A Method of Constructing Mobile Ground Station Location System Based on Optimizing Algorithms

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Abstract. Aiming at the problem that the satellite navigation and positioning system can not cover the whole area and that the positioning accuracy of the existing ground-based reinforcement system decreases with the increase of the distance between the target and the ground station, a method for optimizing the positioning system of mobile ground station based on whale optimization algorithm is proposed. Based on the mobile ground station, the method identifies the positioning target with the optimal whale individual and the mobile ground station with other whale individuals, realizes that the position of the ground station varies with the position of the target point, and ensures the high precision positioning of the target in area with weak signals or without satellite navigation and without the support of the enhanced system. The feasibility of this method is proved by MATLAB, which provides a new way of thinking for solving the problem of regional target location.

1. Introduction
The accuracy of intelligence collection is based on the precise positioning of targets, which affects the analysis and judgment of operations, decision support and other links of armed police forces. The key to overcome the enemy in battlefield is to grasp the initiative of intelligence. With the development of the times, the Armed Police Force has shown the characteristics of a sharp increase in the types of tasks, uncertainties in time and place, and a wider range of implementation areas in carrying out diversified tasks. In order to meet the high requirement of information accuracy in the course of task execution, the existing navigation and positioning system must achieve accurate positioning in different environments. However, satellite navigation system is vulnerable to interference and occlusion, which leads to a sharp increase in positioning errors in buildings, urban canyons, underground and jungle, and even unable to provide positioning services [1]. Ground-based reinforcement system can compensate for the shortcomings of satellite navigation system to some extent, but because the ground station position of ground-based reinforcement system is fixed, its reinforcement effect will decrease with the increase of distance between target and ground station, and the site selection requirements of ground station are more stringent, the requirements of terrain, geology and surrounding environment are higher, and the terrain is complex in mountainous areas and the environment is harsh. Foundation reinforcement stations can not be built in desert plateau and other areas. Therefore, the idea of building a mobile ground station positioning system is put forward.
The mobile ground station positioning system combines the signal receiving and transmitting equipment with the modern mobile equipment. It deploys and changes the position rapidly according to the actual needs. It is easy to conceal, does not need to build a fixed station, has low requirements for the surrounding environment, and can realize the positioning system moving with the positioning target. It is a positioning system that ensures high precision positioning and can adapt to various harsh environments. However, before constructing the mobile ground station positioning system, the first problem to be solved is how to deploy the mobile ground station. Whale Optimization Algorithms (WOA) are a new intelligent optimization algorithm proposed in recent years. Its main idea is to determine the position of other whale individuals through the optimal whale location, so as to achieve global optimization. The purpose of this paper is to determine the location of ground stations based on the location of target points, which coincides with the main idea of whale algorithm. The target points to be located in the region are equal to the optimal whale individuals, and the ground stations are equal to other whale individuals. According to the location of target points, the deployment positions of ground stations are determined by using whale optimization algorithm. In order to solve the problem of how to deploy mobile ground stations, based on the maneuverability of various ground stations, the positioning system is constructed according to the regional needs, and the optimal layout of the current ground stations is always ensured at the target point, so as to ensure the high accuracy of the positioning system.

2. Introduction of related algorithms and techniques

2.1. Whale Optimization Algorithm
The whale optimization algorithm, proposed by Seyedali Mirjalili et al. in 2016, is a new intelligent optimization algorithm. It consists of three stages: random search stage, surround predation stage and bubble predation stage. Compared with classical particle swarm optimization, genetic algorithm and ant colony algorithm, WOA algorithm has the advantages of simple operation, few parameters and strong ability to jump out of local optimization, and has been widely used in solving practical problems.

