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基于压缩感知的雷达信号处理应用研究

Study on Application of Compressive Sensing in Radar
Signal Processing

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摘要

当前各种雷达体制如相控阵雷达、宽带/超宽带雷达、合成孔径与逆合成孔径雷达等，都采用数字化处理技术从回波中提取目标参数信息。压缩感知理论能够用远低于奈奎斯特（Nyquist）理论的采样速率采集信号、获取离散数据，然后通过非线性重构算法重建信号，是信号处理领域的一个革命性突破。本文对压缩感知在雷达信号处理中的应用展开研究，拟解决目前雷达信号处理中存在的若干问题，主要内容有：

(1) 远程雷达及多目标跟踪的相控阵雷达对目标跟踪数据率较低，多普勒频率的估计存在模糊问题。本文采用了一种基于压缩感知的随机稀疏脉冲多普勒解模糊新方法。雷达系统只需随机发射稀疏的探测脉冲，通过设计相应的感知矩阵，运用压缩感知重构算法进行信号重建，从而获得无模糊的多普勒频率值。研究分析得出，应用中随机稀疏脉冲的发射时刻设置并非完全随机，还应考虑目标的观测数目和无模糊距离的影响。仿真表明，该方法可以解决远程雷达的多普勒模糊问题，而且大大节省了相控阵雷达的时间资源。

(2) 宽带雷达信号的应用需要高速的模拟数字转换器，造成雷达数据量剧增。本文通过采用宽带逆合成孔径雷达成像信号的方位向稀疏脉冲和距离向压缩采样相结合的方法，既节省了雷达时间资源，同时降低了信号采样率和存储传输代价。在成像时运用压缩感知重构算法重建原始信号，再对重构后的成像数据在距离向和方位向分别作信号预测，从而获得超分辨率的雷达图像。

(3) 低目标跟踪数据率也给远程雷达的微多普勒测量带来较大困难。本文对低脉冲重复频率条件下的微多普勒提取问题进行研究，提出了一种基于压缩感知的低 PRF 微多普勒提取方法。该方法仅需对雷达时间资源调度进行微调，通过发射随机探测脉冲串，然后对回波进行压缩感知信号重构和时频分析，获得雷达的微动特征曲线。仿真表明，压缩感知应用于微多普勒特征提取是可行的。

关键词：压缩感知；多普勒模糊；雷达成像；微多普勒

Abstract

Digital Radar Signal Processing is used for parameters extraction in most radar system such as Phased Array Radar, Broadband/Ultra Wideband Radar, Synthetic Aperture and Inverse Synthetic Aperture Radar. Compressive Sensing (CS) Theory with its advantage of sampling signal at a lower sampling frequency in comparison with the Nyquist theory, is getting the favor of signal processing field since put forward. In this paper, CS is applied in radar signal processing to solve some problems in Radar Signal Processing. The main contents are as follows:

(1) Usually Long Range Radar (LRR) and Phased Array Radar for multi-targets tracking are working at low Pulse Repetition Frequency (PRF). The data rate is too low to inquire unambiguous Doppler frequency. A novel method for Doppler ambiguity problem based on CS is proposed in this paper. Sparse pulses are randomly extracted from traditional fixed PRF, then a random perturbation item is added to the transmitting time of each selected pulses. With the transmitting time, a sensing matrix can be built and the whole target echo could be recovered via CS recovery algorithms. Then the unambiguous Doppler frequency will be estimated. As the random sparse pulse transmission time is not complete random, the effect of targets' number and the unambiguous distance should be considered. Simulations showed that the proposed method can not only solve LRR's ambiguous problem, but also save the Phased Array Radar's time resource.

(2) In broadband radar, high speed Analog to Digital converter is required, resulting in huge radar data. The application of CS in Inverse Synthetic Aperture Radar is investigated in this paper. Sparse pulses in azimuth direction and compressive sampling in range direction are combined to acquire targets information, and then the CS reconstruction algorithm is performed both in cross-range and rang directions to recover the whole radar echo which contain the targets' characteristics. In this way,

radar time resource is saved, and the signal sampling rate and the cost of storage are reduced. In addition, signal prediction processing can be operated to acquire super-resolution radar image.

(3) Working with low PRF also brings greater difficulties to the measurement of micro-Doppler in LRR. A novel micro-Doppler extraction method based on CS is proposed at the end of this paper. We just need to modify the time resource schedule of radar slightly and transmit random sparse probing pulses, then the micro-Doppler spectrum can be recovered via CS recovery algorithms. Experiment results show that it is feasible to apply the CS to micro-Doppler features extraction.

Key Words: Compressive Sensing; Doppler ambiguous; Radar image; Micro-Doppler

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