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Nested sparse sampling and co-prime sampling in sense-through-foliage target detection

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ABSTRACT

This paper firstly introduces nested sampling and co-prime sampling, which were proposed recently, but have never been applied to real world target detection. We apply nested sampling and co-prime sampling to target detection in UWB radar sensor networks (RSN), based on a differential approach. The non-stationary UWB signal needs to be decomposed into several approximate wide sense stationary (WSS) signals so that nested sampling could be used in this situation. We also compare the performance of nested sampling and co-prime sampling against uniform under-sampling. The results show that in terms of good quality data and poor quality data, both nested sampling and co-prime sampling work better.

1. Introduction

Sub-Nyquist sampling has been studied for many years, because it can reduce the complexity and cost of computation significantly. Recently, two new algorithms for under-sampling are introduced [1,2], with potential applications in beamforming and Direction-of-Arrival (DOA). In [3], the author analyzed spectrum efficiency of these new algorithms. Because of its property in second-order statistics of the data, we want to prove these under-sampling methods would be helpful for detecting the target in the foliage environment.

Forests environment is a strong clutter background. The echo of the signal contains information about the target shape and environment, as well as a lot of interference, such as noise [4]. As a result, target-detection in the foliage situation is more challenging and requires extensive data to process. Besides, the channel in this environment is time-varying and non-stationary. Because the nested sampling is based on the premise of the wide-sense stationary signal, we propose a way solving the non-stationary of the channel so that nested sampling can work. Besides, in the existing works on UWB radar based target detection, some algorithms are overviewed [5]. Most of the works can be concluded in two ways, one is in the frequency domain and the other is in the time domain. [6,7] applied a DCT-based approach in the frequency domain to detect the sense-through-foliage target. Meanwhile, [8] mentioned a successful method in the time domain. Other theoretical works on radar sensor network target detection were reported in [9–12]. In this paper, based on the UWB indoor multi-path model (IEEE 802.12.SG3a, 2003) [13] and the differential method in the time domain, we use nested sampling to compress two sets of data, good quality data and poor quality data, to do the detection.

The rest of this paper is organized as follows. In Section 2, we give a brief overview of the experimental background. Then in Section 3, we introduce nested sampling and co-prime sampling. In Section 4, we present the target detection results of nested-sampling and uniform sampling in the case that the signal is good. In Section 5, we apply RSN with nested-sampling and uniform sampling when the signal is poor. The results of using

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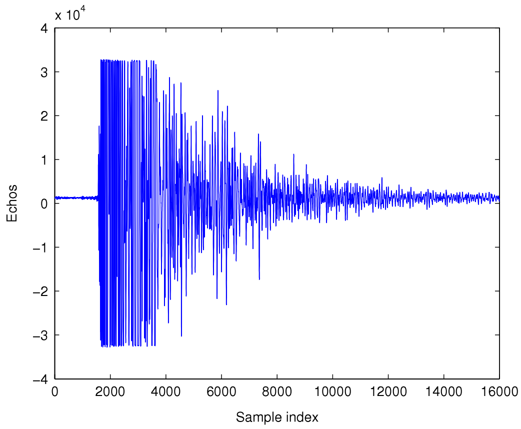
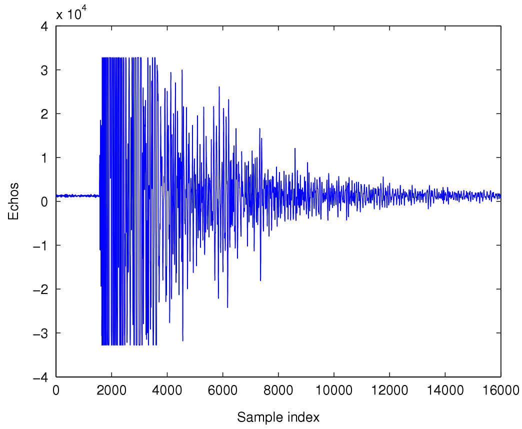
1874-4907/



(a) No target.



