**Biophysical Journal**

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Nothing of interest.

**Vol. 108, no.12**

**Axial Optical Traps: A New Direction for Optical Tweezers**
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Optical tweezers have revolutionized our understanding of the microscopic world. Axial optical tweezers, which apply force to a surface-tethered molecule by directly moving either the trap or the stage along the laser beam axis, offer several potential benefits when studying a range of novel biophysical phenomena. This geometry, although it is conceptually straightforward, suffers from aberrations that result in variation of the trap stiffness when the distance between the microscope coverslip and the trap focus is being changed. Many standard techniques, such as back-focal-plane interferometry, are difficult to employ in this geometry due to back-scattered light between the bead and the coverslip, whereas the noise inherent in a surface-tethered assay can severely limit the resolution of an experiment. Because of these complications, precision force spectroscopy measurements have adapted alternative geometries such as the highly successful dumbbell traps. In recent years, however, most of the difficulties inherent in constructing a precision axial optical tweezers have been solved. This review article aims to inform the reader about recent progress in axial optical trapping, as well as the potential for these devices to perform innovative biophysical measurements.

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**Proceedings of the National Academy of Sciences, USA**

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Nothing of interest

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**Measuring the signal-to-noise ratio of a neuron**
Gabriela Czanner, Sridevi V. Sarma, Demba Ba, Uri T. Eden, Wei Wu, Emad Eskandar, Hubert H. Lim, Simona Temereanca, Wendy A. Suzuki, and Emery N. Brown.
The signal-to-noise ratio (SNR), a commonly used measure of fidelity in physical systems, is defined as the ratio of the squared amplitude or variance of a signal relative to the variance of the noise. This definition is not appropriate for neural systems in which spiking activity is more accurately represented as point processes. We show that the SNR estimates a ratio of expected prediction errors and extend the standard definition to one appropriate for single neurons by representing neural spiking activity using point process generalized linear models (PP-GLM). We estimate the prediction errors using the residual deviances from the PP-GLM fits. Because the deviance is an approximate $\chi^2$ random variable, we compute a bias-corrected SNR estimate appropriate for single-neuron analysis and use the bootstrap to assess its uncertainty. In the analyses of four systems neuroscience experiments, we show that the SNRs are $-10$ dB to $-3$ dB for guinea pig auditory cortex neurons, $-18$ dB to $-7$ dB for rat thalamic neurons, $-28$ dB to $-14$ dB for monkey hippocampal neurons, and $-29$ dB to $-20$ dB for human subthalamic neurons. The new SNR definition makes explicit in the measure commonly used for physical systems the often-quoted observation that single neurons have low SNRs. The neuron’s spiking history is frequently a more informative covariate for predicting spiking propensity than the applied stimulus. Our new SNR definition extends to any GLM system in which the factors modulating the response can be expressed as separate components of a likelihood function.

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Nothing of interest
Nanoscale, vol. 7, no. 23

Increased localization precision by interference fringe analysis

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We report a novel optical single-emitter-localization methodology that uses the phase induced by path length differences in a Mach–Zehnder interferometer to improve localization precision. Using information theory, we demonstrate that the localization capability of a modified Fourier domain signal generated by photon interference enables a more precise localization compared to a standard Gaussian intensity distribution of the corresponding point-spread function. The calculations were verified by numerical simulations and an exemplary experiment, where the centers of metal nanoparticles were localized to a precision of 3 nm.
Abstract

The major concentration of this study is on developing a control scheme with parameter- and load-insensitive features capable of precise angular speed regulation of a permanent magnet (PM) DC motor in the presence of modeling uncertainties. Towards this objective, first, an appropriate nonlinear dynamic model of friction, the modified LuGre model, is opted and incorporated into the mathematical model of a PM DC motor. Then a sliding mode observer (SMO) is designed to estimate the state variable of the friction model. Next, a model reference adaptive control system into which estimated values of the friction state and parameters are fed is designed to track the desired speed trajectory while alleviating the adverse effects of model uncertainties and friction. Stability of the proposed SMO-based MRAC system is discussed via the Lyapunov stability theorem, and its asymptotic stability is verified. In addition to simulation studies, the algorithm is implemented on a new variable structure test-bed which gives us the ability to simulate desired parameter variations and external disturbance changes in experiment. The main contribution of the proposed scheme is the bounded estimation of the system’s friction parameter. While similar control solutions do estimate these parameters, there is no guarantee that they will estimate the correct value of friction parameters. However, in the proposed method, by properly choosing the design parameters, if certain criteria is satisfied, the estimated friction parameters will be in the bounded vicinity of their actual values. The obtained results show the effectiveness of the proposed tracking algorithm and its robustness against load and system parameters’ variations.
Abstract

