New Jamming Method of Netted Radar Based on Time Synchronization Errors

Jian-ming MA\(^1\), Yin-tong LIU\(^1\) and Guang CHEN\(^2\)

\(^1\)91388 Force of the Chinese People’s Liberation Army, Zhanjiang, China
\(^2\)Air Force Early Warning Institute, Wuhan, China

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Abstract. Aiming at time synchronization errors among netted radar sub-stations, the paper established the model that time synchronization errors influenced the netted radar cross-location accuracy, and proposed a new method of using time synchronization errors to jam netted radar. Firstly, time synchronization errors were caused among radar stations in the network by applying deceptive jamming to GPS navigation satellites. Then, jammed the location and tracking of jamming sources in the mode of netted radar cross-location. Finally, according to the parameters of typical netted radar and target jammer, simulation research was developed, and the results verify the method’s effectiveness.

Introduction

Netted radars can realize resource sharing and passive cross-location among radars in the network. Compared with single radar, netted radars have stronger detection performance and anti-jamming ability\(^{[1]}\). In the future battlefield, in order to ensure the penetration probability of our troops or weapons and improve the battlefield survivability, it is necessary to jam the enemy netted radars effectively. At present, there are a lot of research results in the field of netted radar anti-jamming\(^{[2-4]}\), but the research on jamming using time synchronization errors between netted radar stations is relatively rare. Aiming at the problem of time synchronization in cross-location mode of distributed netted radar, a new method of jamming based on time synchronization error is proposed. At the same time, the jamming effect of this method is studied by three-dimensional simulation.

The Impact Models

Model of the effect of Time Synchronization Error on Cross Location

Considering the influence of time synchronization error between netted radar stations on the solution of interference source location, as shown in Figure 1.

![Figure 1. Effect of Time Synchronization Error on Cross Positioning Accuracy.](image)

Assuming that the time synchronization error between radar station \(B\) and radar station \(A\) is \(\Delta t\), \(\Delta t\) is relatively small, and the target jammer is assumed to move in a uniform straight line in this time
interval. When the azimuth and elevation \((\alpha_A, \beta_A)\) are acquired by the radar station \(A\) at the time \(t\), the azimuth and elevation \((\alpha_B, \beta_B)\) are acquired by the radar station \(B\) at the time \(t-\Delta t\), therefore:

\[
\begin{align*}
\alpha_A &= \tan^{-1} \frac{x' - x_A}{y' - y_A} \\
\beta_A &= \tan^{-1} \frac{z' - z_A}{\sqrt{(x' - x_A)^2 + (y' - y_A)^2}}
\end{align*}
\]  

(1)

In formula (1), \(x' = x - v_x \Delta t\), \(y' = y - v_y \Delta t\), \(z' = z - v_z \Delta t\), \(v_x, v_y, v_z\) are respectively represent the three components of the target jammer speed. Through derivation, considering the time synchronization error the target jammer position calculation formula can be obtained as follows:

\[
\begin{align*}
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix} &= \begin{bmatrix}
\tan \alpha_A \tan \alpha_B (y_A - y_B - v_y \Delta t) + x_B \tan \alpha_A - x_A \tan \alpha_B + v_y \Delta t \tan \alpha_B \\
(y_A \tan \alpha_A - (y_A + v_y \Delta t) \tan \alpha_A + x_A - x_A + v_y \Delta t) \\
z = \frac{k_1^2}{k_1^2 + k_2^2} z_1 + \frac{k_2^2}{k_1^2 + k_2^2} z_2
\end{bmatrix}
\end{align*}
\]  

(2)

The Interference Method

Time Synchronization Model

The position relationship between the \(A, B\) radar stations and the navigation satellite is shown in Fig. 2 \[8\]

![Time Synchronization Diagram of Navigation Satellite Common View Method.](image)

Figure 2. Time Synchronization Diagram of Navigation Satellite Common View Method.