2.1.1. Random search stage. In this stage, whales do not know where the food is, so they no longer update their position with the optimal whale location. Second, they randomly conduct a large-scale prey search to avoid falling into local optimum. The mathematical model is as follows:

\[
\overline{D} = \overline{C}, \overline{X}_{\text{rand}} - \overline{X} \quad (1)
\]
\[
\overline{X}_{r+1} = \overline{X}_{\text{rand}} - \overline{A} \times \overline{D} \quad (2)
\]

Among them, \( \overline{A} \) and \( \overline{C} \) are coefficient vectors; \( \overline{X}_{\text{rand}} - \overline{X} \) is a random reference whale position vector; \( \overline{X}_r \) is a current whale position vector; \( \overline{X}_{r+1} \) is a position vector to which the whale is about to move. The coefficient vectors are expressed as:

\[
\overline{A} = 2\overline{a} \overline{r} - \overline{a} \quad (3)
\]
\[
\overline{C} = 2\overline{r} \quad (4)
\]

\( \overline{a} \) is a linear decreasing vector from 2 to 0; \( \overline{r} \) is a random vector of [0,1]. When \( |A| \geq 1 \), the whale was in the stage of wandering and foraging; When \( |A| < 1 \), the whale was in the stage of surround predation and bubble predation.

2.1.2. Enclosure predator stage. When the whale finds food, all the individuals will approach the best whale in the current position and surround the prey. The mathematical model is as follows:
In the formula, $\vec{X}_t^*$ is the location vector of the current global optimal whale individual.

### 2.1.3. Bubble Predator Stage

Whales are approaching the optimal position in a spiral way. At the same time, they will generate bubbles to surround their prey and hunt. The mathematical model is as follows:

$$\vec{X}_{t+1} = \vec{D}e^{bl \cdot \cos(2\pi t\vec{l})} + \vec{X}_t^*$$

In the formula, $\vec{D} = |\vec{C}, \vec{X}_t^* - \vec{X}_t|$ is the distance vector from the individual whale to the present optimal position, $b$ is the shape helical constant and $\vec{l}$ is the random vector between [-1, 1].

A random variable $p$ is defined to distinguish the two stages of surround predation and bubble predation. Probability $p$ is used to surround predation and probability $1 - p$ is used to spiral predation. The specific mathematical model is as follows:

$$\vec{X}_{t+1} = \begin{cases} \vec{X}_t^* - \vec{A} \times \vec{D} & p < 0.5 \\ \vec{D}e^{bl \cdot \cos(2\pi t\vec{l})} + \vec{X}_t^* & p \geq 0.5 \end{cases}$$

### 2.2. Introduction of related technologies

The theoretical deduction formula of GDOP [6-8] is $GDOP = \sqrt{\text{tr}(H^T H)^{-1}}$, $H$ represents a matrix composed of direction cosine vectors from the target to the ground station. From the theoretical deduction formula, it can be concluded that GDOP has the following characteristics: it is the geometric amplification factor from measurement error to position calculation error, the smaller the GDOP value, the higher the positioning accuracy; GDOP is only related to the relative geometric layout of target and ground station. Therefore, by observing the GDOP value, the positioning accuracy of the positioning system can be evaluated intuitively. Generally, it is stipulated that the value of GDOP should not be greater than 5. If it exceeds 5, the result of positioning will be erroneous and unavailable.

TDOA [9-10] technology refers to the use of the difference of the time when the target signal arrives at the ground stations and the coordinates of the ground stations to obtain a set of hyperbolic equations for positioning. Each equation determines a hyperboloid in three-dimensional space, and the intersection of the hyperboloid is the location of the target. The most typical four-station positioning principle is introduced. The space target coordinates are $(x, y, z)$ and the four ground stations are $(x_0, y_0, z_0), (x_1, y_1, z_1), (x_2, y_2, z_2)$ and $(x_3, y_3, z_3)$. The positioning equations can be expressed as follows:

$$\Delta t_0 = c \sqrt{(x_0 - x)^2 + (y_0 - y)^2 + (z_0 - z)^2 - (x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2}$$
$$\Delta t_20 = c \sqrt{(x_0 - x)^2 + (y_0 - y)^2 + (z_0 - z)^2 - (x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2}$$
$$\Delta t_30 = c \sqrt{(x_0 - x)^2 + (y_0 - y)^2 + (z_0 - z)^2 - (x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2}$$

WOA algorithm mainly completes the pre-optimization of ground station location deployment. In its work, it must determine a fitness function as a criterion to judge the quality of the optimization results. The GDOP value is the geometric magnification factor of the measurement error to the position solution error. The smaller the GDOP value, the higher the positioning accuracy. Therefore, this paper takes the GDOP value as the fitness function of the WOA algorithm, uses the minimum GDOP value to guide the WOA algorithm to optimize the layout of the ground station, and evaluates
the results of the WOA algorithm intuitively by observing the GDOP value. Finally, according to the different time when the target signal arrives at the ground station, the location of the target point is solved by using TDOA technology.

