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Dual-antenna multidimensional positioning algorithm based on positioning of disaster relief personnel

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Abstract. When facing a major disaster, firefighters and other rescue workers may also encounter certain dangers, which means certain protective measures are needed to ensure the safety of disaster relief personnel. Due to the complexity of the rescue environment, such as being blocked by obstacles or due to the influence of magnetic field, satellite positioning may not be used, and the position of the personnel in need of rescue can not be accurately located. On account of the above issues, we used search and rescue equipment and handheld terminals, and the dual antenna multidimensional positioning algorithm were also used to determine the position of firefighters in real time. Matlab was used for simulation, and error sources and error sizes were estimated,which ensured the safety of firefighters and provided timely help and rescue in case of firefighters' distress. After simulation, it can be concluded that in the case of large signal-to-noise ratio, the positioning accuracy is high and the positioning effect is pretty well.

Keyword: Disaster Relief, Dual Antenna Multidimensional Positioning Algorithm, Radio Ranging and Direction Finding, Satellite Positioning, Firefighters.

1. Introduction

Some major disasters have been occurring in recent years and firefighters are also faced with great danger during disaster relief. The magnitude of the challenges firefighters face in responding to disasters suggests that protections for firefighters also need to be timely updated. For major disasters, such as Forest Fires, Air Disasters, Earthquakes, etc., firefighters often get lost or go missing. These situations have attracted my attention to firefighters. We need to monitor the location of firefighters in real time and master their location information. Therefore, we measured the position of firefighters through the dual antenna multidimensional positioning algorithm, simulated the scene with matlab, researched the measurement direction and distance, and analyzed the error of the obtained direction and distance. The results of the research can make us be more careful and comprehensive for the safety protection of firefighters.

2. Main body

Literature review: the Multiple Signal Classification (MUSIC) algorithm invented by Schmidt et al. is an important representative of subspace algorithm research [1], and is also the earliest method of direction finding that using subspace. Since then, the resolution of the array direction finding calculation has been greatly improved, and it has become an important node in the history of ultra-high resolution

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direction finding calculation. MUSIC algorithm firstly solves the covariance matrix of the signal through mathematical analysis, and then decomposes and calculates its eigenvalues, and finally obtains the subinterval orthogonal to the two values of the signal noise. And the direction finding of receiving signal is carried out by the characteristics between them The advantage of MUSIC algorithm is that it is no longer constrained by Rayleigh Limitation,which means the resolution has been greatly improved. However, there are numerous disadvantages that still can not be ignored, such as its complexity of calculation, the large storage of array data-flow , and it can not get rid of the constructed array model. Roy et al. proposed the Rotational Invariant Techniques (Estimation of Signal Parameters via Rotational Invariant Techniques， ESPRIT)[2]. It makes use of the rotation invariant characteristics of each individual sub-array column structure obtained by partitioning to carry out signal direction finding, which avoids the high requirements of the hardware system due to the storage of array data-flow in MUSIC algorithm, and greatly reduces the computation amount.

The Wideband Spectral Subspace Algorithm researched in equally spaced array structure is an Incoherent Signal Subspace Algorithm（Incoherent Signal Subspace Method，ISM）[3], which is also proposed by Wax et al., aiming at the incoherent overlapping wideband information obtained by coherence detection. There is also Coherent Signal Subspace Method（Coherent Signal Subspace Method，CSM）[4], which is proposed by Wang et al. for coherent wideband signal direction finding obtained by coherence detection.The ISM algorithm is to cut the wideband signal into multiple narrowband signals through differential tought. However, its direction finding performance is poor, and there are problems such as large amount of calculation and complex operation. Moreover, too low SNR at a single frequency will have a great impact on the total DOA estimation, so this method cannot deal with wideband signals with low SNR. The advantages of CSM method include: less computation, more accurate, and can complete the DOA estimation of wideband coherent signal sources.

The non-equally spaced array is more practical in some applications compared with equally spaced array. The array aperture of the non-equally spaced array which has the same number of elements is several times that of the equally spaced array in theory, which has significantly improved the direction finding accuracy and angle resolution. The direction finding performance of non-equally spaced array is obviously better than that of equally spaced array, but the irregularity of the array also brings many issues. For example, the unreasonable setting of array elements in the array layout will make direction graph of the non-equally spaced array form grating lobes, resulting in the problem of angle blurring.

