A DOA Tracking Method of UCA Based on QPIO in the presence of Impulse Noise

Hongyuan Gao, Wanting Xie, Guojian Zang
College of Information and Communication Engineering
Harbin Engineering University
Harbin, P. R. China
gaohongyuan@hrbeu.edu.cn, xiewt532711258@163.com, zangguojian@hrbeu.edu.cn

***Abstract*-Direction of arrival (DOA) estimation and tracking play an important role in array signal processing applications. In order to achieve 360-degree DOA estimation and improve the accuracy and robustness of DOA tracking in the presence of impulse noise, a DOA tracking method of uniform circular array (UCA) based on quantum pigeon-inspired optimization (QPIO) algorithm is proposed. Experimental results illustrate that the tracking performance of novel method is more robust. The new DOA tracking method broadens the application scope of the DOA estimation and tracking.**

Keywords-direction of arrival tracking; uniform circular array; mode excitation; maximum likelihood; quantum-inspired algorithm; pigeon-inspired optimization

I. Introduction

Dynamic direction of arrival (DOA) estimation is also known as DOA tracking. Typical DOA estimation methods, such as the multiple signal classification (MUSIC) algorithm, the estimation of signal parameters via rotation invariance techniques (ESPRIT) and the weighted subspace fitting (WSF) algorithm, cannot be directly used to solve DOA tracking problem.

For DOA tracking problem, subspace tracking technique is the focus of research. Among these techniques, the projection approximation subspace tracking (PAST) algorithm [1] is widely used. But the research on recursive least squares (RLS) algorithm which is used to track the signal subspace in PAST shows that the RLS algorithm is susceptible to impulse noise and the subspace tracking performance of PAST will decline sharply [2]. In addition, simulations in [3]-[6] assume that the ambient noise is Gaussian noise. In fact, atmospheric noise, sea clutter noise, wireless channel noise and so on are impulse noise that can only be modeled by Alpha stable distribution. It is inevitable to study the DOA tracking method in the impulse noise environment. On the other hand, uniform linear array (ULA) is usually used in DOA tracking [2]-[4][6]. L-shape array is used in [5]. The existing DOA tracking method can only achieve 180-degree DOA estimation and tracking at most.

In order to achieve 360-degree DOA tracking in the presence of impulse noise, a new method of uniform circular array (UCA) based on quantum pigeon-inspired optimization (QPIO) algorithm is proposed in this paper. According to the experimental simulation results, the tracking performance of the new method is more robust when signal sources are coherent.

II. DOA Tracking Method of UCA based on QPIO

Uniform circular array (UCA) is used because of its special array structure which may find 360-degree direction of signal sources. For simplicity, it is assumed that all sources are coplanar with the array, so only azimuthal angle can be considered. The array manifold matrix of UCA is not a Vandermonde matrix. Mode excitation method [7] is applied by constructing a preprocessing matrix to transform a UCA into a virtual ULA.

Signal model after phase mode excitation at the k_{th} snapshot is defined as $z(k)$. Since the second and higher moments of the received signal do not exist under the impact of impulse noise, the weighted signal model is defined as

$$\overline{z}(k) = z(k) \big/ \max\left|z_i(k)\right|^{\delta}, \tag{1}$$

where δ is a constant. Hence, the fractional lower order covariance of the weighted signal (WSFLOC) is constructed as

$$\boldsymbol{C}_{\text{FLOC}} = \mathrm{E}[\overline{z}^{\langle p\rangle}(\overline{z}^{\langle p\rangle})^{\mathrm{H}}], \tag{2}$$

where $(\bullet)^{\langle p\rangle} = \left|\bullet\right|^{p-1}(\bullet)$, p is the WSFLOC parameter and $0 < p \le 1$.

However, the WSFLOC needs to be updated dynamically to track the DOA of the signal sources whose incident angle changes rapidly. The WSFLOC at the first snapshot is defined as

$$\boldsymbol{C}(1) = \overline{z}(1)^{<p>}(\overline{z}(1)^{<p>})^{\mathrm{H}}, \tag{3}$$

and the estimated WSFLOC at the $(k+1)_{\text{th}}$ snapshot is updated as

$$\boldsymbol{C}(k+1) = \mu\boldsymbol{C}(k) + (1-\mu)\overline{\boldsymbol{C}}(k+1), \tag{4}$$

where μ is update factor, $\boldsymbol{C}(k)$ is the WSFLOC of k snapshot data, $\overline{\boldsymbol{C}}(k+1)$ is the WSFLOC at the $(k+1)_{\text{th}}$ snapshot and it is defined as

$$\overline{\boldsymbol{C}}(k+1) = \overline{z}(k+1)^{<p>}(\overline{z}(k+1)^{<p>})^{\mathrm{H}}. \tag{5}$$

Then, a new maximum likelihood (ML) equation on the basis of the WSFLOC (WSFLOC-ML) can be derived as follows,

$$\hat{\boldsymbol{\theta}} = \arg\max_{\boldsymbol{\theta}} \operatorname{trace}[\boldsymbol{P}_{\boldsymbol{B}(\boldsymbol{\theta})}\boldsymbol{C}(k)], \tag{6}$$

$$\boldsymbol{P}_{\boldsymbol{B}(\boldsymbol{\theta})} = \boldsymbol{B}(\boldsymbol{\theta})[\boldsymbol{B}^{\mathrm{H}}(\boldsymbol{\theta})\boldsymbol{B}(\boldsymbol{\theta})]^{-1}[\boldsymbol{B}(\boldsymbol{\theta})]^{\mathrm{H}}, \tag{7}$$

where $\boldsymbol{\theta}$ is azimuthal angle of the narrow-band far-field sources, $\boldsymbol{B}(\boldsymbol{\theta})$ is a matrix which has Vandermonde structure, $\hat{\boldsymbol{\theta}}$ is the estimated value of the WSFLOC-ML equation.