3. Construction Scheme of Mobile Ground Station Location System Based on WOA Algorithms

The construction of mobile ground station positioning system can be divided into two stages: determining the deployment position of the ground station and the stage of maneuvering and setting up. Specifically, it can be summarized as the following steps:

- The target is equated with the best individual whale, and each ground station is equated with the individual whale. The position, size, dimension of the whale group (ground station) and the parameters required for the whale algorithm are initialized.
- The GDOP value is used as the fitness function of the whale algorithm, and the minimum GDOP value is used to guide the whale algorithm to get the best ground station deployment position in the region.
- According to the specific position coordinates obtained in step 2, according to the actual situation of the target area, the type, size and function of the signal receiving equipment are selected, and the combination of motorization, command vehicle, air transportation, personnel and machine carrying is adopted, the ground station can be quickly maneuvered and positioning system can be constructed.
- On the basis of several ground stations constructed in step 3, according to the time difference of arrival, the precise target location can be achieved by using TDOA multi-point positioning technology.

The scheme flow is as follows:

![Flow chart of system construction](image-url)

Figure 1. Flow chart of system construction
4. Simulation analysis

Assuming that a 400 km area in a mountainous area in Beijing is a battle area, there is no foundation reinforcement system near the mountainous area. Because of the dense vegetation and high canopy, the received satellite navigation signals are very weak, and the normal positioning service cannot be provided. A shelter in this area is taken as the target point (the Geodetic coordinates are (-2.177651563049443e+06, 4.388773767048367e+06, 4.070140665066030e+06)), to validate the positioning accuracy of the mobile ground station positioning system.

In the environment of MATLAB R2016b, considering the robustness of the positioning system in battle, the positioning accuracy of the system is verified by using 7-station positioning system. Firstly, the simulation experiment is used to locate the hut, and the results are shown as follows:

![Figure 2. Location error map](image)

In the figure, the red point represents the actual position coordinates of the building, and the blue point represents the position coordinates of the building obtained by the positioning system. The errors from the actual X, Y and Z coordinates of the building are 0.338m, 0.416m and 0.125m, respectively. In order to ensure the validity of the conclusion, 10 different target points are selected randomly to verify the positioning accuracy of the system. The positioning results and actual coordinate errors are shown in Table 1, unit m.

|   | X      | Y      | Z      |
|---|--------|--------|--------|
| 1 | 0.39   | 0.57   | 0.12   |
| 2 | 0.89   | 0.32   | 0.17   |
| 3 | 0.47   | 0.34   | 0.35   |
| 4 | 0.52   | 0.43   | 0.24   |
| 5 | 0.69   | 0.51   | 0.39   |
| 6 | 0.26   | 0.46   | 0.14   |
| 7 | 0.35   | 0.37   | 0.27   |
| 8 | 0.78   | 0.24   | 0.48   |
| 9 | 0.56   | 0.45   | 0.15   |
| 10| 0.38   | 0.39   | 0.22   |

From the above, the overall positioning error of the mobile ground station system based on the method in this paper reaches decimeter level, and the elevation error is the smallest, and the positioning error of a certain target point is not too large. However, nowadays, the general error of satellite navigation and positioning is meter level, which can only be reached decimeter level after processing. The result shows that the positioning accuracy of the positioning system is high and to a certain extent. It shows that the system improves the disadvantage that the positioning accuracy of the foundation reinforcement system decreases with the increase of the target distance.
5. Concluding remarks

Aiming at the problems that the satellite navigation and positioning system can not cover the whole area, the positioning accuracy of the ground-based reinforcement system decreases with the increase of the target distance and is easily destroyed in wartime, this paper proposes a method to construct a mobile ground station positioning system, and formulates a practical and feasible maneuvering scheme for different types of regions. Mobile ground station positioning system is also a supplement to satellite navigation and positioning system, and it can independently realize positioning. Its greatest advantage is the mobility of ground station, which can be built in real time according to needs. Compared with ground enhancement system, it has no stringent environmental requirements for station construction. It overcomes the shortcomings that positioning accuracy decreases with the increase of distance and can meet the increasing enlargement of armed police forces. And the requirement of positioning system in battle area with unknown environment.

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