The array elements can be arranged arbitrarily on the principle of non-equally spaced array, but in practical engineering applications, there are mainly three categories: Minimum Redundancy Array (MRA), Nested Array and Co-prime Array. The concept of Minimum Redundancy Array (MRA) was first proposed by Moffett, which the arrangement of this array improves the freedom degree of array and expands the covariance matrix of the antenna array. On account of the good spatial structure of the Minimum Redundant Array, the equally spaced array obtained virtually is arranged more densely. However, the covariance matrix of the extended antenna array is limited by the given number of sampling snapshots, which means the improvement limitation of direction finding performance. Moffett extended the covariance matrix of the array and performed positive definite transformation, which further improved the performance of the spatial spectrum direction finding algorithm. However, the process of positive definite transformation of the covariance matrix requires multiple iterations, which was time-consuming and can only reach the local optimal value. Piya Pal proposed a nested array method, in which several subarrays are nested to form a new array. This design method can increase array aperture and enhance the freedom of array. Vectorizing of array covariance matrix by nested arrays [5] to eliminate the limitation of the minimum redundant array. But the nested array algorithm assumes that the signal is independent, so the design method of the nested array cannot be used for coherent source signal direction finding.

In this research, according to the practical application of MUSIC algorithm, the dual antenna multidimensional positioning algorithm is used to locate the required target under the premise of satellite positioning failure.

3. Methodology

3.1. Algorithms

The dual antenna multidimensional positioning algorithm measures the distance between the search-and-rescue personnel and the search-and-rescue personnel through the flight time of the signals between the search and rescue equipment and the handheld terminal. The MUSIC algorithm is used to decompose the signals received by the dual antennas into signal subspace and noise subspace. And the orthogonality of the two Spaces is used for direction finding and ranging [6].

Dual antenna multidimensional algorithm includes Ranging algorithm and Direction Finding algorithm.

3.1.1. Two-Way Ranging algorithm. The basic principle is that when an electromagnetic wave propagates in space, its phase changes linearly with the transmission distance. In ranging systems, the distance is usually calculated by finding the time taken by the signal to go back and forth. However, when the distance is longer, the signal is more likely to be affected during the transmission, leading to signal weakening and difficulty in receiving the signal. There are two solutions to improve this issue. One is to increase the power of the propagated signal, the other is to use the spread spectrum technology to increase the processing gain.

The spread spectrum ranging method selects the spread spectrum code with well periodic autocorrelation as the ranging scheme, which can effectively reduce the identification interference of search and rescue signals [7]. In the process of ranging, it is necessary to meet the condition that the period of the code sequence is longer than the time of the back and forth of the signal, otherwise it will lead to fuzzy targets and fuzzy distance in the measurement. In the spread spectrum ranging system, the distance between the transmitter and the receiver is calculated by calculating the time difference between the local sequence of the receiver and the arrival signal [8].