Even though PID control has been available for a long time, there are still no tuning methods including derivative action that have gained wide acceptance in industry. Also, there is still no general consensus for when one should use PID, PI or even I control on a process. The focus of this article is to present a new method for optimal PID control design that automatically picks the best controller type for the process at hand. The proposed PID design procedure uses a software-based method to find controllers with optimal or near optimal load disturbance response subject to robustness and noise sensitivity constraints. It is shown that the optimal controller type depends on maximum allowed noise sensitivity as well as process dynamics. The design procedure thus results in a set of PID, PI and I controllers with different noise filters that the user can switch between to reach an acceptable control signal activity. The software is also used to compare PI and PID control performance with equivalent noise sensitivity and robustness over a large batch of processes representative for the process industry. This can be used to show how much a particular process benefits from using the derivative part.
Performance of Sinusoidal Scanning With MPC in AFM Imaging
Rana, M.S.; Pota, H.R.; Petersen, I.R.
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Abstract
An atomic force microscope (AFM) is an extremely versatile investigative tool in the field of nanotechnology, the performance of which is significantly influenced by its conventional zig-zag raster pattern scanning method. In this paper, in order to increase its imaging speed, we consider the use of a sinusoidal scanning method, i.e., a spiral scanning method with an improved model predictive control (MPC) scheme. In this approach, spirals are generated by applying waves, each with a single frequency and slowly varying amplitude, in the X-piezo (sine wave) and Y-piezo (cosine wave) of the piezoelectric tube scanner (PTS) of the AFM. As these input signals are single frequencies, the scanning can proceed faster than traditional raster scanning, without exciting the resonant mode of the PTS. The proposed MPC controller reduces the phase error between the reference position input and measured output sinusoids and provides better tracking of the reference signal. Also, a notch filter is designed and included in the feedback loop to suppress vibrations of the PTS at the resonant frequency. The experimental results show that, using the proposed method, the AFM is able to scan a 6 m radius image within 2.04 s with a quality better than that obtained using the conventional raster pattern scanning method.

Precision Sinusoidal Local Scan for Large-Range Atomic Force Microscopy With Auxiliary Optical Microscopy
Chih-Lieh Chen; Jim-Wei Wu; Yi-Ting Lin; Li-Chen Fu
Nat. Taiwan Univ

Abstract
Atomic force microscopy (AFM) is a powerful measurement instrument which can build 3-D topography image of conductive and nonconductive samples at nanoscale resolution. However, due to the scan method of conventional AFM, the induced mechanical resonance of the scanner and the scan in area of uninterest would strictly limit the scan speed. In this study, we improve these problems with our designed AFM system from three aspects. First, the sinusoidal trajectory is applied to lateral scanning of the AFM rather than the traditional raster trajectory, so the scan rate can be increased without inducing vibration of the lateral scanner. Second, with this promising scan trajectory, the internal model principle-based neural network complementary sliding-mode controller and adaptive complementary sliding-mode controller are designed to achieve high precision scanning and to cope with the system parameter uncertainties and external disturbance. Finally, with the aid of an auxiliary optical microscopy and the scanned information during the scanning process, scan path planning can be adopted to focus the scanning on samples such that the total scan time is further shortened. Extensive experimental results are provided to show the appealing performance of the proposed method.

Quantization of Eigen Subspace for Sparse Representation
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NJIT

Abstract
We propose sparse KarhunenLoeve Transform (SKLT) method to sparse eigen subspaces. The sparsity (cardinality reduction) is achieved through the pdf-optimized quantization of basis function (vector) set. It may be considered an extension of the simple and soft thresholding (ST) methods. The merit of the proposed framework for sparse representation is presented for auto-regressive order one, AR(1), discrete process and empirical correlation matrix of stock returns for NASDAQ-100 index. It is shown that SKLT is efficient to implement and outperforms several sparsity algorithms reported in the literature.

