IEEE Transactions on Signal Processing (Issue 18, 19)

IEEE/ASME Transactions on Mechatronics (Issue 6)

Distributed Compressed Sensing for Static and Time-Varying Networks

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Abstract

We consider the problem of in-network compressed sensing from distributed measurements. Every agent has a set of measurements of a signal x, and the objective is for the agents to recover x from their collective measurements using only communication with neighbors in the network. Our distributed approach to this problem is based on the centralized Iterative Hard Thresholding algorithm (IHT). We first present a distributed IHT algorithm for static networks that leverages standard tools from distributed computing to execute in-network computations with minimized bandwidth consumption. Next, we address distributed signal recovery in networks with time-varying topologies. The network dynamics necessarily introduce inaccuracies to our in-network computations. To accommodate these inaccuracies, we show how centralized IHT can be extended to include inexact computations while still providing the same recovery guarantees as the original IHT algorithm. We then leverage these new theoretical results to develop a distributed version of IHT for time-varying networks. Evaluations show that our distributed algorithms for both static and time-varying networks outperform previously proposed solutions in time and bandwidth by several orders of magnitude.

The Restricted Isometry Property for Banded Random Matrices

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Abstract

In this paper, we investigate the problem of determining the conditions under which the restricted isometry property (RIP) is satisfied for a particular type of matrix referred to in here as a banded random matrix (BRM). Such matrices have been recognized as suitable models for a number of compressive-sensing based sampling architectures, including the interleaved random demodulator, the random demodulator, the parallel non-interleaved random demodulator, the random sampler, and the periodic nonuniform sampler. It is thus important to establish the conditions under which the BRM satisfies the RIP; to our knowledge, this question has not been theoretically addressed in the literature. If the resulting conditions are satisfied, full signal recovery using a convex optimization algorithm is guaranteed. The specific objective of this research is to determine the conditions under which the RIP is satisfied for two possible sampling matricies: a BRM and a BRM multiplied by the discrete Fourier matrix.

A Linear Source Recovery Method for Underdetermined Mixtures of Uncorrelated AR-Model Signals Without Sparseness

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Abstract

Conventional sparseness-based approaches for instantaneous underdetermined blind source separation (UBSS) do not take into account the temporal structure of the source signals. In this work, we exploit the source temporal structure and propose a linear source recovery solution for the UBSS problem which does not require the source signals to be sparse. Assuming the source signals are uncorrelated and can be modeled by an autoregressive (AR) model, the proposed algorithm is able to estimate the source AR coefficients from the mixtures given the mixing matrix. We prove that the UBSS problem can be converted into a determined problem by combining the source AR model together with the original mixing equation to form a state-space model. The Kalman filter is then applied to obtain a linear source estimate in the minimum mean-squared error sense. Simulation results using both synthetic AR signals and speech utterances show that the proposed algorithm achieves better separation performance compared with conventional sparseness-based UBSS algorithms.

Joint Sparse Recovery Method for Compressed Sensing With Structured Dictionary Mismatches

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Abstract

In traditional compressed sensing theory, the dictionary matrix is given a priori, whereas in real applications this matrix suffers from random noise and fluctuations. In this paper, we consider a signal model where each column in the dictionary matrix is affected by a structured noise. This formulation is common in direction-of-arrival (DOA) estimation of off-grid targets, encountered in both radar systems and array processing. We propose to use joint sparse signal recovery to solve the com- pressed sensing problem with structured dictionary mismatches and also give an analytical performance bound on this joint sparse recovery. We show that, under mild conditions, the reconstruction error of the original sparse signal is bounded by both the sparsity and the noise level in the measurement model. Moreover, we implement fast first-order algorithms to speed up the computing process. Numerical examples demonstrate the good performance of the proposed algorithm and also show that the joint-sparse recovery method yields a better reconstruction result than existing methods. By implementing the joint sparse recovery method, the accuracy and efficiency of DOA estimation are improved in both passive and active sensing cases.

