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Wideband coherent sources localization based on a two-node distributed sensor networks

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ABSTRACT

In conventional research of source localization using sensor networks, usually many sensors were required, and only a small number of sources could be localized. Meanwhile it is still very hard to deal with coherent sources for conventional methods. In this paper, a new approach is proposed to localize wideband coherent sources based on a distributed sensors networks. For this sensor networks, only two node-arrays are required, and each node-array consists of only two sensors. Firstly, direction-of-arrivals (DOAs) estimation is done at each node-array by employing a new algorithm proposed in this paper, which can estimate DOAs of multiple wideband coherent sources only using two sensors. Next, combining the pattern matching idea and the prior geometrical information of sources, a cost function is constructed, and the localization problem is converted to obtain an optimal solution that minimizes the cost function. Combining the cost function and the estimated DOAs results of each node-array, multiple wideband coherent sources can be localized. Numerical examples are provided to demonstrate effectiveness of the proposed approach.

1. Introduction

In sensor networks, how to locate source (target) nodes is one of the fundamental tasks due to the importance of position information for many applications such as target tracking, intrusion detection, energy-efficient routing, monitoring, underground, deep water, outer space explorations, etc. [1]. In recent decade, some types of measurement approaches based on sensor networks, including time difference of arrival [2–6], angle of arrival [7,8] and received signal strength, and energy measurement-based [9–12] approaches have been proposed for source localization. Each sensor-node in the networks consists of one, a pair, or more sensors. The sensor-node with multi-sensors also can be called node-array.

When sensor-node consists of only one sensor, signal strength or energy measurement-based methods can be employed to localize sources. In [9], based on received signal strength observed by sensor-node of a wireless sensor networks, the authors first formulated the localization problem as the intersection computation of a group of sensing rings, and then converted this non-convex problem into two weighted convex optimization problems for source localization. In [10], the received signal strength (RSS)-based non-cooperative and cooperative localization problems were proposed, and authors applied convex relaxations that were based on second-order cone programming and semidefinite programming for non-cooperative and cooperative localization, respectively. In [11], the energy-based localization problem in wireless sensor networks was addressed, and a semidefinite relaxation method was proposed to solve this problem, then source localization was achieved. As mentioned above, methods based on convex optimization have become hotspots in the research of

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localization using sensor networks. In sensor networks, where node consist of a pair of sensors, the time difference of arrival (TDOA) often was measured at each node, then data fusion processing of TDOAs were done to locate source, especially for acoustic source localization [13–15]. When the node consists of multi-sensors whose number is more than two, the node can be uniform linear array (ULA) [8,16], uniform circular array (UCA) [17], or spherical array [18]. Based on each node-array, the direction-of-arrivals (DOAs) of sources can be estimated, and fusion processing of all DOAs can be employed for sources localization. Since there are enough sensors at each node-array, traditional approaches can be employed to obtain DOAs, such as subspace-based methods [8,18].

In general, the less sensors a sensor networks consists of, the lower hardware cost and complexity the networks will have. Moreover, the small number of sensors also implies lower communication traffic and power consumption for entire networks, and simpler design and implement of communication components. However in many literatures, many nodes were needed [4,6,13,14,19,32], and the number of sources considered often was small such as only one [2,9]. When considering multi-sources, there were often constraints on the characteristics of sources, such as the frequency spectrum of sources cannot be completely overlapped [15,19], even so, these methods fail to localize coherent sources. In practice, coherent signals present in the situations such as reverberation, multi-path, etc. It is also very hard to localize coherent sources for TDOA methods [4,6,13–15].

Besides, in many applications using sensor networks, the signals involved may be wideband, such as acoustic signals [13–15], ultra-wideband (UWB) radar signals [20–22]. Therefore the wideband signal processing for sensor networks has been an important research direction.

In this paper, a novel sources localization approach is proposed based on a distributed sensor networks. The network consists of only two nodes, and each node consists of only two sensors. Using the sensor networks, multiple coherent and uncorrelated source coexisting can be localized.

