Parameter Estimation of Target in Interference Localization Background in Impulse Noise Environment

Li Li
Information Engineering College
Information Engineering College
Dalian University
Dalian, China
ffsimple@163.com

Xiaofei Shi
Information Science and Technology College
Information Science and Technology College
Dalian Maritime University
Dalian, China
shi_xiao_fei_57@163.com

***Abstract*—This paper proposes an airplane parameter estimation algorithm based on the study of the problem of interference localization in impulsive noise environment. Firstly, an extended signal model to accurately estimate parameters of the target is proposed with Alpha-stable distribution model. A method of Doppler estimation based on the peak of the fractional lower-order power spectrum is proposed. The 2D-FLOS-MUSIC algorithm is applied to estimate the azimuth angle and elevation angle. The correctness and effectiveness of the proposed method are verified with the computer simulation.**

***Keywords*—interference localization; parameter estimation; 2D-FLOS-MUSIC; impulsive noise**

I. INTRODUCTION

With increase of radio stations quantity, the interfered probability of civil aviation radio frequency increases. It is key point how to make it safe operation of civil aviation radio frequency. Due to high flight height of civil airplane, signal coverage can reach hundreds of thousands of square kilometers. It shows that interference source in this coverage may influenced on flight safety. Especially, malicious interference has uncertainty of time and location, so monitor method in air can do nothing about it. Interference localization is realized by utilizing Doppler frequency shifts of the scattered signals from civil airplane in the receiver. [1] Proposes two algorithms to locate interference by scattered signals of civil airplanes. Two algorithms are achieved by the intersection of several zero-error contours and the comparison of theoretical and measured maximum cross-correlation values. [2] Proposes a Gaussian approximation particle filtering algorithm to locate interference in -stable distribution noise. The location information and velocity information of civil airplane are the prerequisite for localization interference in these literatures. If real-time state information of airplane is not obtained, interference localization is not realized. It is shown that accurate estimation of airplane state information is very important.

Furthermore, in most parameter estimation methods for array signal processing[7-9], additive noise is assumed to be Gaussian, which has finite second-order statistics[7]. In some scenarios, it is inappropriate to model the noise as Gaussian noise. Therefore, this paper develops a new wideband signal model in impulsive noise. This paper studies that parameter estimation in bistatic Multiple-Input Multiple-Output radar system in impulse noise environment.

II. THE EXTENDED SIGNAL MODEL

In this paper, the airplane tracking and localization is realized by employing the principle of parameter estimation in bistatic Multiple-Input Multiple-Output radar system[3-6]. Fig.1 illustrates a bistatic MIMO radar system. The considered bistatic MIMO radar is composed of M transmit antennas and N receive antennas with an interelement spacing of $\lambda/2$. D is the base line distance between the transmit reference element and the receive reference element. θ_{t} and φ_{t} are azimuth angle and elevation angle correspond to the transmit array. θ_{r} and φ_{r} are azimuth angle and elevation angle correspond to the receive array. The elevation angle θ_{t} and θ_{r} are measured counter clockwise from the x-coordinate axis of the coordinate system. The azimuth angle φ_{t} and φ_{r} are measured counter clockwise from the coordinate plane xoy of the coordinate system. The transmitting antennas emit orthogonal waveforms $x_m(t)$ for $m = 1,...,M$. The received signals contain time-variant Doppler due to the three dimension motion of airplane. If the cubic phase is ignored, the performance of parameter estimation and airplane tracking will degrade. This paper presents a new signal model for the bistatic MIMO radar system. The echo of the nth receiving antenna is

$$y_n(t) = \sum_{m=1}^{M} x_m(t)\exp\left(j2\pi f_d t\right) a_{tm}\left(\theta_t, \varphi_t\right) a_{rn}\left(\theta_r, \varphi_r\right) + w_n(t) \tag{1}$$

where f_d is Doppler frequency, $a_{tm}\left(\theta_t, \varphi_t\right) = \exp\left(-j\pi(m-1)\sin\theta_t \cos\varphi_t\right)$, $a_{rn}\left(\theta_r, \varphi_r\right) = \exp\left(-j\sin\theta_r \cos\varphi_r\right)\exp\left(-j\pi(n-1) + 2\pi D/\lambda\right)$. The noise $w(t)$ is a sequence of i.i.d isotropic complex $S\alpha S$ random variable with $1 < \alpha \le 2$.

