This brief investigates optimal reset law design of reset control systems with fixed reset time instants. First, closed-loop reset control systems are changed to discrete-time linear control systems with reset values as control inputs. Then the optimal reset law design problems are transferred to linear quadratic regulation problems and the optimal reset laws are then obtained by solving algebraic Riccati equations. As an application, the proposed technique is applied to track-seeking control of a kind of hard disk drive systems. Simulations show that the transient response is improved significantly. Especially, the proposed long-span seeking reset control is almost bang-bang, but the design process is much simpler.

A system for tracking multiple nanometer-scale fluorescent particles in a confocal microscope and an experimental validation is described. Position estimates of an individual fluorescent particle are generated from fluorescence intensity measurements taken at a small number of discrete locations. Tracking is achieved by combining the estimation procedure with a linear quadratic Gaussian (LQG) regulator. Multiple particles are tracked by combining the models for individual particles into a single system, applying the same LQG framework, and then cycling the control through each subsystem in turn. Experimental results are presented for single and multiple particles. For validation purposes, during each experiment images from a charge-coupled device camera were captured and analyzed offline using a standard Gaussian fit method. The estimated trajectories were in good agreement with those produced by the LQG algorithm, thereby verifying the tracking scheme.

An active vibration control system using an inertial actuator for suppression of multiple unknown and/or time-varying vibrations will be presented. The objective is to minimize the residual force by applying an appropriate control effort through the inertial actuator. The system does not use any additional transducer for getting in real-time information upon the disturbances. A direct feedback adaptive regulation scheme for the suppression of multiple unknown and/or time-varying vibrations will be used and evaluated in real time. It uses the internal model principle and the Youla–Kucera parametrization. In the Appendix, a comparison with an alternative indirect adaptive regulation scheme is presented.
Reset Control for Midfrequency Narrowband Disturbance Rejection With an Application in Hard Disk Drives
Y. Li, G. Guo, Y. Wang

A reset disturbance compensation scheme is developed to reject midfrequency narrowband disturbances, with an application to the hard disk drives (HDDs). Generally, disturbance at the midfrequency band is not effective to reject through the feedback control based on the internal-model principle or high gain control due to phase stability. This paper investigates a reset control scheme and its favorable approximate frequency response using the describing function. The reset control makes its gain-phase frequency response break through the fundamental Bode’s constraint of linear time-invariant system and provides a maximal phase lead at desired frequencies without affecting gain’s characteristic. With additional phase lead, the issue of phase stability can be solved. A reset midfrequency narrowband compensator is designed by incorporating the reset controller and a narrowband filter. The implementation on a real HDD servo system shows the removal of midfrequency disturbance due to disk vibration is improved by 50% compared with the linear control scheme, resulting in a track misregistration (TMR) reduction of 32%.

Reducing Vibration by Digital Filtering and Input Shaping
W. Singhose, J. Vaughan

The residual vibration of flexible systems can be reduced by shaping the reference command with notch filters, low-pass filters, and input shapers. Since the introduction of robust input shaping, there has been substantial evidence that input shaping is better than both notch and low-pass filtering for suppressing vibration in mechanical systems. Much of this evidence is empirical comparisons between traditional filters and robust input shapers. Given the large variety of filters and shapers and the large number of design strategies and parameters, there is still some uncertainty as to which approach is better. This paper seeks to end this debate by proving that notch and low-pass filters are never better than input shapers for suppressing mechanical vibration. This paper expands on previous efforts by presenting a proof showing that input shapers suppress vibration more quickly than notch or low-pass filters. The problem of suppressing multi-mode vibration is also examined. Experimental results from a portable bridge crane verify key theoretical results.

