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Ant intelligence inspired blind data detection for ultra-wideband radar sensors

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ABSTRACT

Given the computational complexity and sophisticated implementation of traditionally parametric channel estimators, it has been gradually recognized that the existing data detection methodologies based on the finite impulse response (FIR) propagation channel modeling may become infeasible for ultra-wideband (UWB) radar sensors, especially in some large-scale distributed scenarios. By exploiting the implicit information involved in the received signals, in this investigation, we present a non-parametric UWB data detection scheme for the distributed radar sensor networks. A novel characteristic representation is suggested first. From a pattern classification point of view, a group of quantitative features are then extracted by making full use of the inherent property of UWB propagations. Thus, UWB data detection is formulated as a pattern classification problem in a multidimensional feature space. By thoroughly utilizing the self-similarity of the representative patterns, the ant swarm intelligence inspired clustering algorithm, with the new designed ant movement strategy, is adopted to perform unsupervised data detections. The developed scheme is independent of any *a priori* modeling information, which essentially avoids the expensive parametric estimators and thus enables practically feasible realizations. To alleviate the computational burden, the principle component analysis (PCA) is further employed to compress the feature space. The simulation results validate the new algorithm, which is superior to the other popular non-parametric data analysis schemes.

1. Introduction

With the potential to provide extremely high-data-rate surpassing 1 Gbit/s, ultra-wideband (UWB) has long been considered as a candidate for the wireless data transmissions in future short-range applications [33,43]. Meanwhile, the distinguishing merits, e.g., precise ranging and material penetration, make UWB extremely attractive to specific military applications such as high-precision radars [19], through-wall target detection and homeland security [45]. Currently, with the rapid development of the internet of things (IOTs), UWB techniques also show great promise for the emerging large-scale distributed sensor networks [6] because the transmission strategies can be further optimized according to the estimated geographical/range information [34]. In the various scenarios, UWB radar sensors can be properly utilized to collect data or monitor environments, such as remote medical monitoring and water pollution sensing [46].

UWB impulse radio (UWB-IR) is one of the physical proposals considered for high-speed wireless connections. In sharp contrast to another transmission techniques, i.e., orthogonal frequency division multiplexing (OFDM), in UWB-IR, the emitted information bit is directly coded into the baseband pulses with short durations [38,39]. Due to the enormous emission

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bandwidth, which occupies several Gigahertz (GHz), data processing is of great significance to UWB-IR receivers. Unfortunately, the intensive multipath propagations posed great challenges to the design of low-complexity UWB receivers.

Within the framework of traditional coherent detection, which is in essence built on a parametric multipath channel modeling, e.g., the widely adopted finite impulse response modeling (FIR), the UWB receiver is expected to capture dozens of resolvable multipath components (MPCs) or estimate the complete FIR parameters (i.e., the time delays and amplitude weights of each resolvable MPC). Thus, channel estimation algorithms in such a case tend to be computationally unaffordable [11,25,41,43]. Meanwhile, the popular coherent detector requires a population of correlation fingers for the delayed MPCs, which could lead to considerable difficulties in hardware implementations [3,32]. As a consequence, the well-developed and *model-based* data processing architectures may generally become inapplicable to UWB radar sensors, especially for large-scale sensor networks that consider simple realizations. To overcome the challenges, the transmitted-reference (T-R) structure is introduced in Refs. [14,18]. Because the first dedicated reference pulse in TR carries no information, nevertheless, there is a remarkable degradation in transmission efficiency inevitably. More importantly, the accurate delay line in the TR structure is practically difficult to realize, resulting in the noticeably deteriorated detection performance.

Recently, the simplified parametric data detectors represented by energy detection (ED) have attracted intensive attention for their potential in low-complexity UWB radar sensors [5,41]. As a noncoherent method, ED can avoid the computational channel estimators accompanying RAKE structures by only concentrating on the received signal power other than the parametric channel impulse response (CIR). In addition, ED is relatively immune to practical imperfections, which thus enables the adoption of low-sampling-rate devices, further making the low-complexity UWB sensor nodes feasible [5]. By excluding the channel parameters, however, only the UWB signal power can be utilized, which may produce unsatisfactory detection performance. Moreover, as a noise sensitive method, the inaccurate estimation of noise power may also greatly deteriorate its performance in practice.

This work aims to reinforce the data detection performance and simultaneously address the great problems posed by classical parametric techniques, which are premised on the FIR channel modeling. By resorting to the unsupervised data clustering technique inspired by ant colony intelligence, we develop a *nonparametric* and *noncoherent* data processing scheme for distributed UWB radar sensor networks. Accordingly, our main contributions in this investigation may be twofold.

1. By exploiting the underlying information of UWB multipath signals, we first develop a novel characteristic representation of the received data samples. Then, from a promising data mining (or pattern classification) point of view, a group of distinguishing features are extracted from the derived characteristic waveform, which may thoroughly reflect the discrimination between the UWB data samples and the additive background noise. To simplify the computational complexity of subsequent processing by using the PCA technique, the established multidimensional feature space is compressed and projected to a two-dimensional (2-D) plane. Consequently, UWB data detection is formulated to *blindly* classify the two-group patterns on the established 2-D feature plane.
2. The clustering algorithm inspired by ant colony intelligence, with a newly designed and more efficient ant movement strategy, is properly adopted to perform unsupervised (or blind) data analysis in the 2-D representative feature space. With the PCA-based initial projection, the ant clustering scheme can blindly recognize the input pattern objects in a much more efficient way. Alternatively, given that the computation complexity of ant colony clustering increases linearly with the problem dimension, the full-space (or high-dimensional) ant clustering can be suggested to further promote detection performance by avoiding the information loss, which is inevitably caused by the PCA-based compression procedure. The presented scheme is independent of any *a priori* model information, which essentially avoids the computation-demanding parametric estimators, resulting in the practically feasible implementation. Another two popular pattern classification techniques, i.e., the blind fuzzy c-means (FCMs) and the supervised support vector machines (SVM), are also investigated for the purpose of comprehensive performance evaluations. Simulation derivations validate the presented algorithm, which is superior to the other non-parametric data analysis techniques.

The remainder of this article is outlined as follows. In Section 2, we briefly describe the typical UWB propagation model and formulate the traditional signal processing system model. We then develop a promising nonparametric data processing infrastructure for UWB radar sensors in Section 3. Two popular data classification algorithms are also introduced in this section. From a novel data mining/classification aspect, the ant colony intelligence inspired clustering algorithm, with a new-designed and more efficient ant movement strategy, is finally presented to realize blind data detection in the constructed feature space. Section 5 is dedicated to numerical simulations and performance evaluations. Finally, we conclude the whole investigation in Section 6.

2. UWB system model

According to the regulation of the US Federal Communications Commission (FCC), UWB generally refers to the communication systems with an absolute signal bandwidth of at least 500 MHz or a fractional bandwidth (i.e., its −10 dB bandwidth divided its center frequency) of larger than 20% [43]. By avoiding the sophisticated radio frequency (RF) processing, UWB signals can be conveniently generated by driving an RF antenna with extremely short pulses whose duration is on the order