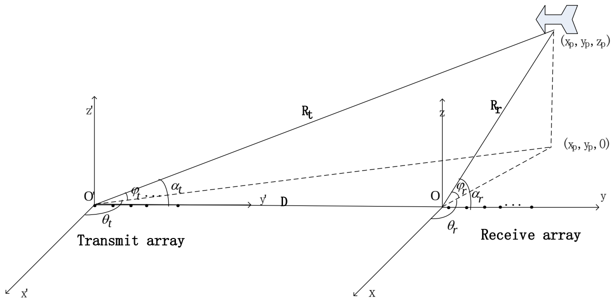

Fig. 1. Bistatic MIMO radar system

Since the transmitted waves are orthogonal with each other, there are $\langle x_q, x_k \rangle = 0, q \neq k$ and $\|x_q\|^2 = 1$, for $k = 1,...,M$ and $q = 1,...,M$. At each receiving antenna, these orthogonal waveforms can be extracted by M matched filters. The extracted signals by the q th matched filter can be expressed as

$$s_{mn}(t) = x_m(t)\exp(j2\pi f_d t)a_{tm}(\theta_t,\varphi_t)a_{rn}(\theta_r,\varphi_r) + w_n(t) \quad (2)$$

The vector of all output of M matched filter can be expressed as

$$\boldsymbol{S}(t) = \boldsymbol{A}D(f_d) + w_n(t) \quad (3)$$

where $\boldsymbol{A} = \boldsymbol{A}_t(\theta,\varphi) \otimes \boldsymbol{A}_r(\theta,\varphi)$, $\otimes$ is Kronecker product, $\boldsymbol{A}_t(\theta,\varphi) = [a_{t1}(\theta,\varphi),...,a_{tM}(\theta,\varphi)]^{\mathrm{T}}$, $\boldsymbol{A}_r(\theta,\varphi) = [a_{r1}(\theta,\varphi),...,a_{rN}(\theta,\varphi)]^{\mathrm{T}}$, $D(f_d) = \exp(j2\pi f_d t)$.

III. PARAMETERS ESTIMATION AND TARGET TRACKING

A. Doppler Estimation

Firstly, the spectrum analysis of the signal $s_{mn}(t)$ can be taken, A rough estimator of Doppler frequency is estimated by peak-searching in the Fourier transform domain. Secondly, M point refining is adopted to obtain Doppler frequency high-precision estimation. Next, Rife like frequency modificatory algorithm is adopted to obtain the estimator of Doppler frequency[4].

For two jointly $S\alpha S$ random variables X and Y with $1 < \alpha \leq 2$, their p th order fractional lower-order cross-correlation can be defined as

$$R_{xy}^p = [X,Y]_\alpha = E\left(XY^{\langle p-1 \rangle}\right),\ 1 \leq p < \alpha \quad (4)$$

where $Y^{\langle p \rangle} = |Y|^{p-1} Y^*$. p is the fractional lower-order moment. For $p = 2$, the fractional lower-order cross-correlation gives a regular second-order cross-correlation.

According to the literature[10], the equation (4) is processed by a Fourier transform. We can obtain the fractional lower-order power spectrum of random signal P_{xy}^p. The Doppler frequency is estimated by peak-searching of the fractional lower-order power spectrum.

B. Azimuth angle and elevation angle estimation

Both receive subarrays $\boldsymbol{R}_1$ and $\boldsymbol{R}_2$ constructed in this paper can be expressed by

$$\boldsymbol{R}_1 = [\boldsymbol{S}_{11} \quad \boldsymbol{S}_{12} \quad ... \quad \boldsymbol{S}_{1N}] = \boldsymbol{A}_r(\theta,\varphi)D + \boldsymbol{N}_1 \quad (5)$$

$$\boldsymbol{R}_2 = [\boldsymbol{S}_{1n} \quad \boldsymbol{S}_{2n} \quad ... \quad \boldsymbol{R}_{Mn}]^{\mathrm{T}} = \boldsymbol{A}_t(\theta,\varphi)D + \boldsymbol{N}_2 \quad (6)$$