On Generalized Dynamic Preisach Operator With Application to Hysteresis Nonlinear Systems
Y. Ma, J. Mao, Z. Zhang

The behavior of hysteresis as a controlled plant obviously changes with not only the history of input, but also the compressive stress and excitation rate experienced. In this paper, a generalized dynamic Preisach operator is proposed for describing the dynamic hysteresis nonlinearity under varying compressive stress, excitation rate, as well as their couple effect, which can also be expanded for other varying factors, such as temperature, etc.. The developed operator features introducing the dependence of the density function on the compressive stress and excitation rate to the classical Preisach operator by a multi-criteria decision-making evaluation framework. The parameter identification scheme employing a fuzzy tree method is investigated to formulate the inverse compensator. On accounting of application, a feedback control scheme combined with a feedforward compensator is implemented to a magnetostrictive smart structure for real-time precise trajectory tracking. Both simulations and experiments demonstrate the proposed operator and corresponding control scheme a dramatically improved performance of mitigating the effects of hysteresis.
Directional Repetitive Control of a Metrological AFM
R. J. E. Merry, M. J. C. Ronde, R. van de Molengraft, K. R. Koops, M. Steinbuch

Atomic force microscopes (AFMs) are used for sample imaging and characterization at nanometer scale. In this work, we consider a metrological AFM, which is used for the calibration of transfer standards for commercial AFMs. The metrological AFM uses a three-degree-of-freedom (DOF) stage to move the sample with respect to the probe of the AFM. The repetitive sample topography introduces repetitive disturbances in the system. To suppress these disturbances, repetitive control (RC) is applied to the imaging axis. A rotated sample orientation with respect to the actuation axes introduces a nonrepetitiveness in the originally fully repetitive errors and yields a deteriorated performance of RC. Directional repetitive control (DRC) is introduced to align the axes of the scanning movement with the sample orientation under the microscope. Experiments show that the proposed directional repetitive controller significantly reduces the tracking error as compared to standard repetitive control.

Optimization-Based Constrained Iterative Learning Control
S. Mishra, U. Topcu, M. Tomizuka

We consider the problem of synthesis of iterative learning control (ILC) schemes for constrained linear systems executing a repetitive task. The ILC problem with affine constraints and quadratic objective functions is formulated as a convex quadratic program, for which there exist computationally efficient solvers. The key difference between standard convex optimization and the corresponding constrained ILC problem is that each iteration in the latter requires an experiment run. We implement an interior-point-type method to reduce the number of iterations (and hence the number of experiment runs). We discuss the system-theoretic interpretations of the resulting optimization problem that lead to reductions in computational complexity and compare the performance of the implementation based on the interior-point method to another approach based on the active set method on a simulation example. We demonstrate the technique on a prototype wafer stage system with actuator saturation constraints and $\ell_2$ norm of the tracking error as the objective function. The key contribution of this paper is the systematic use of numerical tools from constrained convex optimization in the ILC design.

Optics Express
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Tracking rotational diffusion of colloidal clusters
G. L. Hunter, K. V. Edmond, M. T. Elsesser, E. R. Weeks

We describe a novel method of tracking the rotational motion of clusters of colloidal particles. Our method utilizes rigid body transformations to determine the rotations of a cluster and extends conventional proven particle tracking techniques in a simple way, thus facilitating the study of rotational dynamics in systems containing or composed of colloidal clusters. We test our method by measuring dynamical properties of simulated Brownian clusters under conditions relevant to microscopy experiments. We then use the technique to track and describe the motions of a real colloidal cluster imaged with confocal microscopy.
High-density localization of active molecules using Structured Sparse Model and Bayesian Information Criterion
T. Quan, H. Zhu, X. Liu, Y. Liu, J. Ding, S. Zeng, and Z. Huang

Localization-based super-resolution microscopy (or called localization microscopy) rely on repeated imaging and localization of active molecules, and the spatial resolution enhancement of localization microscopy is built upon the sacrifice of its temporal resolution. Developing algorithms for high-density localization of active molecules is a promising approach to increase the speed of localization microscopy. Here we present a new algorithm called SSM_BIC for such purpose. The SSM_BIC combines the advantages of the Structured Sparse Model (SSM) and the Bayesian Information Criterion (BIC). Through simulation and experimental studies, we evaluate systematically the performance between the SSM_BIC and the conventional Sparse algorithm in high-density localization of active molecules. We show that the SSM_BIC is superior in processing single molecule images with weak signal embedded in strong background.