For \(\rho_A, \rho_B\) are the real distances from the stations \(A, B\) to the navigation satellite respectively, \(\rho'_A, \rho'_B\) are the pseudo-distances between satellites and radar stations measured by local clock time at the same time, at \(A\) and \(B\) stations respectively, the satellite transmits signals at the time \(t_s\), and the two stations receive signals at the time \(t_A\) and \(t_B\) respectively, therefore:

\[
t_B - (t_s + \Delta t_{BS}) = \Delta B + (\text{ion}_B + \text{trop}_B) \tag{3}
\]

\[
t_A - (t_s + \Delta t_{AS}) = \Delta A + (\text{ion}_A + \text{trop}_A) \tag{4}
\]

In formula (3), (4), \(\Delta t_{BS}, \Delta t_{AS}\) are the clock difference between the clock and satellite at the stations \(A, B\) ; \(\text{ion}_A, \text{ion}_B, \text{trop}_A, \text{trop}_B\) are additional delays of ionosphere and troposphere to the stations \(A, B\); \(\Delta A, \Delta B\) are propagation delays between the satellites and the stations \(A, B\). Then, \(\Delta t_{AB}\) is the time difference between the stations \(A\) and \(B\), it can be expressed as:
\[ \Delta t_{AB} = \Delta t_{A5} - \Delta t_{B5} = t_B - t_A + \Delta A - \Delta B + (\text{ion}_A - \text{ion}_B) + (\text{trop}_A - \text{trop}_B) \]
\[ = \frac{\rho_A'}{c} - \frac{\rho_B'}{c} + \frac{\rho_A}{c} - \frac{\rho_B}{c} + (\text{ion}_A - \text{ion}_B) + (\text{trop}_A - \text{trop}_B) \]  
\[ \text{(5)} \]

In the formula, \( c \) is the speed of light. The time synchronization error can be obtained by using the above formula. Then the time synchronization of the two radars can be realized by compensating the time delay of the transmitted signals of the stations \( A, B \).

**Interference Method**

The navigation satellite is jammed by a combination of suppressed jamming and deceptive jamming. The function of suppressed jamming is to suppress the navigation satellite receiver signal in radar substation by transmitting strong jamming signal, so that the receiver cannot receive the satellite signal. The function of deceptive jamming is to make the radar substation receive the wrong information by transmitting false signals similar to navigation satellite. Forwarding deception jamming is usually used in practical use, because its technology is relatively easy to implement, and other signals are identical with navigation satellite except for different delay. Radar substation receivers are very easy to be deceived.

![Interference Method Diagram](image)

The principle block diagram of the interference method is shown in Fig. 3. Specific applications are described as follows: the jamming source first jams the radar substation with suppressed jamming, so that the navigation satellite receiver cannot receive the navigation satellite signal, and then the jamming source switches to the forward deception jamming, so that the receiver of the radar substation locks on the deception signal, and repeats this over a period of time. Thus effective interference is successfully realized.

The pseudo-range between the receiver and the navigation satellite is:

\[ \rho' = c(t - t_S + \Delta t + \tau) \]  
\[ \text{(6)} \]

In the formula, \( t \) is the ground receiving clock, \( t_S \) is the satellite clock, \( \Delta t \) is the propagation delay error and other errors, \( \tau \) is the time delay imposed on the jammer.

From the (5) and (6) formula, when the jammer imposes forward deception jamming on the stations \( A, B \), the time difference between the two stations \( A \) and \( B \) is as follows:

\[ \Delta t'_{AB} = \Delta t'_{A5} - \Delta t'_{B5} = \frac{\rho_A'}{c} - \frac{\rho_B'}{c} + \frac{\rho_A}{c} - \frac{\rho_B}{c} + (\tau_B - \tau_A) + (\text{ion}_A - \text{ion}_B) + (\text{trop}_A - \text{trop}_B) \]  
\[ \text{(7)} \]

In the formula (7), the time delays imposed by the jammers on the two stations are respectively. The added value of synchronization time error after jamming is obtained from the difference between formula (7) and formula (5).

\[ \Delta t'_{AB} - \Delta t_{AB} = \tau_B - \tau_A \]  
\[ \text{(8)} \]
Simulation Analysis

Simulation Results

Compiling MATLAB simulation program, taking the time interval of 20s, the real distance, station estimation distance, absolute estimation error (absolute positioning accuracy) and relative estimation error (relative positioning accuracy) of the target jammer at each time can be calculated respectively under different time synchronization errors. The simulation results of positioning accuracy are shown in tables 1-4.

Table 1. Location accuracy at 0.01s.

<table>
<thead>
<tr>
<th>T(s)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔR (m)</td>
<td>3.168</td>
<td>2.986</td>
<td>2.806</td>
<td>2.660</td>
<td>2.614</td>
<td>2.842</td>
<td>3.814</td>
<td>6.918</td>
<td>16.438</td>
</tr>
<tr>
<td>ΔR/R (%)</td>
<td>0.003</td>
<td>0.004</td>
<td>0.004</td>
<td>0.005</td>
<td>0.007</td>
<td>0.011</td>
<td>0.026</td>
<td>0.080</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Location accuracy at 0.1s.