The fractional correlation matrix $\boldsymbol{R}_{R_1R_1}^{(p)}$ of the subarray $\boldsymbol{R}_1$ is defined as

$$\boldsymbol{R}_{R_1R_1}^{(p)} = E\left\{\boldsymbol{R}_1\left[\boldsymbol{R}_1^*\right]^{\langle p-1 \rangle}\right\} \quad (7)$$

As the signal $\boldsymbol{D}$ is independent of the noise $\boldsymbol{N}$, (7) can be rewritten as

$$\boldsymbol{R}_{R_1R_1}^{(p)} = \boldsymbol{B}E\left\{\boldsymbol{D}\left[\boldsymbol{D}^*\right]^{\langle p-1 \rangle}\right\}\boldsymbol{B}^{\mathrm{H}} + \gamma_1\boldsymbol{I} = \boldsymbol{B}\boldsymbol{R}_{DD}^{(p)}\boldsymbol{B}^{\mathrm{H}} + \gamma_1\boldsymbol{I} \quad (8)$$

where matrix $\boldsymbol{R}_{DD}^{(p)}$ is the signal fractional covariance matrix, $\gamma_1 = \mathrm{E}\left\{N_1\left\{[BD + N_1]^*\right\}^{\langle p-1 \rangle}\right\}$ and $\boldsymbol{I}$ is the unit matrix.

Taking eigen value decomposition to matrix $\boldsymbol{R}_{DD}^{(p)}$, we can get

$$\boldsymbol{R}_{R_1R_1} = \boldsymbol{U}_D \sum\nolimits_D \boldsymbol{U}_D^{\mathrm{H}} + \boldsymbol{U}_N \sum\nolimits_N \boldsymbol{U}_N^{\mathrm{H}} \quad (9)$$

where the column vectors of $\boldsymbol{U}_D$ and $\boldsymbol{U}_N$ are the eigenvectors spanning the signal subspace and noise subspace of $R_{R_1R_1}$ respectively, with the associated eigenvalues on the diagonals of $\sum_D$ and $\sum_N$.

Spatial spectrum of 2D-FLOS-MUSIC can be obtained based on 2D-MUSIC algorithm, which can be expressed as

$$P(\theta_r,\varphi_r) = \frac{1}{\boldsymbol{A}_r^{\mathrm{H}}(\theta_r,\varphi_r)\boldsymbol{U}_N\boldsymbol{U}_N^{\mathrm{H}}\boldsymbol{A}_r(\theta_r,\varphi_r)} \quad (10)$$

Searching spectral peak of $P(\theta_r,\varphi_r)$, we can get the azimuth angle estimator θ_{r} and elevation angle estimator φ_{r}.

Similarly, spatial spectrum of 2D-FLOS-MUSIC of subarray $\boldsymbol{R}_2$ can be obtained based on 2D-MUSIC algorithm, which can be expressed as

$$P(\theta_t,\varphi_t) = \frac{1}{\boldsymbol{A}_t^{\mathrm{H}}(\theta_t,\varphi_t)\boldsymbol{U}_N\boldsymbol{U}_N^{\mathrm{H}}\boldsymbol{A}_t(\theta_t,\varphi_t)} \quad (11)$$

Searching spectral peak of $P(\theta_t,\varphi_t)$, we can get the azimuth angle estimator θ_t and elevation angle estimator φ_t.

IV. SIMULATION RESULTS

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

The considered bistatic MIMO radar is composed of $M = 6$ transmit antennas and $N = 8$ receive antennas with an interelement spacing of $0.5\mathrm{m}$. The base line distance between the transmit reference element and the receive reference element is $D = 5\text{Km}$. The azimuth angle and elevation angle correspond to the transmit array is $(\theta_r, \varphi_r) = (50, 20)$. Azimuth angle and elevation angle correspond to the receive array is $(\theta_t, \varphi_t) = (60, 30)$. Doppler frequency parameters are $f_d = 28.7939$. The sampling frequency f_s is 1MHz. Let root mean-squared errors (RMSE) of airplane localization is defined by $\text{RMSE} = \frac{1}{500}\sum_{k=1}^{500}\sqrt{(\hat{x}_p - x_p)^2 + (\hat{y}_p - y_p)^2 + (\hat{z}_p - z_p)^2}$, where $\hat{x}_p$, $\hat{y}_p$ and $\hat{z}_p$ are estimators of 3D coordinates of airplane. The number of Monte Carlo iterations is 500 in all simulations.