(b) With target.

Fig. 1. Measurement with very good signal quality and 100 pulses average. (a) No target on range, (b) with target on range (target appears at around sample 14,000).

co-prime sampling are described in Section 6. We give the conclusion in Section 7.

2. Sense-through-foliage experimental settings

Our data is from the experiment based on the radar-based sense-through-foliage in late summer and fall. The measurements were conducted by Virtual Machines Company in Holliston, Massachusetts [14]. Because of the limited rainfall, late summer foliage involved decreased water content. Late fall and winter measurements involved largely defoliated but dense forest. There are two sets of data used, good quality and poor quality. In Fig. 1, we plot the good quality signal with target and without target.

The experiment is constructed on a seven-ton man lift which had a total lifting capacity of 450 kg [15]. The principle pieces of equipment secured on the lift are: Barth pulser, Tektronix model 7704 B oscilloscope, dual antenna mounting stand, two antennas, rack system, IBM laptop, HP signal Generator, Custom RF switch and power supply and Weather shield (small hut).

Throughout this work, a Barth pulse source (Barth Electronics, Inc. model 732 GL) was used. The pulse generator uses a coaxial reed switch to discharge a charge line for a very fast rise time pulse outputs. The model 732 pulse generator provides pulses of less than 50 picoseconds (ps) rise time, with amplitude from 150 V to greater than 2 kV into any load impedance through a 50 Ω coaxial line. The generator is capable of producing pulses with a minimum width of 750 ps and a maximum of 1 μs. This output pulse width is determined by charge line length for rectangular pulses, or by capacitors for $1/e$ decay pulses. The interval of each sample is 50 ps, and each set of data contains 16,000 samples for a total time duration of 0.8 μs at the rate about 20 Hz. The Barth pulse source was operated at low amplitude and 35 pulses reflected signal were averaged for each collection. Some existing works on sense-through-foliage target detection based on these data were reported in [16–19].

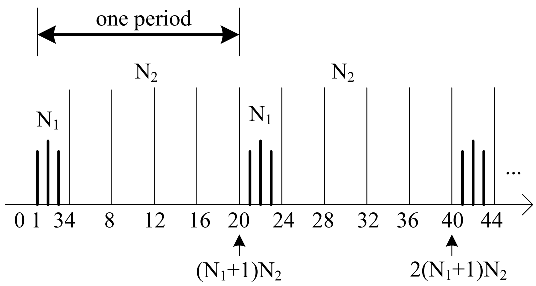


Fig. 2. Two-level nested sampling with $N_1 = 3$, $N_2 = 5$.

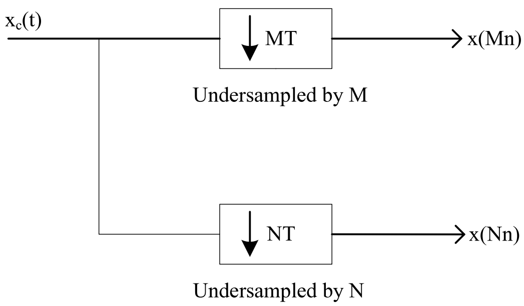


Fig. 3. Co-prime sampling in the time domain using M, N.

3. Nested sampling and co-prime sampling

In [2], it introduces nested arrays, a structure obtained by two or more uniform linear arrays. This structure can generate N^2 degrees of freedom with N physical sensors. Similarly, in [1], co-array can also generate MN freedoms with $M + N$ sensors. This property of nested sampling and co-prime sampling help us to compress the data of UWB radar echoes, without lose information in the data. We plot a two-level nested sampling in Fig. 2, with $N_1 = 3$ and $N_2 = 5$.

The level 1 samples and level 2 samples are separately located at N_1 and N_2, and satisfy

$$1 \le l \le N_1 \tag{1}$$

$$(N_1 + 1)m, \quad 1 \le m \le N_2. \tag{2}$$