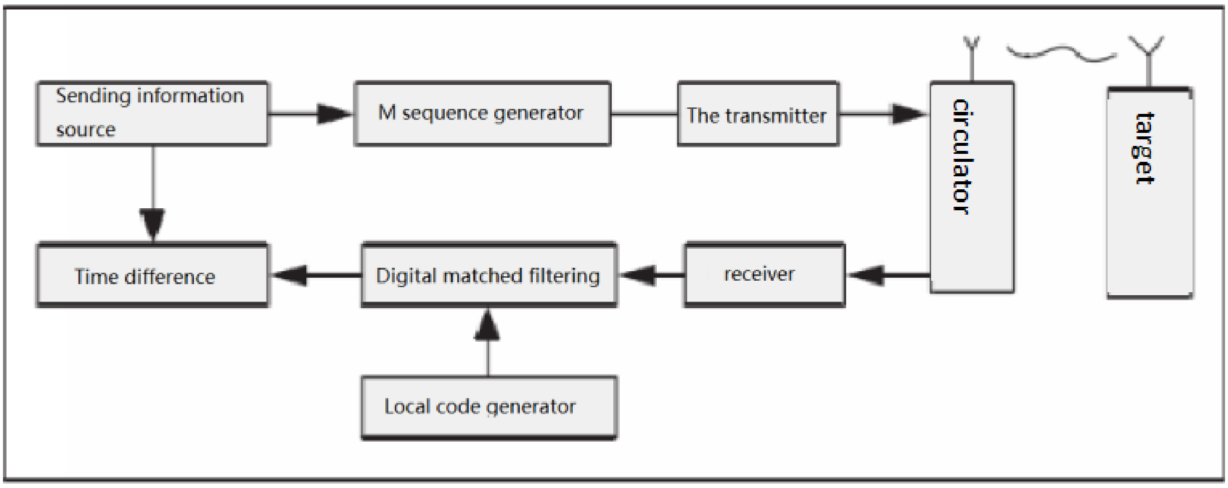

Figure 1. Signal processing process.

The specific principle of spread spectrum measurement is as follows: the information source is transmitted by the transmitter after spread spectrum and frequency modulation at the sending end, and the signal is transmitted by frequency conversion and recoding through the target to be measured.At the receiving end, the time difference between the signal transmitting and receiving is measured through down-conversion and de-expansion processing, so as to calculate the distance between the target to be measured and the transmitter [9].

$$\textit{Measuring Distance:} L = \frac{C}{2} * (T - \Delta t) \quad (1)$$

$$\textit{Ranging Accuracy:}\ \ P = \frac{C}{2} * (A + Af + Aj) \quad (2)$$

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Where: T is the arrival time, Δt is the target to be measured and local processing time, C is the speed of light, A is the width of the spreading code, Af is the measurement error of the transmission time, and Aj is the transmission time error of the target to be measured.

3.1.2. Dual Antenna Direction Finding Algorithm: The direction finding system uses a dual antenna array. Select one of the arrays and assume that its initial phase is 0. After receiving the radio signal, the antenna array element extracts the amplitude information of the signal, so as to obtain the covariance matrix of the received signal. Finally, the direction finding can be carried out through the mutual orthogonality between the two spaces [10].

The direction finding system uses a dual antenna array, so it can only find the direction of a single receiving signal at most. Assuming that the distress signal in space is a single frequency sinusoidal signal of 243MHz, the equally spaced linear array, which is dual array, is used for signal reception. The output signal of the array can be expressed as:

$$X(t) = AS(t) + N(t) \tag{3}$$

Where: $A = [A_1 \quad A_2]^T A_1$ is the steering vector of antenna 1 $A_2$is the steering vector of antenna 2S is the sampled data vector of distress signal$N(t)$ is a 2+1 dimensional matrix representing the noisy data vector of the array. Then start to calculate the output data covariance matrix of the array:

$$R_x = E[X(t)X(t)^H] = AE[S(t)S(t)^H]A^H + E[N(t)N(t)^H] \tag{4}$$

Assume that the sampling data within the observation time is L. Thus, the maximum likelihood estimation form of the output data covariance matrix Rx of the array can be obtained [11] :

$$\hat{R}_x = \frac{1}{L}\sum_{l=1}^{L} x(n_1)\, x^H(n_1) = \frac{1}{L}X^H X \tag{5}$$

Then carry out the eigenvalue decomposition of the measured $\hat{R}_x$. Therefore, the covariance matrix can be expressed as:

$$\hat{R}_x = U_S \sum S U_S^H + \sigma^2 U_N U_N^H \tag{6}$$

Where，$U_S = [u_1]$， $U_N = [u_2]$， $\sum S = \begin{bmatrix} \lambda_1 + \sigma^2 & 0 \\ 0 & \lambda_2 + \sigma^2 \end{bmatrix}$.Us is the same as the subspace spanned by the steering vector A:

$$span\{a(\theta_1), a(\theta_2)\} = span\{e_1\} \tag{7}$$

In practice, R_x cannot be accurately estimated, so the noise subspace U_N cannot be completely orthogonal to the array flow pattern matrix. It can be done to perform an eigenvalue decomposition on the maximum likelihood estimate $\hat{R}_x$ of R_x to obtain the estimate of U_N is $\hat{U}_N$. Then, the following function can be used to search the spectral peak, and the corresponding direction angle can be obtained [12]

$$\theta_{MUSIC} = arg \ \min_{\theta} a^H(\theta)\hat{U}_N\hat{U}_N^H a(\theta) \tag{8}$$