Joint Power and Admission Control: Non-Convex $L_q$ Approximation and An Effective Polynomial Time Deflation Approach
Ya-Feng Liu, Yu-Hong Dai, and Shiqian Ma
Chinese Academy of Sciences

Abstract
In an interference limited network, joint power and admission control (JPAC) aims at supporting a maximum number of links at their specified signal-to-interference-plus-noise ratio (SINR) targets while using minimum total transmission power. Various convex approximation deflation approaches have been developed for the JPAC problem. In this paper, we propose an effective polynomial time non-convex approximation deflation approach for solving the problem. The approach is based on the non-convex $\ell_q$ ($0 < q < 1$) approximation of an equivalent sparse $\ell_0$ reformulation of the JPAC problem. We show that, for any instance of the JPAC problem, there exists a $\bar{q} \in (0, 1)$ such that it can be exactly solved by solving its $\ell_q$ approximation problem with any $q \in (0, \bar{q}]$. We also show that finding the global solution of the $c\ell_q$ approximation problem is NP-hard. Then, we propose a potential reduction interior-point algorithm, which can return an $\epsilon$-KKT solution of the NP-hard $\ell_q$ approximation problem in polynomial time. The returned solution can be used to check the simultaneous supportability of all links in the network and to guide an iterative link removal procedure, resulting in the polynomial time non-convex approximation deflation approach for the JPAC problem. Numerical simulations show that the proposed approach outperforms the existing convex approximation approaches in terms of the number of supported links and the total transmission power, particularly exhibiting a quite good performance in selecting which subset of links to support.

Gaussian Mixtures Based IRLS for Sparse Recovery With Quadratic Convergence
Chiara Ravazzi, Enrico Magli
the Politecnico di Torino

Abstract
In this paper, we propose a new class of iteratively re-weighted least squares (IRLS) for sparse recovery problems. The proposed methods are inspired by constrained maximum-likelihood estimation under a Gaussian scale mixture (GSM) distribution assumption. In the noise-free setting, we provide sufficient conditions ensuring the convergence of the sequences generated by these algorithms to the set of fixed points of the maps that rule their dynamics and derive conditions verifiable a posteriori for the convergence to a sparse solution. We further prove that these algorithms are quadratically fast in a neighborhood of a sparse solution. We show through numerical experiments that the proposed methods outperform classical IRLS for $\ell_r$ -minimization with $r \in (0, 1]$ in terms of speed and of sparsity-undersampling tradeoff and are robust even in presence of noise. The simplicity and the theoretical guarantees provided in this paper make this class of algorithms an attractive solution for sparse recovery problems.
interesting paper but not useful:

**An Approach Toward Fast Gradient-Based Image Segmentation**
Benjamin Hell, Marc Kassubeck, Pablo Bauszat, Martin Eisemann and Marcus Magnor
*Technische Universität Braunschweig*

**Abstract**
In this paper, we present and investigate an approach to fast multilabel color image segmentation using convex optimization techniques. The presented model is in some ways related to the well-known Mumford-Shah model, but deviates in certain important aspects. The optimization problem has been designed with two goals in mind. The objective function should represent fundamental concepts of image segmentation, such as incorporation of weighted curve length and variation of intensity in the segmented regions, while allowing transformation into a convex concave saddle point problem that is computationally inexpensive to solve. This paper introduces such a model, the nontrivial transformation of this model into a convex-concave saddle point problem, and the numerical treatment of the problem. We evaluate our approach by applying our algorithm to various images and show that our results are competitive in terms of quality at unprecedentedly low computation times. Our algorithm allows high-quality segmentation of megapixel images in a few seconds and achieves interactive performance for low resolution images (Fig. 1).