Last, combination the pigeon-inspired optimization (PIO) algorithm [8] and the quantum computing, the quantum pigeon-inspired optimization (QPIO) algorithm is designed for obtaining the

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optimal solution of the WSFLOC-ML equation derived before. The difference with PIO is that each pigeon's quantum position $\boldsymbol{x}$ in the first stage can be updated as

$$\boldsymbol{x}^{t+1} = |\,\boldsymbol{x}^{t} \times \cos(\boldsymbol{v}^{t+1}) + \mathrm{sqrt}(1-(\boldsymbol{x}^{t})^{2}) \times \sin(\boldsymbol{v}^{t+1})\,|, \quad (8)$$

where t denotes the number of iterations, $\boldsymbol{v}$ denotes the pigeon's velocity. The pigeon's position $\bar{\boldsymbol{x}}$ is the mapping state of the quantum position $\boldsymbol{x}$, the mapping relationship between the two is

$$\bar{\boldsymbol{x}}^{t} = l(k) + \boldsymbol{x}^{t}[u(k) - l(k)], \quad (9)$$

where $u(k)$ and $l(k)$ are respectively upper and lower boundary of the angle search space at the k_{th} snapshot. The dynamic update method of the search space proposed in [4] is used to effectively reduce calculated amount of the multidimensional search.

Essentially, DOA estimation problem is the parameter estimation problem of azimuthal angle. The positions of pigeons denote potential solutions. Therefore, the fitness function of QPIO is

$$f(\bar{\boldsymbol{x}}) = \mathrm{trace}[\boldsymbol{P}_{\boldsymbol{B}(\bar{x})}\boldsymbol{C}(k)]. \quad (10)$$

The global optimal position outputted by QPIO is the estimated result. After that, the DOA estimation problem is transformed into the continuous optimization problem for searching the optimal position of QPIO.

III. Experimental Simulation Results

For verifying the validity of the method (WSFLOC-ML-QPIO) based on WSFLOC-ML and QPIO, simulations are designed in this section. Since there are few DOA tracking methods of UCA in the impulse noise environment, the FLOM-ML-CPSO proposed in [4] is selected as a comparison method in simulations. In all the simulations, the UCA of M omni-directional sensors with equal distance d is used, where $M=16$, $d=0.3\lambda$, λ is the signal wavelength.

Assuming that three signal sources are equal power, the first and the second signal sources are coherent, the third signal source is independent. Figure 1 shows the DOA tracking results of the FLOM-ML-CPSO and WSFLOC-ML-QPIO when $\alpha=1.5$ and GSNR=10, where α is characteristic exponent of Alpha stable distribution. It is shown that WSFLOC-ML-QPIO approximates the real value faster than FLOM-ML-CPSO within 100 snapshots. Around the 200_{th} snapshot, WSFLOC-ML-QPIO can better suppress the impact of impulse noise. It also can be seen that the error of the WSFLOC-ML-QPIO is smaller.

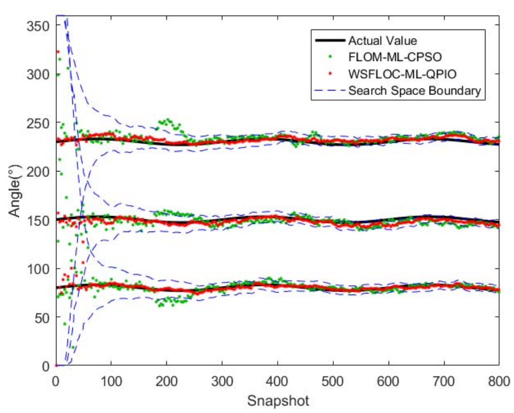

Figure 1. DOA tracking results of one independent source and two coherent sources

IV. Conclusion

WSFLOC-ML-QPIO of UCA is proposed in this paper to achieve 360-degree dynamic DOA tracking in the presence of impulse noise. Mode excitation method is used by constructing a preprocessing matrix to transform a UCA into a virtual ULA and then some methods that only work with linear arrays can be used. WSFLOC is constructed and WSFLOC-ML equation is derived to estimate the DOA. PIO algorithm combines with quantum computing to QPIO algorithm for fast obtaining the optimal solution of the WSFLOC-ML equation. Experimental simulations are designed to verify the effectiveness of the novel method, and the results compared with FLOM-ML-CPSO. In conclusion, WSFLOC-ML-QPIO has better DOA tracking performance.

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