Research and Design of Navigation Interference Source Positioning System Based on Unmanned Aerial Vehicle

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Abstract. Global Satellite navigation systems are widely used for their wide coverage and low operating costs. However, due to the use of MEO, IGSO and GEO satellites, the signal power received in land is low and susceptible to interference. Therefore, in order to ensure the normal use of GNSS, it is necessary to carry out research on the detection and positioning of navigation interference sources. In view of the problems of the existing ground interference source positioning equipments, such as weak maneuverability, small coverage, and high environmental dependence, this paper presents a design of a navigation interference source positioning system based on unmanned aerial vehicle(UAV), and researches its key technologies such as UAV trajectory planning. By carrying a direction-finding load on the UAV, interference sources can be located in the air. It has the advantages of strong maneuverability, large coverage, low environmental dependence, etc. It can quickly locate the interference source and is suitable for use in mountains, jungles and cities.

1. Introduction
Because of its wide coverage and low cost of use, satellite navigation system is widely used in various fields of society. For now, GPS, BDS, GLONASS and Galileo have provided free navigation and time services. The GPS satellites operate in orbit at an altitude of 20200 kilometers. The GLONASS satellites operate in orbit at an altitude of 19100 kilometers. The Galileo satellites operate in orbit at an altitude of 23222 kilometers. The BDS space segment consists of a number of satellites located in the Geostationary Earth Orbit (GEO) which is at an altitude of 35,786 kilometers, Inclined Geosynchronous Orbit (IGSO) which is at an altitude of 35,786 kilometers and Medium Earth Orbit (MEO) which is at an altitude of 21,528 kilometers. The signal power on ground is extremely low because of the distance. The minimum received power levels on ground of the GPS signals are specified to be -158.5dBW[1], the BDS signals are specified to be -163dBW[2], the GLONASS signals are specified to be -161dBW[3], the Galileo signals are specified to be -155dBW[4]. The signal strength equals to the light of a 25w bulb from 10000 miles away[5], so that the signal is highly susceptible to natural environment and human interference. The interference source of 1w power is likely to make the civil receivers completely paralyzed within the radius of 20 km scope[6]. In 1997, U.S. army formally put forward the concept of "Navigation Warfare"[7], which included the jamming and anti-jamming in satellite navigation system. Meanwhile, with the increasing of electromagnetic signals and navigation interference signal, the navigation signal received the serious influence.

There are three main methods of satellite navigation signal anti-interference. Firstly, improving the anti-interference ability to satellite signals, including to improve the transmitting power of satellite signal and adopt new navigation signal [8-9]; secondly, improving anti-interference ability to receiver, including to use the integrated navigation technology[10], such as the combination of GPS and INS.
(inertial navigation system), adaptive zero antenna adjustment[11], military code direct capture technology and so on; thirdly, shutting down or destroying the interference sources, including to detect and position the interference RF signal of the satellite navigation system. In the third method, the ground interference source positioning system and hand-held interference source positioning equipment are widely used. The ground interference source positioning system has the problems of weak mobility, long positioning time, high dependence of the environment, while the search process with the hand-held interference source positioning equipment is greatly affected by the ground environment. In order to solve the above problems and explore the feasibility of a new way to locate the interference source, this paper presents a design method and the key technologies of navigation interference source positioning system based on unmanned aerial vehicle(UAV). The system uses UAV to carry monitoring and direction-finding load to monitor and locate the interference signal in the air and has the advantages of strong maneuverability, large coverage, low environmental dependence, etc. It can quickly locate the interference source and is suitable for use in complex terrain, such as mountains, jungles, and cities.

2. The basic principle
The direction-finding technique is used to measure the arrival angle (incoming wave direction) of the interference source by the directional antenna or array antenna. The angle of arrival wave is related to the relative position between the coordinates of the interference source at a certain time and the direction-finding station (or machine). Triangulation is the most basic method. As shown in Fig. 1, using two (or more) direction-finding stations P1 and P2 configured on a known baseline, the direction line with azimuth is obtained after the direction finding of the interference source, and the intersection point of two or more direction lines is the geographical position of the interference source.

![Fig. 1 Schematic Diagram](image)

The navigation interference source detection and positioning system based on UAV can overcome the limitation of complex geographical environment, locate the interference source.

