutter area} \\
0 & \text{in clutter area} 
\end{cases} \quad (2)
\]

Formula 3 shows how to get the subordination degree of the defilade area. According to the RAG map of the defilade area, when the target is located in the defilade area, its height measurement has low precision due to the blocked beam in this area. Therefore, the target in the defilade area has low confidence level of height measurement.

\[
d = \begin{cases} 
1 & \text{out of defilade area} \\
0 & \text{in defilade area} 
\end{cases} \quad (3)
\]

Formula 4 shows how to get the subordination degree of the blind area. According to the RAG map of the blind area, when the target is located in the blind area, its height measurement has low precision. Therefore, the target in the blind area has low confidence level of height measurement.

\[
b = \begin{cases} 
1 & \text{out of blind area} \\
0 & \text{in blind area} 
\end{cases} \quad (4)
\]

In the three-beam (beam 1, beam 2 and beam 3) amplitude-comparison height measurement, the deviation of pointing directions of beam 1 and beam 3 from beam 2 may lead beam amplitude fluctuation, as shown in Figure 4. Figure 5 shows the influence of the fluctuation of the amplitude of beam 3 on the precision of the target elevation measurement under various amplitude differences between beam 1 and beam 2. Therefore, the beam amplitude subordination degree function calculated in this paper is shown in Formula 5.

\[
a = \begin{cases} 
1 & |AD_1 - AD_2| < \Phi \text{ or } |AD_2 - AD_3| < \Phi \\
0 & \text{otherwise} 
\end{cases} \quad (5)
\]

In Formula 5, \( AD_1 \), \( AD_2 \) and \( AD_3 \) represent the amplitudes of beam 1, beam 2 and beam 3 respectively. \( \Phi \) represents the threshold of the beam amplitude difference. When the amplitude difference between two adjacent beams is smaller than the threshold \( \Phi \), the subordination degree of the beam amplitude is 1; otherwise the subordination degree of the beam amplitude is 0.

Formula 6 shows how to get the subordination degree of the height measurable area. According to the RAG map of the height measurable area, when the target is located out of the height measurable area, its height measurement is inaccurate.

\[
h = \begin{cases} 
1 & \text{in height measurable area} \\
0 & \text{out of height measurable area} 
\end{cases} \quad (6)
\]

Formula 7 shows how to get the subordination degree of target maneuvering. When the target is maneuvering, the RCS of the target will fluctuate, which causes inaccurate target height measurement. Therefore, when the target is maneuvering, its height measurement is inaccurate.
\[ m = \begin{cases} 1 & \text{reliable target} \\ 0 & \text{maneuvering target} \end{cases} \]  

In summary, the value of the target height confidence level ranges from 0 to 3, which has 4 levels. If the value is greater, the confidence level of the height measurement is higher. According to Formula 1, when the target is in the clutter area, the defilade area or the blind area, the confidence level of height measurement is 0, which means unbelievable. In other cases, the confidence level of height measurement is based on the subordination degree of the beam amplitude, the height measurable area and the moving status of the target.

5 Height Processing in Special Areas

In the clutter environments, error plot association often happens during the plot-to-track association process of the target, which can cause the sudden jumping of the target observation height. Therefore, the radar data processing software could perform special processing to let the target keep the same tracking height (the target height obtained from the original observation height via filtering process) to its previous value, when it is crossing the clutter area. After the target leaves out of the clutter area, its track height changes according to the observation height of the associated plot. This similar height processing is also suitable for the blind area and the defilade area.

The big sector area on the left side of Figure 6 represents the clutter area. The label "T 558" indicates that the track number of the target is 558 and "HS091" indicates that the ATC height of the target is 9100(91*100)m. The ATC height is the actively responded height by the target itself, which is very close to the real height. However, the ATC height can only be obtained from the target equipped with a secondary radar transponder. Generally, we can only get the ATC height from the cooperation civil aviation aircraft targets, except from noncooperation targets. "HP094" indicates that the target track height is 9400(94*100)m. In the upper left corner of Figure 6, we can see that the real-time observation height associated with the target "T 558" is 10000(100*100)m, when it is crossing the clutter area, but its track height still maintains the height of 9400m, which is the same to the height before flying into the clutter area. The maintained height value of 9400m is closer to the ATC height 9100m, which demonstrates that this special height processing is effective for improving the precision of the target height in the special areas.

6 Conclusion

Target height measurement in 3D radar directly affects the guidance and attack of the supporting weapon system to threat targets, and thus the precision of target height measurement is becoming more and more important in the modern defense system. The background of the targets affects the precision of target height measurement in 3D radar. Based on the background knowledge of air targets, this paper proposes a multi-model meteorological parameter correction scheme to improve the influence of atmospheric waveguides on target height measurement, designs a height confidence evaluation model to establish the confidence evaluation architecture of target height measurement and optimize the target height processing in the special areas to improve the precision of target height in 3D radar. The research results in this paper can be easily implemented in the engineering of height measurement processing software for 3D radar and are effective for improving the precision of target height measurement.

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