A Measurement Rate-MSE Tradeoff for Compressive Sensing Through Partial Support Recovery

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Abstract

We consider the problem of estimating sparse vectors from noisy linear measurements in the high dimensionality regime. For a fixed number k of nonzero entries, we study the fundamental relationship between two relevant quantities: the measurement rate, which characterizes the asymptotic behavior of the dimensions of the measurement matrix in terms of the ratio m/log n (with m being the number of measurements and n the dimension of the sparse vector), and the estimation mean square error. First, we use an information-theoretic approach to derive sufficient conditions on the measurement rate to reliably recover a part of the support set that represents a certain fraction of the total vector power. Second, we characterize the mean square error of an estimator that uses partial support set information. Using these two parts, we derive a tradeoff between the measurement rate and the mean-square error. This tradeoff is achievable using a two-step approach: first support set recovery, and then estimation of the active components. Finally, for both deterministic and random vectors, we perform a numerical evaluation to verify the advantages of the methods based on partial support set recovery.

Cooperative Distributed Source Seeking by Multiple Robots: Algorithms and Experiments

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Abstract

We consider the problem of source seeking using a group of mobile robots equipped with sensors for source concentration measurement. In the formulation, the robot team cooperatively estimates the gradient of the source field, moves to the source by tracing the gradient-ascending direction, and keeps a predefined formation in movement. We present two control algorithms with all-to-all and limited communications, respectively. For the case of all-to-all communication, rigorous analytic analysis proves that the formation center of the robots converges to the source in the presence of estimation errors with a bounded error, the upper bound of which is explicitly given. In the case of limited communication where centralized quantities are not available, distributed consensus filters are used to distributively estimate the centralized quantities, and then embedded in the distributed control laws. Numerical simulations are given to validate the effectiveness of the proposed approaches. Experimental results on the E-puck robot platform demonstrate satisfactory performances in a light source seeking application.

Experimental Investigation of Robust Motion Tracking Control for a 2-DOF Flexure-Based Mechanism

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Abstract

The design, parameter identification and robust motion tracking control of a two degree of freedom (2-DOF) flexure-based micro/nanomechanism are presented in this paper. In the presented compliant mechanism, the cross-axis coupling ratio is below 1% indicating excellent decoupling performance. Despite this, during motion tracking the cross coupling effect cannot be ignored. To enhance the accuracy of micro/nanomanipulation, a laser interferometry-based sensing and measurement system is established. Nonlinearities such as creep/drift and hysteresis are present in this system, which are compensated with closed-loop control. Open-loop tracking results for a 1-DOF trajectory, with and without cross-axis coupling compensation are also presented. Robust motion tracking control is extended to support 2-DOF motion trajectories. This controller is implemented to track the desired trajectories over one and two axes of motion. Robust motion control demonstrates high precision and accurate motion tracking of the 2- DOF flexure-based mechanism. The cross-axis coupling is treated as a known disturbance and the performance of tracking 1-DOF trajectory, with and without cross-axis coupling compensation, is presented. Circular motion trajectories with radii of 10 μm, 1 μm, and 250 nm are also tracked. The experimental results presented in this paper demonstrate effective compensation of the cross-axis coupling with high precision motion tracking. The resultant 2-DOF closed-loop position tracking error in the X and Y axes are within $\pm$20 nm during dynamic motion, and $\pm$8 nm in the steady state.

Characterization and Modeling of Biomimetic Untethered Robots Swimming in Viscous Fluids Inside Circular Channels

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Abstract

Miniaturized robots with bioinspired propulsion mechanisms, such as rotating helical flagella, are promising tools for minimally invasive surgery, diagnosis, targeted therapy, drug delivery, and removing material from the

human body. Under- standing the locomotion of swimmers inside fluid-filled channels is essential for the design and control of miniaturized robots inside arteries and conduits of living organisms. In this paper, we describe scaled-up experiments and modeling of untethered robots with a rotating helical tail and swimming inside a tube filled with a vis- cous fluid. Experiments mimic low Reynolds number swimming of miniaturized robots inside conduits filled with aqueous solutions. A capsule that contains the battery and a small dc motor is used for the body of the robots. Helical tails with different geometric parameters are manufactured and used to obtain swimming speeds and body rotation rates of robots inside the cylindrical channel. Three-dimensional incompressible flow around the robot inside the channel is governed by Stokes equations, which are solved numerically with a computational fluid dynamics (CFD) model. Predicted velocities of robots are compared with the experimental results for the validation of the CFD model, which is used to analyze effects of the helical radius, pitch, and the radial position of the robot on the swimming speed, forces acting on the robot, and efficiency.