By inverting the above equation, the spatial spectrum under the dual antenna multidimensional positioning algorithm can be obtained:

$$P_{MUSIC} = \frac{1}{a^H(\theta)\hat{U}_N\hat{U}_N^H a(\theta)} \tag{9}$$

When the spectrum in the above equation reaches maximum value, it indicates that there is a incidence of signal in the direction corresponding to θ, which is the direction of the receiving signal of the distress signal.

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4. Analysis

The main reasons affecting the direction finding results in the actual direction finding search and rescue process are as follows: (1) The inherent error of the dual array antenna. (2) Interference in the spread of distress signals. (3) Error of dual channel inconsistency. (4) Error of direction finding calculation , etc. These errors are analyzed in detail below.

(1) The inherent error of the dual array antenna.

In the analysis of the previous parts, it is assumed that the array antenna used is omnidirectional and the gain is 1. But in the actual direction finding process, due to the technological issues in the manufacturing process of the antenna, the two antennas cannot be guaranteed to be identical and ideal omnidirectional antenna. Therefore, the amplitude of the signal received by the dual antennas is different

(2) Interference in the spread of distress signals.

The far-field signals received at the same time by different antenna array of the direction finding array are equal, while the signals received by the same antenna of the direction finding array at different times are correlated. Notwithstanding, in the application scene of multi aircraft cooperative search and rescue, the spread process of the distress signal is easy to be interfered by the electromagnetic signal. The distress signal is no longer the same and becomes unstable after receiving the interference, resulting in the instability and inaccuracy of the distress signal output by the direction finding array, which further affects the direction finding results.

(3) Error of dual channel inconsistency.

When the receiving channel of the direction finding array is amplifying and converting the distress signal, the hardware used in the receiving channel leads to the inconsistency of the signal processing result, which leads to the phase deviation after the signal processing. The phase difference between the output and input of the direction finding and search receiver designed in this system produces phase deviation. In the data processing module, the sampling accuracy of AD9361 in the sampling process is affected accordingly, and there will be errors in the acquisition and tracking after receiving the distress signal. These factors will affect the consistency of the two signals, leading to errors in the results of spatial spectral direction finding.

(4) Error of direction finding calculation.

In the process of direction finding calculation, that is, the decomposition of eigenvalues, the calculation of eigenvectors and the calculation of spatial spectrum peak of signal orthogonal processing, there will be calculation cumulative errors. In addition, the above three kinds of errors will also cause errors in the processed signal, resulting in a certain deviation in the final calculated signal direction angle.

The four kinds of errors can affect the signals processed by the data receiving module and the data processing module, and then affect the direction finding results of the dual channel direction finding array. The direction finding calculation error can be eliminated to a certain extent by means of mathematical average or curve fitting. The inherent error of dual array antenna, the error caused by the inconsistency of dual channel and the error caused by the interference in the process of distress signal transmission have great influence on the result of direction finding. Next, reasonable simulation parameters will be set for analysis.

Simulation Conditions: Assuming that the incident signal is a single-frequency sinusoidal signal, the direction of receiving wave is 20 ° and the signal frequency is set to 250MHz. After receiving the signal, perform amplification, filtering and frequency conversion processing. The sampling frequency f_s is set at 4.8KHz for 500 points of sampling,and array 3 and 4 in the given array are used to form a dual antenna array for direction finding. Considering the difference in the amplitude of the received signals caused by the inherent errors of the dual antennas, assume that the signal of antenna 1 is: $S_1 = \sin(2\pi ft)$ and the signal of antenna 2 is: $S_2 = 1.2\sin(2\pi ft)$. Due to the noise difference between the two antennas, the noise of antenna 2 is set to be 0.5dB higher than that of antenna 1. The signal to noise ratio (SNR) was set as -10DB-20dB, and the initial phase deviation of the antenna was set as 0 degree, 2 degree, 5 degree, 8 degree and 10 degree, respectively. 100 times of Monte Carlo simulation experiments were carried out in MATLAB to calculate the direction finding deviation and root mean square error under the corresponding situation.