The UAV takes off in the disturbed area on the ground. According to the surrounding environment, the UAV is set up to a certain height. The antenna array is used to monitor and measure the direction of the RF signal. Multi-point intersection positioning can be used to determine the location range of the interference source and display it on the map. According to the initial positioning results of the interference source, the UAV can approach the interference source by manual control mode, or it can use the program guidance method to automatically set the tracking route. The UAV platform is equipped with camera equipment, and the image information can be transmitted back to the ground control station during the approaching, which is convenient for quickly determining the interference source.

3. System design

3.1. System composition
The navigation interference source positioning system based on UAV consists of three parts: UAV, aerial monitoring and direction-finding load and ground control station. As shown in Fig. 2.

Fig. 2 System composition diagram

### 3.2. UVA

The UVA as a monitoring platform, equipped with aerial monitoring and direction-finding load, PTZ, antenna and other equipment, mainly used for aerial maneuvering, has the characteristics of large load capacity and high stability, with basic remote control, tracking, hovering, automatic return home and other functions. Sufficient space is reserved between the fuselage and the landing gear for mounting larger pods and PTZ. At the same time, the UAV can also provide power for its own flight and payload. At present, mainstream UAV include fixed-wing UAVs, small multi-rotor UAVs, fixed-wing and multi-rotor hybrid UAVs, tethered UAVs, airships, and tethered airships. As shown in Table 1.

| UAV                       | Advantage                                                | Disadvantage                                      |
|---------------------------|----------------------------------------------------------|---------------------------------------------------|
| fixed-wing UAV            | Long battery life, wide range of activities, and fast flight speed | High price and complicated use                    |
| small multi-rotor UAV     | The price is moderate, vertical lift, hovering, high safety, easy to use | The carrying load less than 15kg, short battery life |
| fixed-wing and multi-rotor hybrid UAV | Long battery life, vertical lift and fast flight speed | High prices and no hovering                        |
| tethered UAV              | Long battery life, high safety                           | Lifting height less than 100m, limited range of motion, poor maneuverability |
| airship                   | Longer battery life, vertical lift and hovering          | High price, complicated use and high maintenance cost |
| tethered airship           | Longer battery life, vertical lift and hovering          | High price, complicated use and high maintenance cost |
3.3. Aerial monitoring and direction-finding load
As the core equipment for the detection and positioning of interference sources, the aerial monitoring and direction-finding load is composed of three parts: interference monitoring and direction-finding equipment, image acquisition equipment, and position acquisition equipment. Among them, the interference monitoring and direction-finding equipment includes a detection antenna array, an antenna selector, Multi-channel down-converter, signal processor and data transmission equipment, mainly complete the fixed frequency, frequency hopping and other signals monitoring and direction measurement and real-time return of monitoring data; image acquisition equipment including PTZ and camera, image transmission equipment, mainly completed Real-time photographing and image information of interference environment and interference source; location acquisition equipment includes electronic compass, GNSS+INS/MEMS equipment.

3.4. Ground control station
The ground control station mainly completes two works: one is to complete the control of the UAV and display the flight path; the second is to complete the real-time reception, processing and display of the interference signal. The hardware equipment of the ground control station mainly includes data transmission equipment, image transmission equipment, flight control terminals, monitoring computers, etc. The software includes flight control software and radio monitoring management software.

4. The Key Technology

4.1. Spectrum-based interference detection technology
Spectrum-based interference detection technology includes energy interference detection method and cyclic spectrum method. The principle of the energy detection method is to determine whether the interference signal exists by the energy of the received signal. Without knowing the relevant information of the interference signal, the energy detection method can quickly detect interference and is commonly used. The common interference signals in the GNSS frequency band mainly include narrow-band continuous wave, continuous sweep wave, 2FSK, BPSK, etc. These signals are periodic stationary signals in common, and the cyclic spectrum can be obtained through correlation operations, and then obtained after certain processing. The detection rate of cyclic spectroscopy is relatively slow, The cyclic spectrum method can distinguish the noise energy from the interference signal energy, but it is rate is relatively slow. Therefore, spectrum-based interference detection method can use energy method to quickly determine the interference signal strength, and then use the cyclic spectrum method to detect the type of interference signal.

4.2. High-precision direction-finding technology
The related interferometer direction-finding method can obtain the signal direction use the phase information of the signal received by the antenna, it has been widely used in the field of signal monitoring. In order to achieve high-precision direction-finding, based on the related interferometer direction-finding method, the high-precision direction-finding technology is studied from three aspects: optimized direction-finding algorithm, advanced true north measurement method and UAV calibration method. The antenna array with large aperture should be selected as far as possible.