Volume 19, Issue 19 (September 12, 2011)
Weak avalanche discrimination for gated-mode single-photon avalanche photodiodes
S. Cho, S. Kang

The after-pulsing effect is a common problem that needs to be overcome for high-speed single-photon detection based on gated-mode single-photon avalanche photodiodes (SPADs). This paper presents a simple and practical method for suppression of the after-pulsing probability using an auxiliary signal to discriminate quite weak avalanches. The detection efficiency and after-pulse probability of an InGaAs/InP SPAD are investigated with a 10 MHz gating for conventional and proposed methods, and a sharp decrease of after-pulse probability is demonstrated with the application of the proposed method. At a gating frequency of 100 MHz, a detection efficiency of 10.4% is achieved with an after-pulse probability of 5.6% without dead time.

Volume 19, Issue 20 (September 26, 2011)
Localization-based super-resolution microscopy with an sCMOS camera

In the community of localization-based super-resolution microscopy (or called localization microscopy), it is generally believed that the emission of single molecules is so weak that an EMCCD (electron multiplying charge coupled device) camera is necessary to be used as the detector by eliminating read noise. Here we evaluate the possibility of a new kind of low light detector, scientific complementary metal-oxide-semiconductor (sCMOS) camera in localization microscopy. We demonstrate experimentally that sCMOS is capable of imaging actin bundles with FWHM diameter of 37 nm, evidencing the capability of sCMOS in localization microscopy. We further characterize the noise performance of sCMOS and find out that, with the use of a bright fluorescence probe such as d2EosFP, localization microscopy imaging is now working in the shot noise limited region.

Digital holographic tracking of microprobes for multipoint viscosity measurements
G. Bolognesi, S. Bianchi, R. Di Leonardo

Digital holographic microscopy provides an ideal tool for 3D tracking of microspheres while simultaneously allowing a full and accurate characterization of their main physical properties such as: radius and refractive index. We demonstrate that the combination of high resolution multipoint tracking and accurate optical sizing of tracers provides an ideal tool for precise multipoint viscosity measurements. We also report a detailed evaluation of the technique’s accuracy and precision in relation to the primary sources of error.
Compressed sensing (CS) is an emerging field that has attracted considerable research interest over the past few years. Previous review articles in CS limit their scope to standard discrete-to-discrete measurement architectures using matrices of randomized nature and signal models based on standard sparsity. In recent years, CS has worked its way into several new application areas. This, in turn, necessitates a fresh look on many of the basics of CS. The random matrix measurement operator must be replaced by more structured sensing architectures that correspond to the characteristics of feasible acquisition hardware. The standard sparsity prior has to be extended to include a much richer class of signals and to encode broader data models, including continuous time signals. In our overview, the theme is exploiting signal and measurement structure in compressive sensing. The prime focus is bridging theory and practice; that is, to pinpoint the potential of structured CS strategies to emerge from the math to the hardware. Our summary highlights new directions as well as relations to more traditional CS, with the hope of serving both as a review to practitioners wanting to join this emerging field, and as a reference for researchers that attempts to put some of the existing ideas in perspective of practical applications.

