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An Improved Hybrid Positioning Weighted Method for Low Altitude Target

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Abstract. On the basis of advantages of the DOA and TDOA methods in passive locating algorithm, DOA method is simple and less computation, but the precision is relatively poor; TDOA method has high precision, but the demand of time unification is very high for each observation station, the system is more complex, however the positioning error is high for low altitude target. So an improved hybrid positioning weighted method is presented, first we calculate the target localization by a master station and a secondary station measurement information in turn, then fuse several positioning results which calculate with different secondary station measurement information, through the introduction of appropriate weighting factor, to get the final radiation source location coordinates. The simulation result shows the effectiveness of the improved weighted method.

Keywords: DOA; TDOA; fusion; weight.

1. Introduction

With the unceasing development of passive location technology methods, using a single positioning method for radiation source target localization has been unable to meet the actual demand, the improvement of positioning accuracy 、 response speed increase highly. DOA(direction of arrival) method for three-dimensional localization of target only use two observation stations at the same time on site, but it just can guarantee low altitude positioning accuracy, meanwhile target positioning error is obvious at baseline and lateral border. Using TDOA(time difference of arrival) method for three-dimensional localization of target requires at least four observation stations, it can obtain higher positioning accuracy, but it has very strict requirement of time synchronization between each station, the system is more complex, computational amount is larger, but when the radiation source is located at low altitude, the target pitch angle is very small, TDOA accuracy is poor [4].So the combination of direction finding equipment and the measured time or frequency difference equipment is feasible to improve radiation source target localization precision, using a variety of positioning method advantage. For example, in order to solve low altitude precision problem, we can use the combination of DOA and TDOA, compensate inadequacy each other.1

2. Improved hybrid positioning method of DOA and TDOA

In order to obtain the better stability and positioning precision, first we can calculate the target localization by a master station and a secondary station measurement information in turn, using the basic analytical algorithm, then fuse several positioning results which calculate with different secondary station measurement information, through the introduction of appropriate weighting factor, to get the final radiation source location coordinates.

As an example, we deduce two stations solving the positioning results and error directly with the master station and first deputy station measurement information. Using the principle that half plane constituted by observed azimuth, conical surface formed by elevation angle and hyperbolic surfaces composed by distance difference can get the coordinates of the radiation source position provide columns of equation, we can

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obtain the following equations:

$$\begin{cases}\tan\theta_0 = \dfrac{y-y_0}{x-x_0} \\ \tan\varphi_0 = \left(\dfrac{z-z_0}{y-y_0}\right)\cdot\sin\theta_0 \\ \Delta r_1 = \sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2} - \sqrt{(x-x_1)^2+(y-y_1)^2+(z-z_1)^2}\end{cases} \qquad (1)$$

After simply strain consolidation, the formula (1) is changed as:

$$\begin{cases}x\tan\theta_0 - y = x_0\tan\varphi_0 - y_0 \\ y\tan\varphi_0 - z\sin\theta_0 = y_0\tan\varphi_0 - z_0\sin\theta_0 \\ (x_0-x_1)x+(y_0-y_1)y+(z_0-z_1)z = l + r_0\Delta r_1\end{cases} \qquad (2)$$

In which, $l = \frac{1}{2}\left[\Delta r_1^2 + (x_0^2+y_0^2+z_0^2)-(x_1^2+y_1^2+z_1^2)\right]$, $r_0 = \sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}$.

The formula (2) expressed in matrix form is that: $B\cdot X = H$ (3)

In which

$$B = \begin{bmatrix} 0 & \tan\varphi_0 & -\sin\theta_0 \\ \tan\theta_0 & -1 & 0 \\ x_0-x_1 & y_0-y_1 & z_0-z_1\end{bmatrix}, X=[x \quad y \quad z]^T, H=\left[y_0\tan\varphi_0 - z_0\sin\theta_0 \quad x_0\tan\theta_0 - y_0 \quad l+r_0\Delta r_1\right]^T.$$

Thus the positioning results can be obtained: $X = B^{-1}\cdot H$ (4)