In order to study the robustness of the propose method, complex isotropic symmetric $\alpha-$stable $(S\alpha S)$ noise [15] model is considered. The characteristic function of a univariate $S\alpha S$ distribution is $\beta(\omega) = \exp\left(-\gamma|\omega|^{\alpha}\right)$, where $\alpha \in (0, 2]$ is the characteristic exponent. The smaller it is, the heavier the tails of the density are. The positive-valued scalar γ is the dispersion parameter of the distribution which plays a role analogous to that of the variance for the second-order process. We describe the signal-to-noise condition of $S\alpha S$ using the generalized signal-noise-ratio $\left(\text{GSNR} = 10\lg(\sigma_s^2/\gamma)\right)$, where, σ_s^2 is the signal power [11].

Simulation 1: The Characteristic exponent α

In this simulation, the signal to noise ratio is set as $SNR = 15\text{dB}$. Fig.2 to Fig.4 show the RMSE of the parameters of airplane estimates versus the number of snapshots.

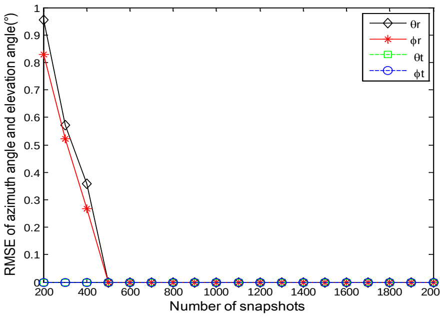

Fig. 2. RMSE of azimuth and elevation angle versus number of snapshots

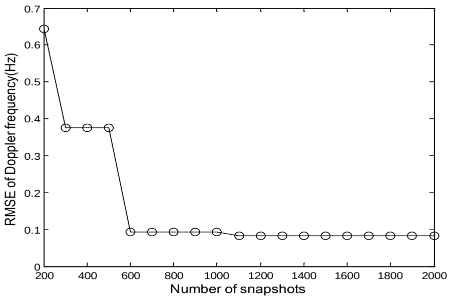

Fig. 3. RMSE of Doppler versus number of snapshots

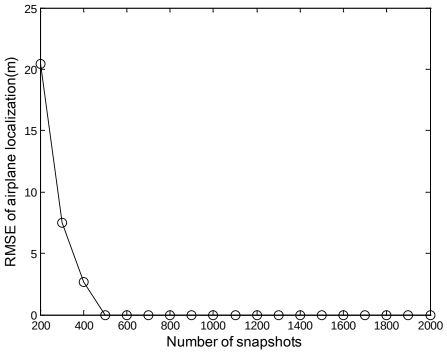

Fig. 4. RMSE of airplane localization versus number of snapshots

From these figures, we find that the RMSE of airplane parameters estimate decrease versus the increase of Number of snapshots. We also find that the RMSE tends to be stable when the number of snapshots $N_s \geq 600$. We adapt $N_s = 1000$ in the later simulations.

Simulation 2: Generalized Signal to Noise Ratio (GSNR)

Fig.5 –Fig.7 depict the RMSE as a function of SNR when $N_s = 1000$. From these figures, we find that the RMSE of airplane parameters estimate decrease versus the increase of SNR.