Performance Bounds for Expander-Based Compressed Sensing in Poisson Noise

This paper provides performance bounds for compressed sensing in the presence of Poisson noise using expander graphs. The Poisson noise model is appropriate for a variety of applications, including low-light imaging and digital streaming, where the signal-independent and/or bounded noise models used in the compressed sensing literature are no longer applicable. In this paper, we develop a novel sensing paradigm based on expander graphs and propose a maximum a posteriori (MAP) algorithm for recovering sparse or compressible signals from Poisson observations. The geometry of the expander graphs and the positivity of the corresponding sensing matrices play a crucial role in establishing the bounds on the signal reconstruction error of the proposed algorithm. We support our results with experimental demonstrations of reconstructing average packet arrival rates and instantaneous packet counts at a router in a communication network, where the arrivals of packets in each flow follow a Poisson process.
C-HiLasso: A Collaborative Hierarchical Sparse Modeling Framework
P. Sprechmann, I. Ramírez, G. Sapiro, Y. C. Eldar

Sparse modeling is a powerful framework for data analysis and processing. Traditionally, encoding in this framework is performed by solving an ell_1-regularized linear regression problem, commonly referred to as Lasso or Basis Pursuit. In this work we combine the sparsity-inducing property of the Lasso at the individual feature level, with the block-sparcity property of the Group Lasso, where sparse groups of features are jointly encoded, obtaining a sparsity pattern hierarchically structured. This results in the Hierarchical Lasso (HiLasso), which shows important practical advantages. We then extend this approach to the collaborative case, where a set of simultaneously coded signals share the same sparsity pattern at the higher (group) level, but not necessarily at the lower (inside the group) level, obtaining the collaborative HiLasso model (C-HiLasso). Such signals then share the same active groups, or classes, but not necessarily the same active set. This model is very well suited for applications such as source identification and separation. An efficient optimization procedure, which guarantees convergence to the global optimum, is developed for these new models. The underlying presentation of the framework and optimization approach is complemented by experimental examples and theoretical results regarding recovery guarantees.

Direction-of-Arrival Estimation Using a Sparse Representation of Array Covariance Vectors
J. Yin, T. Chen

A new direction-of-arrival (DOA) estimation method is proposed based on a novel data model using the concept of a sparse representation of array covariance vectors (SRACV), in which DOA estimation is achieved by jointly finding the sparsest coefficients of the array covariance vectors in an overcomplete basis. The proposed method not only has high resolution and the capability of estimating coherent signals based on an arbitrary array, but also gives an explicit error-suppression criterion that makes it statistically robust even in low signal-to-noise-ratio (SNR) cases. Simulation experiments are conducted to validate the effectiveness of the proposed method. The performance is compared with several existing DOA estimation methods and the Cramér–Rao lower bound (CRLB).

Volume 59, Issue 10 (October 2011)
From Bernoulli–Gaussian Deconvolution to Sparse Signal Restoration
C. Soussen, J. Idier, D. Brie, J. Duan

Formulated as a least square problem under an ell_0 constraint, sparse signal restoration is a discrete optimization problem, known to be NP complete. Classical algorithms include, by increasing cost and efficiency, matching pursuit (MP), orthogonal matching pursuit (OMP), orthogonal least squares (OLS), stepwise regression algorithms and the exhaustive search. We revisit the single most likely replacement (SMLR) algorithm, developed in the mid-1980s for Bernoulli–Gaussian signal restoration. We show that the formulation of sparse signal restoration as a limit case of Bernoulli–Gaussian signal restoration leads to an ell_0-penalized least square minimization problem, to which SMLR can be straightforwardly adapted. The resulting algorithm, called single best replacement (SBR), can be interpreted as a forward–backward extension of OLS sharing similarities with stepwise regression algorithms. Some structural properties of SBR are put forward. A fast and stable implementation is proposed. The approach is illustrated on two inverse problems involving highly correlated dictionaries. We show that SBR is very competitive with popular sparse algorithms in terms of tradeoff between accuracy and computation time.
The In-Crowd Algorithm for Fast Basis Pursuit Denoising
P. R. Gill, A. Wang, A. Molnar