The above calculation process use r_0 as the known quantity, the specific location coordinates can be gotten after taking r_0 expression into the specific analytic type. But the positioning error is large, depend only on the primary station and a secondary station, sometime it may emerge ambiguous position, at the same time the target coordinates is not sole. Generally we can use the positioning results negative of two stations to eliminate false location coordinates by select reasonable layout, or through the deputy station redundant direction information to eliminate. But these methods can not guarantee the positioning accuracy. Therefore, first we can calculate the target localization by a master station and a secondary station measurement information in turn, using the basic analytical algorithm, then fuse several positioning results which calculate with different secondary station measurement information, through the introduction of appropriate weighting factor $w_{x_{IJ}} = \frac{1}{\sigma_{x_{ij}}^2}(Dx)^{-1}$, to get relatively accurate radiation source location coordinates.

Then give weighted algorithm location accuracy analysis based on DOA and TDOA.

Taking positioning error analysis of master and first deputy station as the example, the remaining two deputy station are similar, seeking differential coefficient both sides at the same time for formula (1):

$$\begin{cases}d\theta_0 = -\dfrac{\sin^2\theta_0}{y-y_0}dx + \dfrac{\cos^2\theta_0}{x-x_0}dy + l_{\theta_0} \\ d\varphi_0 = -\dfrac{(z-z_0)\cos\theta_0}{r_0^2}dx - \dfrac{(z-z_0)\sin\theta_0}{r_0^2}dy + \dfrac{\cos\varphi_0}{r_0}dz + l_{\varphi_0} \\ d\Delta r_1 = (k_{1x}-k_{0x})dx + (k_{1y}-k_{0y})dy + (k_{1z}-k_{0z})dz + l_0 - l_1\end{cases} \qquad (5)$$

In which,

$$l_{\theta_0} = \frac{\sin^2\theta_0}{y-y_0}dx_0 - \frac{\cos^2\theta_0}{x-x_0}dy_0, \quad l_{\varphi_0} = \frac{(z-z_0)\cos\theta_0}{r_0^2}dx + \frac{(z-z_0)\sin\theta_0}{r_0^2}dy - \frac{\cos\varphi_0}{r_0}dz,$$

$$k_{ix} = \frac{x-x_i}{r_i}, k_{iy} = \frac{y-y_i}{r_i}, k_{iz} = \frac{z-z_i}{r_i}, l_i = k_{ix}d_{ix} + k_{iy}d_{iy} + k_{iz}d_{iz}, (i=0,1)$$

The formula (5) can be arranged into matrix: $dV = K\cdot dX + dX_S$ (6)

In which dV denote observation error vector, dX denote positioning error vector, dX_s denote position error vector.

Thus we get the master and first deputy station positioning error:

$$dX = K^{-1}(dV - dX_S) \qquad (7)$$

Then the corresponding positioning error covariance matrix:

$$P_{dX_1} = E\left[dX\cdot dX^T\right] = K^{-1}\left\{E\left[dV\cdot dV^T\right] + E\left[dX_s\cdot dX_s^T\right]\right\}K^{-T}$$

$$= \begin{bmatrix} \sigma_{\theta_0}^2 + \dfrac{\sigma_s^2}{(x-x_0)^2+(y-y_0)^2} & 0 & 0 \\ 0 & \sigma_{\varphi_0}^2 + \dfrac{\sigma_s^2}{r_0^2} & 0 \\ 0 & 0 & \sigma_{\Delta r_1}^2 + 2\sigma_s^2 \end{bmatrix} \quad (8)$$

Assuming that the observation error satisfies the zero mean, are not related and Gauss white noise, σ_{θ_0}、σ_{φ_0} in formula (8) denote azimuth angle and pitch angle measurement standard deviation error respectively, $\sigma_{\Delta r_1}$ denote master and first deputy station time difference measurement standard deviation error, each station position error is σ_s, and independent of each other.

