Angular glint compensation for seekers based on multicharacter techniques

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Abstract: To solve the problem caused by angular glint in the terminal guidance process, which effects steady target tracking and results in the final miss, the influence of angular glint on the seeker's angle tracking and angular glint compensation methodology using multiple output angle error equation with different detection frequencies at single sensing period to extract the unknown parameters of the target model based on the orthogonal multicharacter technique is proposed here. The method is verified reasonable and feasible through the simulation analysis, the analysis result can be applied to improve the tracking precision of the seeker's terminal guidance process.

1 Introduction
Angular glint is an inherent characteristic of the target itself. The target, with multiple scattering points, whose magnitude of size can be compared with that of the wavelength of the sensing signal, will produce angular glint [1]. Fig. 1 presents a diagram of angular glint.

When the seeker is close to the target, the target cannot be treated as a single point, but a model with many different scattering points. The echo amplitude, phase, and polarisation measured at different angles are not the same, so the position of the equivalent scattering centre changes acutely, even escape from the target, which make the seeker unable to track the target position accurately. In order to make use of the characteristics of angular glint, the aircraft usually installs the jamming system in the small pod of the wing tip and uses the wave-front distortion received by the seeker to form a false target outside the aircraft to mislead the seeker.

On the basis of giving an angular glint model and analysing its influence on angle tracking of seeker, angular glint compensation methodology based on orthogonal multicharacter technique is proposed in this paper. The effectiveness of the method is verified by simulation.

2 Angular glint model and effects analysis

2.1 Angular glint model
The angular glint model is given in [2]. The author considers the influence of angular glint on amplitude and phase of echo.

The target model can be indicated as $n$ scattering points. The coordinate of the point $j$ is $(x_j, y_j, z_j)$. The radar cross-section of the point $j$ is $\sigma_j$. The nearest scattering point of the seeker is the seeker's tracking object, and the other scattering points are interferences.

The whole analysis of angular glint effects on radar or seeker is based on amplitude comparison monopulse target detection and tracking scheme. The sum and difference monopulse patterns presented in [2] are used in this paper and can be written as [3]:

$$\Sigma(\theta) = e^{j\pi b \theta / \lambda}$$ (1)
$$\Delta(\theta) = 1.56(\theta / \theta_b)e^{-j2\pi \theta / \lambda}$$ (2)

where $\theta$: beam direction deviation angle, $\theta_b$: antenna beamwidth.

According to the calculation formula of the echo power given in reference [4], under the influence of angular glint, the sum, and difference patterns can be written as:

$$S = \sum_{j=1}^{n} PG\Sigma(\theta_j)\lambda^2\sigma_j e^{j\omega t}$$ (3)
$$D = \sum_{j=1}^{n} PG\Delta(\theta_j)\lambda^2\sigma_j e^{j\omega t}$$ (4)

where $n$: the number of scattering points, $j = 1, 2, \ldots, n$, $P$: output power of transmitter, $G$: antenna gain, $\theta_j$: angle between beam direction and point $j$ direction, $\lambda$: wavelength of sensing signal, $\sigma_j$: radar cross-section of point $j$, $d_{mn}$: distance between radar point $j$ and missile, $L$: loss, $\phi$: phase of point $j$ echo.

Equations (3), (4) can be simplified as:

$$S = \sum_{j=1}^{n} \frac{A\Sigma(\theta_j)\sigma_j e^{j\omega t}}{d_{mn}}$$ (5)
$$D = \sum_{j=1}^{n} \frac{A\Delta(\theta_j)\sigma_j e^{j\omega t}}{d_{mn}}$$ (6)

Error voltage gotten by receivers can be illustrated as:

$$E = \text{Re}[D/S]$$ (7)
2.2 Angular glint effects analysis

The multi-point model of the aircraft target is shown in Table 1, and the coordinates of the scattering points and their radar cross-sections are listed.

The first scattering point in Table 1 is nearest to the seeker to track, and the other seven scattering points are interference scattering points.

Taking the eight scattering points aircraft in Table 1 as an example, the simulation result of target tracking under the influence of the above angular glint model at the terminal guidance process based on MATLAB platform is given in Fig. 2 [5].

In Fig. 2, the transverse coordinate is missile flight time, and the longitudinal coordinate is elevation angle of the missile. There is a total of nine curves, the first scattering point is the real target for seeker to track, the blue solid curve is the seeker’s tracking direction to this point; the green-dash-dotted curve is one of the directions of seven other interference scattering points, point 2 is chosen; the red-dotted curve is the direction of seeker influenced by angular glint. As shown in Fig. 2, the error of elevation angle influenced by angular glint is obvious, the seeker trembles among the directions of the scattering points.