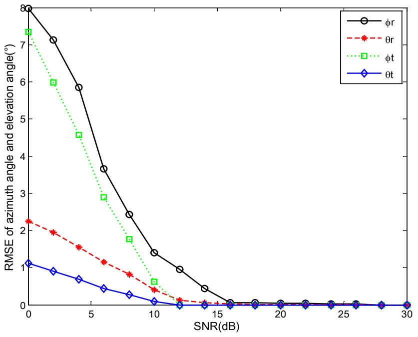

Fig. 5. RMSE of azimuth and elevation angle versus SNR

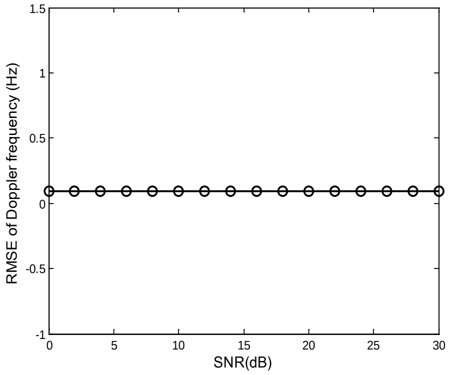

Fig. 6. RMSE of azimuth and elevation angle versus SNR

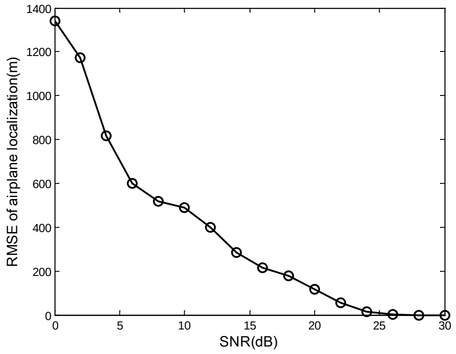

Fig. 7. RMSE of airplane localization versus SNR

V. CONCLUSION

Interference source can be localized in ground-air communication of civil aviation when moving state information of civil airplane is known. It is shown that accurate estimation of airplane state information is very important for interference localization. Aim at this research background, this paper proposes an extended signal model to accurately estimate parameters of the airplane in the impulse noise environment. 2D-FLOS-MUSIC algorithm is proposed to estimate the azimuth angle and elevation angle. The correctness and effectiveness of the proposed method are verified with the computer simulation.

ACKNOWLEDGMENT

This work was partly supported by the National Science Foundation of China under Grants 61401055 and the fund of Key Laboratory of marine management technology in State Oceanic Administration People's Republic of China under Grant 201504.

REFERENCES

[1] H.F. Tan, and J. Li, “Emitter locating algorithm by scattered signals of civil airplanes,” Radio communications Technology, vol.35, pp. 40-42, February 2009.

[2] T.S. Qiu, N. Xia, and J.C. Li, “An interference localization algorithm based on Gaussian approximation particle filtering with stable distribution noise,” Signal Processing, vol.28, pp. 1248-1253, September 2012.

[3] Y.S. Zhang, Y.D. Guo, G.Q. Zhao, and B.H. Wang, “Multitarget localization in three dimensions for MIMO bistatic Radar,” Journal of Electronics & Information Technology, vol.32, pp. 2820-2824, December 2010.

[4] F.B. Huang, and B.Z. He, “A carrier frequency accurate estimation algorithm for satellite signal,” Modern Electronics Technique, vol. 35, pp. 129-134, March 2012.

[5] S.L. Wu, J.Q. Luo, adn Y.J. Liu, “A method for recognition of spectrum peaks in 2-D MUSIC algorithm,” IEEE International Symposium on Microwave, Antenna, Propagation and EMC technologies for Wireless communications, vol.1, pp. 704-707, January 2005.

[6] J.F. Li, and X.F. Zhang, “Improved Joint DOD and DOA Estimation for MIMO Array with Velocity Receive Sensors,” IEEE Signal Processing, vol. 18, pp. 717-720, Decmber 2011.

[7] X.D. Zhang, “Modern Signal Processing (Second Edition),” Tsinghua University press, 2004.

[8] T. Tsao, M. Slamani, P. Varshney, and D. Weiner, “Ambiguity Function for a Bistatic Radar,” IEEE Transactions on Aerospace and Electronic Systems, vol.33, pp.1041-1051, March 1997.

[9] M.L. Yang, B.X. Chen, and F.L. Qi, “Ambiguity functions of multiple-carrier frequency MIMO radar,” Systems Engineering and Electronics, vol.31, pp.5-9, January 2009.

[10] S.H. Liu, S. Tao, R. Tao, Y.D. Zhang, G. Zhang; F. Zhang, and Y. Wang, “Sparse Discrete Fractional Fourier Transform and Its Applications,” *IEEE Transactions on Signal Processing*, vol. 62, pp: 6582 – 6595, December 2014.

[11] C.L. Nikias, and M. Shao, “Signal Processing with Alpha-stable Distribution and Application. New York: John Wiley & Sons, Inc, 1995.