(1) In order to reduce the error caused by the direction-finding algorithm of the related interferometer, precise phase extraction algorithm, efficient direction-finding correlation algorithm, accurate direction estimation algorithm and advanced sampling calibration technology are adopted.
(2) In order to reduce true north error, a high-precision electronic compass and an accurate magnetic deflection angle calculation method are adopted.
(3) In order to reduce the direction-finding error caused by the influence of the UAV’s flightis, advanced calibration antenna and electronic compass calibration method are adopted for rapid calibration.
4.3. UAV trajectory planning technology for interference source positioning

UAV equipped with interference source positioning devices adopt different positioning modes and route planning schemes at different flight stages, including overflight target positioning method and airborne multi-point direction-finding cross positioning method.

4.3.1. Overflight target positioning method and route planning

The overflight target positioning method is mainly used for the fast and accurate positioning of the close-range GNSS interference sources. During the UAV’s flight, the position of the signal source is determined according to the changes in signal strength around or above the interference source.

The symmetrical dipole antenna as interference source is used widely, its directivity diagram of three-dimensional and vertical are shown in figure 3. The interference signal is radiating around, but there is almost no signal above the antenna. The position of the interference source can be determined according to this feature.

Based on the above principles, as shown in Fig. 4, the trajectory planning scheme is designed as follows:

1. The UAV measures the intensity and direction of the radio signal at height H and position P0.
2. The UAV flies from P0 to P1, continuously monitors and tracks direction during the flight, and records the flight path.
3. During the path of P0 to P1, the interference source can be confirmed when the direction and intensity of the interference signal are significantly changed, and the position of the interference source(PS) can be obtained through the track record.

Fig. 4 Route Planning Chart
4.3.2. **Airborne multi-point direction-finding cross positioning method and route planning**

The multi-point direction-finding cross positioning method is mainly suitable for the fast positioning of UAV to the mid- and long-distance GNSS interference sources. The UAV performs direction-finding at different positions, and the position of the interference source is determined by the change of the direction-finding angle.

As shown in Fig.5, UAV measures the angle $\theta_1$ between the interference source and the horizontal direction at position 1 and moves to position 2 after a certain distance S, and measures the angle between the interference source and the horizontal direction to $\theta_2$. The angle $\phi$ between the UAV running track and the horizontal direction can be measured by the inertial navigation system or the satellite navigation system. Then the distance R between the interference source and the UAV can be calculated from distance S and angles $\theta_1$, $\theta_2$ and $\phi$. The relationship as follows:

$$
\begin{align*}
R_1 &= \frac{\sin(\theta_2 + \phi)}{\sin(\theta_2 - \theta_1)} S, \quad \theta_2 \neq \theta_1 \\
R_2 &= \frac{\sin(\theta_1 + \phi)}{\sin(\theta_2 - \theta_1)} S
\end{align*}
$$

According to the above formula, obtain the the angle and distance between the interference source and the UAV, then the position of the interference source relative to the UAV can be obtained. When the planned flight distance of UAV is much smaller than the direction-finding distance or flight direction on the connection between UAV and the interference source, then $\theta_1=\theta_2$ or $\theta_1=\theta_2$, R1 and R2 cannot be calculated accurately, and the position of the interference source cannot be determined.

In order to simplify the description of the planning model, let $\theta$ be the angle between two directions, and design the route planning according to the different measurement results of $\theta$ as follows.
Based on the above principles, the trajectory planning scheme is designed. The UAV flight altitude is $H$, and the initial trajectory planning is $P_0$ to $P_1$. At $P_0$ (initial direction-finding position), the interference signal is detected and direction-finding is performed. After flying for a certain distance $d$ according to the established cruise route to $P_1$, the direction-finding is performed, and the angle $\theta$ is calculated. (1) If angle is too small, the interference source cannot be accurately located, and the trajectory needs to be re-routed or alternately planned, as shown in Figure 8 (a); (2) If angle is moderate, the position of the interference source can be obtained by calculation, as shown in Figure 8(b); (3) If angle is small but not too small, UAV continues to fly to the $P_2$ position at a moderate angle, and calculate the position of the interference source, as shown in Figure 8(c); (4) If angle is too big, it is impossible to locate the interference source accurately. UAV needs to turn back to the $P_2$ position with a moderate angle to calculate the location of the interference source, as shown in Figure 8(d).
5. Conclusion
This paper proposes a design scheme for a navigation interference source positioning system based on UAV, and researches the key technologies such as the UAV trajectory planning. The system has the advantages of strong maneuverability, large coverage, low environmental dependence, etc. It can quickly locate the interference source and is suitable for use in mountains, jungles and cities.

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