We introduce a fast method, the “in-crowd” algorithm, for finding the exact solution to basis pursuit denoising problems. The in-crowd algorithm discovers a sequence of subspaces guaranteed to arrive at the support set of the final solution of ell_1 regularized least squares problems. We provide theorems showing that the in-crowd algorithm always converges to the correct global solution to basis pursuit denoising problems. We show empirically that the in-crowd algorithm is faster than the best alternative solvers (homotopy, fixed point continuation and spectral projected gradient for ell_1 minimization) on certain well- and ill-conditioned sparse problems with more than 1000 unknowns. We compare the in-crowd algorithm’s performance in high- and low-noise regimes, demonstrate its performance on more dense problems, and derive expressions giving its computational complexity.

Xampling: Signal Acquisition and Processing in Union of Subspaces
M. Mishali, Y. C. Eldar, A. J. Elron

We introduce Xampling, a unified framework for signal acquisition and processing of signals in a union of subspaces. The main functions of this framework are two: Analog compression that narrows down the input bandwidth prior to sampling with commercial devices followed by a nonlinear algorithm that detects the input subspace prior to conventional signal processing. A representative union model of spectrally sparse signals serves as a test-case to study these Xampling functions. We adopt three metrics for the choice of analog compression: robustness to model mismatch, required hardware accuracy, and software complexities. We conduct a comprehensive comparison between two sub-Nyquist acquisition strategies for spectrally sparse signals, the random demodulator and the modulated wideband converter (MWC), in terms of these metrics and draw operative conclusions regarding the choice of analog compression. We then address lowrate signal processing and develop an algorithm for that purpose that enables convenient signal processing at sub-Nyquist rates from samples obtained by the MWC. We conclude by showing that a variety of other sampling approaches for different union classes fit nicely into our framework.

Recovery of Sparse Translation-Invariant Signals With Continuous Basis Pursuit
C. Ekanadham, D. Tranchina, E. P. Simoncelli

We consider the problem of decomposing a signal into a linear combination of features, each a continuously translated version of one of a small set of elementary features. Although these constituents are drawn from a continuous family, most current signal decomposition methods rely on a finite dictionary of discrete examples selected from this family (e.g., shifted copies of a set of basic waveforms), and apply sparse optimization methods to select and solve for the relevant coefficients. Here, we generate a dictionary that includes auxiliary interpolation functions that approximate translates of features via adjustment of their coefficients. We formulate a constrained convex optimization problem, in which the full set of dictionary coefficients represents a linear approximation of the signal, the auxiliary coefficients are constrained so as to only represent translated features, and sparsity is imposed on the primary coefficients using an L1 penalty. The basis pursuit denoising (BP) method may be seen as a special case, in which the auxiliary interpolation functions are omitted, and we thus refer to our methodology as continuous basis pursuit (CBP). We develop two implementations of CBP for a one-dimensional translation-invariant source, one using a first-order Taylor approximation, and another using a form of trigonometric spline. We examine the tradeoff between sparsity and signal reconstruction accuracy in these methods, demonstrating empirically that trigonometric CBP substantially
outperforms Taylor CBP, which, in turn, offers substantial gains over ordinary BP. In addition, the CBP bases can generally achieve equally good or better approximations with much coarser sampling than BP, leading to a reduction in dictionary dimensionality.

Compressive Sampling With Generalized Polygons
K. Gao, S. N. Batalama, D. A. Pados, B. W. Suter

We consider the problem of compressed sensing and propose new deterministic low-storage constructions of compressive sampling matrices based on classical finite-geometry generalized polygons. For the noiseless measurements case, we develop a novel exact-recovery algorithm for strictly sparse signals that utilizes the geometry properties of generalized polygons and exhibits complexity that depends on the sparsity value only. In the presence of measurement noise, recovery of the generalized-polygon sampled signals can be carried out effectively using a belief propagation algorithm. Experimental studies included in this paper illustrate our theoretical developments.