Still use GDOP (geometric dilution of positioning error) to measure the positioning accuracy. Weighted fusion positioning error: $GDOP = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2}$ (9)

In which,

$$\sigma_x = (Dx)^{-\frac{1}{2}}, \sigma_y = (Dy)^{-\frac{1}{2}}, \sigma_z = (Dz)^{-\frac{1}{2}}, Dx = \sum_{i=1}^{3} \frac{1}{P_{dX_i}(1,1)}, Dy = \sum_{i=1}^{3} \frac{1}{P_{dX_i}(2,2)}, Dz = \sum_{i=1}^{3} \frac{1}{P_{dX_i}(3,3)}.$$

3. Simulation

Then we use Matlab to simulate for the improved hybrid positioning weighted method of DOA and TDOA, adopt three baseline combined positioning simulation embattling mode in literature [5]. Simulation conditions: four measuring stations, a master station and three side stations, using Y embattling mode, the master station coordinate is (0, 0, 0), three deputy stations coordinates are (86.6, 50, 0), (86.6, 50, 0) and (0, 100, 0), assumes that the target height is 5, setting station embattling error is 0.00005, azimuth angle and pitch angle direction error $\sigma_\theta = \sigma_\varphi = 0.5^o$ respectively, the standard deviation of time measurement error is 0.0006. According to improved weighted fusion method based on analytic algorithm, simulating in area of X:-200~200, Y:-200~200, so the experiment figure is:

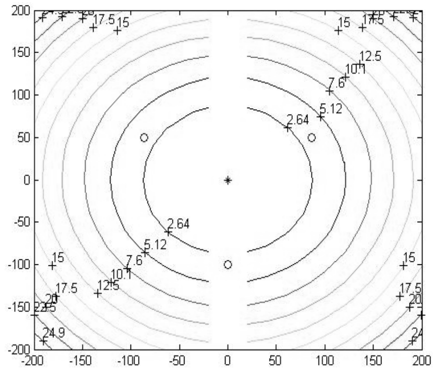

Fig. 1 GDOP contour map based on the improved hybrid positioning weighted method

If we change the location error, remaining other conditions unchanged, we can get the comparison of improved weighted method and three baseline positioning method shown as Table 1.

Tab. 1 Comparison of improved weighted method and three baseline positioning method

Measure	**Direction error**	**0.1°**	**0.2°**	**0.3°**	**0.4°**	**0.5°**
Improved weighted method	Precision	6.2	10.6	14.2	19.1	25.7
	Time consuming(s)	27.1	39.9	45.1	54.7	67.2
Three	Precision	28.2	32.5	37.9	44.6	50

baseline method	Time consuming(s)	63.2	88.1	95.4	113.9	133.3

At the same time we can get the locating invalid number with the effect of different methods shown as Tab. 2 and Tab. 3.

From the Fig. 1, contrasting with three baseline positioning results in literature [5], it can be seen that the improved weighted method GDOP distribution is symmetrical in location region, the GDOP apex reduce from 50 to about 26, positioning precision is improved obviously. At the same time we can see clearly from several tables, improved weighted method reduces time consuming effectively on condition that the precision is improved, and the locating invalid number are controlled under lower times.

Tab.2 The effect of different methods

Direction error	Locate invalid number	
	Improved	Three baseline
$\alpha = 0.1^O$	4	7
$\alpha = 0.2^O$	8	21
$\alpha = 0.3^O$	12	27
$\alpha = 0.4^O$	17	43
$\alpha = 0.5^O$	22	61

Tab. 3 The effect of different embattling mode

Embattling mode	Locate invalid number	
	Improved	Three baseline
Y shape	4	7
Star shape	6	10
Triangle shape	12	15

4. Conclusions

Base on the advantages and disadvantages of the DOA and TDOA methods in passive locating algorithm, we can combine the advantages to achieve better positioning effect. DOA method is simple and less computation, but the precision is relatively poor; TDOA method has high precision, but the demand of time unification is very high for each observation station, the system is more complex, at the same time positioning error is high for low altitude target. This article first studied commonly used positioning method which was combined of DOA and TDOA, on the basis of this, an improved hybrid positioning weighted method is presented based on weighted fusion algorithm. The simulation result shows the effectiveness of the improved weighted method, it has an certain significance for low altitude target radiation source.

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