Multi station TDOA location method based on improved artificial bee colony algorithm

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Abstract. In modern battlefield, passive location technology based on multi-station TDOA of UAV platforms has important application value, but the traditional Newton iteration algorithm requires higher initial value of iteration, and the positioning accuracy needs to be improved. We have found a new algorithm in our research, which is based on ABC algorithm, and is also a method used in UAV positioning system. Comparing with the traditional algorithm, simulation results of this algorithm indicate that it can remarkably improve the precision of TDOA passive location.

1. Introduction
The application of UAV is more and more widely in modern warfare. It is an important application of UAV to reconnaissance and localization of target radiation source[1]. Airborne passive location technology of multi-UAV is a key technology of target reconnaissance in future war, and therefore is of significant research value.

The most commonly used method of coordinated positioning of multiple UAVs is to calculate the time difference between the target emitter signals and the UAVs, and locate the UAVs by instant difference[2]. In this paper, four unmanned aerial vehicles (UAVs) are used as platform to analyze the principle and error of passive location with four-station TDOA. It is studied that the application of improved artificial bee colony algorithm in passive location with four-station TDOA. And compared with that of traditional Newton iteration algorithm by simulation, the positioning accuracy of this algorithm is of better performance.

2. TDOA location principle
Multi-aircraft TDOA positioning is a quadratic positioning method[3,4], which measures the time difference between the target emitter signal and the UAV receivers and can obtain at least three hyperboloids. The intersection of the three hyperboloids is calculated to achieve passive positioning of the target emitter. The schematic diagram of time difference passive location for four UAV platforms is as follows.
Figure 1. Schematic diagram of airborne four station TDOA passive location.

As shown in Figure 1, the coordinate position of the target emitter in the WGS-84 coordinate system is \( \mathbf{u} = [x, y, z]^T \), the coordinate positions of the four UAVs are \( \mathbf{s}_i = [x_i, y_i, z_i]^T \). For the sake of generality, the UAV \( S_1 \) is chosen as the host, and the distance between the target and the UAV receivers is obtained according to the arrival time.

\[
    r_i = \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2}
\]

The time difference of arrival is derived.

\[
    r_{i,1} = c d_{i,1} = r_i - r_1 + c n_{i,1}
\]

In formula (2), \( i = 2, 3, 4, c \) is the light speed, \( d_{i,1} \) is the time difference between the target source signal reaching the \( i \)th UAV and the first UAV, \( n_{i,1} \) as measurement noise.

The coordinates of the target radiation source can be obtained by solving the nonlinear equations (2).

3. Localization algorithm based on ABC

3.1. Principle of ABC algorithm

The basic ABC algorithm contains three kinds of bees: hired bees, observation bees and search bee. Suppose that in \( D \)-dimensional space, the population size is \( 2 \times N \) ( \( N_{\text{hired}} = N_{\text{observation}} = N \) ), the honey source corresponds to the hired bee, the location of the \( i \)th honey source is recorded as \( X_i = (X_{i1}, X_{i2}, \ldots, X_{iD}) \), which is a possible solution, \( i = 1, 2, \ldots, N \), and \( D \) represent the dimension of the problem to be optimized[5]. Generate \( N \) initial solutions according to the following formula:

\[
    X_{i,j} = X^U_j + \text{rand}_j (X^L_j - X^U_j)
\]

In formula (3), \( i = 1, 2, \ldots, N \), \( j = 1, 2, \ldots, D \), \( X^U_j \) and \( X^L_j \) are the upper and lower bounds of the \( j \) dimension. \( \text{rand}_j \) is the random number between \([0, 1]\) of the \( j \) dimension.

The traditional artificial bee colony algorithm is divided into 3 stages and circular search:
(1) Employment bee stage: each hired bee generates a candidate solution $V_i = (V_{i1}, V_{i2}, ..., V_{in})$ at the corresponding food source $X_i$ as formula 4. If $f(V_i) < f(X_i)$ ($f$ represents a function value, where the minimum value is taken as an example), replace $X_i$ with $V_i$, as follows:

$$V_{i,j} = X_{i,j} + \phi_{i,j}(X_{i,j} - X_{k,j})$$

(4)

In formula (4), $\phi_{i,j} \in [-1,1]$ represents a randomly selected number, $k \neq i$ represents a randomly selected food source, and $j$ is a randomly selected dimension.

(2) Observation bee stage: After the hired bee has completed the reconnaissance, the Observation bee randomly chooses a food source $i$ to further exploit according to the following probability:

$$P_i = F_i / \sum_{i=1}^{N} F_i$$

(5)

In formula (5), $F_i$ is the fitness of food source $X_i$. According to the formula, the more adaptable the food source, the easier it is to be found by the observed bees. And in the formula, $F_i = \begin{cases} 1/(1 + f_i) & f_i \geq 0 \\ 1 + \text{abs}(f_i), f_i < 0 &\end{cases}$, where $f_i$ is the objective function value of the $i$ solution.