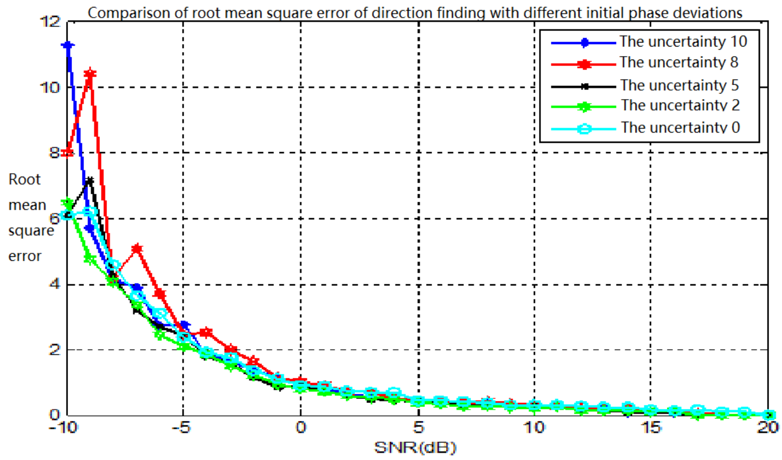

Figure 2. Root mean square error of dual channel direction finding.

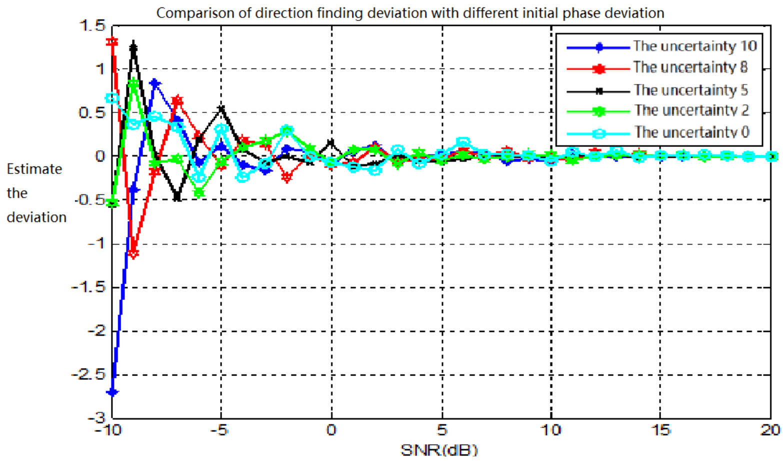

Figure 3. Dual channel direction finding deviation.

5. Discussion

The inherent error of the antenna is simulated in the simulation process by adjusting the amplitude difference of the received signal of the dual antenna. The interference received by the signal in the transmission process is simulated by superimposing different Gaussian noise on different received signals. The phase difference at the output of the dual channel receiver is not equal to the phase difference at the input, but a certain phase offset is superimposed. The phase shift caused by the inconsistent receiving channels is simulated by superimposing different initial phase deviations on the dual antenna signals in the simulation process. As can be seen from the simulation diagram, as a whole, with the increase of SNR, the direction finding accuracy of the direction finding algorithm gradually increases, and the direction finding results become more accurate. The size of the initial phase deviation has an impact on the accuracy of dual channel direction finding in the case of low SNR. The larger is the initial phase deviation, the larger is the direction finding error However, with the increase of SNR, the effect of the initial phase difference on the direction finding results gradually decreases.

Therefore, the positioning accuracy is high in the case of large SNR, whose positioning effect is very good. And they can be used as the safeguard measures for firefighters.

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6. Conclusion

This research studies the dual antenna multidimensional positioning algorithm for the positioning of firefighters. The conclusion obtained from MATLAB simulation is that the positioning accuracy and effect are high and pretty good in the case of large SNR. The existing disadvantage is that for coherent waves, the signals are too similar, and the positioning accuracy will be reduced. In the future, further studies will focus on solving the issue of interference between coherent waves to further improve the positioning accuracy.

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