Sparse Approximation Property and Stable Recovery of Sparse Signals From Noisy Measurements
Q. Sun

In this correspondence, we introduce a sparse approximation property of order for a measurement matrix $A$: \[ \| x_s \|_2 \leq D \| Ax \|_2 + \beta \left( \sigma_s(x) \right) \sqrt{s} \] for all $x$ where $x_s$ is the best $s$-sparse approximation of the vector $x$ in $\ell^2$, $\sigma_s(x)$ is the $s$-sparse approximation error of the vector $x$ in $\ell^1$, and $D$ and $\beta$ are positive constants. The sparse approximation property for a measurement matrix can be thought of as a weaker version of its restricted isometry property and a stronger version of its null space property. In this correspondence, we show that the sparse approximation property is an appropriate condition on a measurement matrix to consider stable recovery of any compressible signal from its noisy measurements. In particular, we show that any compressible signal can be stably recovered from its noisy measurements via solving an $\ell^1$-minimization problem if the measurement matrix has the sparse approximation property with $\beta \in (0,1)$, and conversely the measurement matrix has the sparse approximation property with $\beta \in (0,\infty)$ if an compressible signal can be stably recovered from its noisy measurements via solving an $\ell^1$-minimization problem.

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A General Framework for Sparsity-Based Denoising and Inversion
A. Gholami, S. M. Hosseini

Estimating a reliable and stable solution to many problems in signal processing and imaging is based on sparse regularizations, where the true solution is known to have a sparse representation in a given basis. Using different approaches, a large variety of regularization terms have been proposed in literature. While it seems that all of them have so much in common, a general potential function which fits most of them is still missing. In this paper, in order to propose an efficient reconstruction method based on a variational approach and involving a general regularization term (including most of the known potential functions, convex and nonconvex), we deal with i) the definition of such a general potential function, ii) the properties of the associated “proximity operator” (such as the existence of a discontinuity), and iii) the design of an approximate solution of the general “proximity operator” in a simple closed form. We also demonstrate that a special case of the resulting “proximity operator” is a set of shrinkage functions which continuously interpolate between the soft-thresholding and hard-thresholding. Computational experiments show that the
The recently emerged compressive sensing (CS) framework aims to acquire signals at reduced sample rates compared to the classical Shannon-Nyquist rate. To date, the CS theory has assumed primarily real-valued measurements; it has recently been demonstrated that accurate and stable signal acquisition is still possible even when each measurement is quantized to just a single bit. This property enables the design of simplified CS acquisition hardware based around a simple sign comparator rather than a more complex analog-to-digital converter; moreover, it ensures robustness to gross nonlinearities applied to the measurements. In this paper we introduce a new algorithm—restricted-step shrinkage (RSS)—to recover sparse signals from 1-bit CS measurements. In contrast to previous algorithms for 1-bit CS, RSS has provable convergence guarantees, is about an order of magnitude faster, and achieves higher average recovery signal-to-noise ratio. RSS is similar in spirit to trust-region methods for nonconvex optimization on the unit sphere, which are relatively unexplored in signal processing and hence of independent interest.

A Coding Theory Approach to Noisy Compressive Sensing Using Low Density Frames
M. Akcakaya, J. Park, V. Tarokh

We consider the compressive sensing of a sparse or compressible signal $x \in \mathbb{R}^M$. We explicitly construct a class of measurement matrices inspired by coding theory, referred to as low density frames, and develop decoding algorithms that produce an accurate estimate $\hat{x}$ even in the presence of additive noise. Low density frames are sparse matrices and have small storage requirements. Our decoding algorithms can be implemented in $O(Md_v^2)$ complexity, where $d_v$ is the left degree of the underlying bipartite graph. Simulation results are provided, demonstrating that our approach outperforms state-of-the-art recovery algorithms for numerous cases of interest. In particular, for Gaussian sparse signals and Gaussian noise, we are within 2-dB range of the theoretical lower bound in most cases.