(3) Search bee stage: Select the food source $X_i$ with the largest number of search failures and more than $l$ times in each cycle, and initialize it randomly with formula (3).

3.2. An improved ABC algorithm

Recently, an improved artificial bee colony algorithm is proposed by Laizhong Cui et al. in document[6](MGABC):

$$V_{i,j} = \begin{cases} X_{i,j} + \phi_{i,j}(X_{i,j} - X_{k,j}), \text{if } \rho < P \\ X_{i,j} + \psi_{i,j}(X_{best,j} - X_{i,j}), \text{others} \end{cases}$$

(6)

In the form, $0 < P < 1$, $\rho$ is the random number between $[0,1]$, $\psi$ is the random number between $[0,1.5]$, and $X_{best}$ is the global optimal solution. The algorithm avoids the oscillation problem of traditional ABC algorithm and is of better performance.

3.3. Time difference location algorithm based on ABC

The problem of multivariate nonlinear equations (2) can be solved by using maximum likelihood estimation for function minimization. Because the measurement of TDOA contains Gauss white noise, it can be regarded as Gauss data and approximately obeys normal distribution. According to the measurement value of TDOA, the distance difference between observation platforms can be obtained.

For random variables obeying normal distribution, $r_i - r_j$ is determined, and $n_{i,j} \sim N(0,\delta^2)$ obeys normal distribution. The corresponding maximum likelihood function is:

$$\prod_{i=2}^{N} \frac{1}{\sqrt{2\pi\delta}} \exp\left\{-\frac{(r_i - r_j)^2}{2\delta^2}\right\} = \left(\frac{1}{\sqrt{2\pi\delta}}\right)^{N-1} \exp\left\{-\frac{\Delta_{r,i} - (r_i - r_j)^T}{2\delta^2}\right\}$$

$$\left(\Delta_{r,i} - (r_i - r_j)^T\right)^T$$

(7)

$$\prod_{i=2}^{N} \frac{1}{\sqrt{2\pi\delta}} \exp\left\{-\frac{(r_i - r_j)^2}{2\delta^2}\right\} = \left(\frac{1}{\sqrt{2\pi\delta}}\right)^{N-1} \exp\left\{-\frac{\Delta_{r,i} - (r_i - r_j)^T}{2\delta^2}\right\}$$

And the maximum likelihood function is equivalent to the minimum value of the following function:

$$\hat{x}, \hat{y} = \arg\min_{(x,y)} \left\{\Delta_{r,i} - (r_i - r_j)^T, \Delta_{r,i} - (r_i - r_j)^T\right\}$$

(8)

The formula (8) is equivalent to the formula (9):

$$(x, y) = \min_{i,j} \left\{\Delta_{r,i} - (r_i - r_j)^T, \Delta_{r,i} - (r_i - r_j)^T\right\} = \min_{i,j} \left\{\sum_{i=2}^{N} \Delta_{r,i} - (r_i - r_j)^T\right\}$$

(9)
Formula (9) can be used as the objective function to solve the target position. The algorithm flow is shown in the figure 2.

**Figure 2.** Flow chart of improving artificial bee colony algorithm for locating equation.

### 4. Simulation comparison of positioning algorithm accuracy

In this section, the time difference positioning system composed of four UAVs is simulated to passively locate the radiation source of the fixed target on the ground. The positioning accuracy of the traditional Newton iteration algorithm and the improved ABC algorithm used in this study, is compared by analyzing the geometric accuracy factor (GDOP).

The coordinates of the four UAVs are as follows: \((10, 10, 20) \text{ km}, (10, 0, 20) \text{ km}, (20, 20, 20) \text{ km}, (0, 10, 20) \text{ km}\). The initial position of the target emitter coordinates is \((12, 25, 7) \text{ km}\), the baseline length of the UAV platform is \(10 \text{ km}\). The UAV self-positioning error is 10 meters, the positioning results of the two algorithms are as follows. In Figure 3 (a), the trend of GDOP with the distance between UAV and target is shown when the time measurement error is 10 ns. In Figure 3 (b), the trend of GDOP with time measurement error is shown when the distance between UAV and target is 30 km.
Figure 3. Simulation comparison of positioning algorithm accuracy.

Simulation results of the improved ABC algorithm show that it can significantly improve the accuracy of four-station TDOA passive location. Because of introducing the global optimal solution $X_{best}$, the error of falling into local optimum is avoided, and the initial value of the solution is not set as Newton's iterative algorithm.

5. Conclusion

In this study, the principle of TDOA location based on multi-UAV platform is described. And the improved ABC algorithm is adopted to solve the non-linear equations of multi-station passive location. The positioning precision of the Newton iteration algorithm and the algorithm is compared by simulation. Simulation results show that, compared with Newton iteration algorithm, the improved ABC algorithm in this study not only has better positioning accuracy, but also does not need to set the initial iteration value, which can meet the needs of UAV reconnaissance and positioning.

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