3 Angular glint effects compensation

3.1 Orthogonal multicarrier technique

Orthogonal multicarrier radar signal uses complement sequence matrices to modulate multiple carriers with orthogonal relations simultaneously [6]. Then, it can be effectively combined with the orthogonal frequency division multiplexing (OFDM) technology, which has become a number of communication standards, and set up a radar communication network [7]. In [8], orthogonal multicarrier technique is applied, the authors utilise different detection frequency to get different error voltage output, establish a number of equations to extract unknown parameters under the influence of multipath effect, and realise multipath effects compensation. Orthogonal multicarrier technique transmits a plurality of carriers at one sensing period to detect the target, so it is suitable for high-speed moving target [9]. Orthogonal multicarrier structure is shown in Fig. 3: $N \times M$ orthogonal multicarrier radar signal uses $N \times M$ complement sequence matrices to simultaneously modulate $N$ orthogonal carriers, whose phase period is $M \times t_b$. Frequency space between carriers $\Delta f$ is $1 / t_b$. Orthogonal multicarrier pulse signal can be written as follows: (see (8))

$$u_n(t) = \sum_{n=1}^{N} W_n \exp\left[j2\pi \left(\frac{N+1}{2} - n\right)t / t_b\right] \times \sum_{m=1}^{M} u_m[t - (m-1)t_b], \quad 0 \leq t \leq Mt_b$$

(9)

where $W_n$: carrier $n$ amplitude weight, $\varphi_{n,m}$: phase $m$ of carrier $n$.

Orthogonal multicarrier pulse exhibits thumbtack ambiguity function, its range resolution is $t_b / N$, velocity resolution is $1 / t_b$, pulse compression ratio is $N \times M$ [10].

3.2 Angular glint compensation theory

Equation (7) can be written as: (see (10) and (11)). The following equation can be obtained by amplitude comparison monopulse target detection and tracking scheme [11]:

$$\Delta(\theta_j) / \Sigma(\theta_j) = P \theta_j$$

(12)

where $n$: the number of scattering points, $j = 1, 2, \ldots, n$, $P$: the proportionality constant of system difference and sum pattern ratio.

Combining (11) with (12), it can be written as:

$$\theta_i = \frac{1}{P} \text{Re}\left[\frac{D}{S}\right]$$

(8)
3.3 Simple method of glint compensation

As (13) is very complex and difficult to be applied in engineering, the following simple method can be adopted.

According to (5), by adjusting the carrier frequency \( f \), the sum pattern can be written as:

\[
S' = \frac{\sigma_1(\theta_1)}{d_{m_1}}e^{j\phi_1} + \sum_{j=2}^{N} \frac{\sigma_j(\theta_j)}{d_{m_j}}e^{j\phi_j} + \Delta \phi(\theta)
\]

Assume that \( \Delta \phi(\theta) = 2\pi \), each time the carrier frequency is adjusted, let the phase change value be \( 2\pi/N \), and add all sum pattern outputs, it can be illustrated as:

\[
S_{\text{sum}} = \frac{1}{d_{m_1}} \sum_{k=1}^{N} \left[ \frac{\sigma_1(\theta_1)}{d_{m_1}}e^{j\phi_1} + \sum_{j=2}^{N} \frac{\sigma_j(\theta_j)}{d_{m_j}}e^{j\phi_j} + \Delta \phi(\theta) \right]
\]

where \( \Delta \phi(\theta) \) is uniformly distributed in \([0, 2\pi]\), so \( \sum_{k=1}^{N} e^{j\Delta \phi(\theta)} \approx 0 \), (22) can be simplified as:

\[
S_{\text{sum}} \approx \frac{N \Delta \sigma(\theta)}{d_{m_1}} e^{j\phi_1}
\]

Similarly, add all difference pattern outputs, it can be illustrated as:

\[
D_{\text{sum}} \approx \frac{N \Delta \sigma(\theta)}{d_{m_1}} e^{j\phi_1}
\]

After compensation, error voltage output can be written as:

\[
E_{\text{comp}} = \text{Re}[D_{\text{sum}}/S_{\text{sum}}] \approx \text{Re}[\Delta(\theta)/\Sigma(\theta)]
\]

3.4 Compensating effect simulation example

Different number of carrier frequency \( N \) is used to compensate angular glint of the aircraft target model in Table 1. The simulation result is shown in Fig. 4.

Fig. 4 is same as Fig. 2 besides a black-dashed curve. The black-dashed curve is the direction of seeker after compensation. As shown in Fig. 4, after compensation, the error of elevation angle decreases a lot. In Fig. 4b, when the number of frequency carriers \( N = 8 \), there is not enough phase change value \( \Delta \phi(\theta) \) to satisfy \( \sum_{k=1}^{N} e^{j\Delta \phi(\theta)} \approx 0 \), so, the echo power of the interference scattering points cannot be effectively offset. In Figs. 4b and 4c, with the increase of N, the accumulation of target echo power is increased, and most of the interference echo power is offset. The compensation effect is almost the same when \( N = 11 \) and \( N = 14 \).

4 Conclusion

Under the influence of angular glint, the target tracking performance becomes worse. Based on orthogonal multicarrier technique, different detection frequencies is utilised to get different
error voltage output, a number of equations are established to extract unknown parameters under the influence of angular glint and realise glint compensation. There exists phase difference in the echo power of interference with different carrier frequencies. The echo power of interference can be offset by properly selecting carrier frequencies, which is a simple method to realise angular glint compensation. The number of carrier frequencies $N$ has an influence on angular glint compensation, with the increase of $N$, the compensation effect becomes better.

5 References

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Fig. 4 Compensating effect simulation example

(a) $N=8$, (b) $N=11$, (c) $N=14$