The remainder of this paper is structured as follows. In Section 2, a new algorithm is presented to estimate DOAs of multiple wideband coherent sources only using two sensors. Section 3 presents a new method to locate sources using sensor networks. The method is based on pattern matching idea and is also a data fusion approach of DOAs results. In Section 4, we provide simulation results to compare the performance of the new proposed DOAs estimation algorithm with conventional algorithm, and simulation results to show the accuracy for sources localization. Finally, in Section 5, we summarize the main conclusions. The following notations are used throughout this paper. $E\{\cdot\}$, $span\{\cdot\}$, $(\cdot)^*$, $(\cdot)^T$, $(\cdot)^H$, $\mathbf{R}$, $\mathbf{C}$ denote the expectation, subspace spanned by columns, conjugation, transpose, conjugate transpose, real domain and complex domain, respectively.

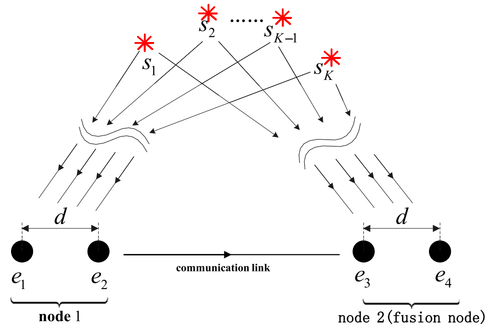

Fig. 1. Tow-nodes distributed sensor networks.

2. DOAs estimation at node-array

2.1. Signal model

In this paper, the distributed sensor networks consists of two nodes which are indexed as node 1 and node 2, and each node consists of two isotropic sensors, therefore each node is a node-array. Assume the distance d between sensors is small enough relative to the distance between sources and nodes, so far field model is considered, as illustrated in Fig. 1.

As showed in Fig. 1, one node is with fusion function and called fusion node. The information of other array-node can be transmitted to the fusion node by wired or wireless communication links for further processing. In [34], an uncorrelated model was presented using two sensors. We further reconstruct the model for coherent and uncorrelated wideband sources. In the distributed sensor networks, consider that each node-array is composed of two isotropic sensors which are indexed as e_1 and e_2, or e_3 and e_4 as illustrated in Fig. 1. There are K wideband source signals, $s_1, s_2, ..., s_K$, impinging on the two node-arrays from distinct directions $\{\theta_1, ..., \theta_K\}$ in the far field and the first L signals are mutually coherent, while the others are uncorrelated and independent of the first L signals. The noise is assumed to be uncorrelated with the signals and be white both temporally and spatially. Following analysis is only for node 1, analysis of node 2 is the same. The outputs of two sensors of node 1 can be modeled in frequency domain as

$$X_1(f) = \sum_{i=1}^{L} \beta_i s_1(f) + \sum_{j=L+1}^{K} s_j(f) + N_1(f)$$
$$X_2(f) = \sum_{i=1}^{L} \beta_i s_1(f) e^{j\varphi_i(f,\theta_i)} + \sum_{j=L+1}^{K} s_j(f) e^{j\varphi_j(f,\theta_j)} + N_2(f) \quad (1)$$

where $s_i(f)$ is the ith incident signal. $\beta_i = \rho_i e^{j\Delta\phi_i}$ denotes the amplitude fading factor and the phase difference of $s_i(f)$ related to $s_1(f)$ (without loss of generality, we assume $\rho_i = 1$, $\Delta\phi_i = 0$). $\varphi_i(f, \theta_i)$ is the phase difference of the ith signal. $N_1(f)$ and $N_2(f)$ are the additive noise in outputs of sensor 1 and sensor 2, respectively.

Assume each incident wideband signal can be decomposed into $2M+1$ sub-band signals in frequency domain by discrete-time Fourier transform (DTFT). The phase