<table>
<thead>
<tr>
<th>T(s)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔR (m)</td>
<td>31.63</td>
<td>29.80</td>
<td>28.00</td>
<td>26.53</td>
<td>26.09</td>
<td>28.42</td>
<td>38.29</td>
<td>69.87</td>
<td>166.91</td>
</tr>
<tr>
<td>ΔR/R (%)</td>
<td>0.033</td>
<td>0.035</td>
<td>0.037</td>
<td>0.039</td>
<td>0.043</td>
<td>0.050</td>
<td>0.066</td>
<td>0.111</td>
<td>0.813</td>
</tr>
</tbody>
</table>

Table 3. Location accuracy at 0.2s.

<table>
<thead>
<tr>
<th>T(s)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔR (m)</td>
<td>63.146</td>
<td>59.462</td>
<td>55.863</td>
<td>52.928</td>
<td>52.061</td>
<td>56.827</td>
<td>76.933</td>
<td>141.295</td>
<td>339.620</td>
</tr>
<tr>
<td>ΔR/R (%)</td>
<td>0.069</td>
<td>0.073</td>
<td>0.078</td>
<td>0.086</td>
<td>0.099</td>
<td>0.132</td>
<td>0.224</td>
<td>0.533</td>
<td>1.654</td>
</tr>
</tbody>
</table>

Table 4. Location accuracy at 0.5s.

<table>
<thead>
<tr>
<th>T(s)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔR (m)</td>
<td>125.822</td>
<td>118.403</td>
<td>111.164</td>
<td>105.291</td>
<td>103.671</td>
<td>113.694</td>
<td>155.361</td>
<td>289.120</td>
<td>703.477</td>
</tr>
<tr>
<td>ΔR/R (%)</td>
<td>0.138</td>
<td>0.146</td>
<td>0.156</td>
<td>0.170</td>
<td>0.198</td>
<td>0.236</td>
<td>0.452</td>
<td>1.091</td>
<td>3.425</td>
</tr>
</tbody>
</table>

Taking the time interval of 10s, the variation curves of positioning accuracy and simulation time under different Δt conditions are obtained as shown in Fig. 4, and the spatial three-dimensional estimation of the moving position of the target jammer is shown in Fig. 5.

Figure 4. Change curve of positioning accuracy and simulation time.

Figure 5. Spatial three-dimensional estimation of the moving position of the target jammer.

Simulation Analysis

From the figures and tables of the above simulation results, it can be seen that:

1. With the continuous movement of the target jammer, i.e. with the passage of simulation time, the positioning accuracy first increases slightly, then decreases gradually. As shown in Fig. 5, the change slope is smaller at the initial stage of the track, while it increases sharply at the end of the track. This shows that the positioning error has a cumulative effect. At the last moment of simulation time, the error is the largest.
(2) When the time synchronization error $\Delta t$ is small, the positioning accuracy of the target jammer is high. In Fig. 6, the "circle" and "pentagonal star" tracks basically coincide with each other and do not open the distance. But when the time synchronization error $\Delta t$ is large, the positioning error increases rapidly, and the "star" track in Fig. 6 obviously opens the distance with other tracks. This shows that the passive cross-location method of netted radar has a high positioning accuracy. In order to interfere with it effectively, it is necessary to produce large errors.

(3) The larger the location accuracy $\Delta t$ is, the worse the positioning accuracy is. Among them, when $\Delta t \leq 0.1s$, the positioning accuracy is smaller than 170m, which is shown in Fig. 6. But when $\Delta t > 0.1s$, the positioning error increases rapidly, and when $\Delta t = 0.5s$, the maximum error can reach 704m. If $\Delta t \geq 1s$, the maximum error will exceed 1000m. This shows that the method proposed in this paper is feasible. As long as enough time delay error can be generated by deceptive jamming, the netted radar can be jammed effectively.

Conclusion
Distributed netted radar has strong anti-jamming ability, especially its passive cross-location method has high accuracy. However, due to the distributed distribution of stations with large spacing, the problem of time synchronization among sub-stations will inevitably arise. In view of the weakness of time synchronization of netted radar, this paper proposes a deceptive jamming method by transmitting GPS navigation satellite signals, which makes the jammed radar sub-stations produce time synchronization errors, and achieves this goal. Effective jamming method for netted radar. The influence model of time synchronization error is established, and the principle of the interference method is analyzed. The simulation results verify the feasibility of the method. The method proposed in this paper can provide theoretical support and practical guidance for our troops to break through enemy air defense radar network.

References