**Image Super-Resolution Based on Structure-Modulated Sparse Representation**
Yongqin Zhang, Jiaying Liu, Wenhan Yang, Zongming Guo
*Northwest University, Xian, China*

**Abstract**
Sparse representation has recently attracted enormous interests in the field of image restoration. The conventional sparsity-based methods enforce sparse coding on small image patches with certain constraints. However, they neglected the characteristics of image structures both within the same scale and across the different scales for the image sparse representation. This drawback limits the modeling capability of sparsity-based super-resolution methods, especially for the recovery of the observed low-resolution images. In this paper, we propose a joint super-resolution framework of structure-modulated sparse representations to improve the performance of sparsity-based image super-resolution. The proposed algorithm formulates the constrained optimization problem for high-resolution image recovery. The multistep magnification scheme with the ridge regression is first used to exploit the multiscale redundancy for the initial estimation of the high-resolution image. Then, the gradient histogram preservation is incorporated as a regularization term in sparse modeling of the image super-resolution problem. Finally, the numerical solution is provided to solve the super-resolution problem of model parameter estimation and sparse representation. Extensive experiments on image super-resolution are carried out to validate the generality, effectiveness, and robustness of the proposed algorithm. Experimental results demonstrate that our proposed algorithm, which can recover more fine structures and details from an input low-resolution image, outperforms the state-of-the-art methods both subjectively and objectively in most cases.

**Bilateral Control of Teleoperation Systems With Time Delay**
Islam, S.; Liu, P.X. ; El Saddik, A. ; Yang, Y.B.
*Harvard*

**Abstract**
In this paper, we address the stability and tracking control problem of constant input-based bilateral teleoperation systems in the presence of time-varying delay. The teleoperation algorithm comprises delayed position and position-velocity signals with undelayed position and velocity signals of the master and slave manipulators. An adaptation law is employed locally to learn and compensate uncertain parameters associated with the gravity loading vector of the master and slave manipulators. Lyapunov-Krasovskii functions are employed to derive
stability and tracking properties of the position, velocity, and synchronizing error of the master and slave manipulator. These properties are established in the presence of symmetrical and unsymmetrical time-varying delays under constant input interaction forces between human and master manipulator and between environment and slave manipulator. Finally, evaluation results are presented to illustrate the theoretical development of this paper.

Flatness-Based Nonlinear Control for Position Tracking of Electrohydraulic Systems
Wonhee Kim ; Daehee Won ; Tomizuka, M.
Dong-A Uni

Abstract
In this paper, a flatness-based nonlinear controller is proposed to improve the position-tracking performance and to reduce the current input ripple in electrohydraulic systems (EHSs). The proposed method consists of feedforward control using a flatness concept and feedback control to yield a stable control system. This paper presents an analysis on the problem of tracking a reference position, conditions for open-loop stability, as well as an analysis on the flatness of EHS. These results are used for a nonlinear feedforward control design. To further improve the position-tracking performance, feedforward control is augmented with a nonlinear feedback control, which is designed based on the flatness property of EHSs. Moreover, the state variable derivatives are not used so that the measurement noise and structural vibration are not amplified, which in turn can increase the machinery’s life expectancy because the current inputs’ ripples are reduced.
Investigation of the numerics of point spread function integration in single molecule localization
Jerry Chao, Sripad Ram, Taiyoon Lee, E. Sally Ward, and Raimund J. Ober
Texas A&M University, USA

The computation of point spread functions, which are typically used to model the image profile of a single molecule, represents a central task in the analysis of single molecule microscopy data. To determine how the accuracy of the computation affects how well a single molecule can be localized, we investigate how the fineness with which the point spread function is integrated over an image pixel impacts the performance of the maximum likelihood location estimator. We consider both the Airy and the two-dimensional Gaussian point spread functions. Our results show that the point spread function needs to be adequately integrated over a pixel to ensure that the estimator closely recovers the true location of the single molecule with an accuracy that is comparable to the best possible accuracy as determined using the Fisher information formalism. Importantly, if integration with an insufficiently fine step size is carried out, the resulting estimates can be significantly different from the true location, particularly when the image data is acquired at relatively low magnifications. We also present a methodology for determining an adequate step size for integrating the point spread function.

High spatio-temporal resolution video with compressed sensing
Roman Koller, Lukas Schmid, Nathan Matsuda, Thomas Niederberger, Leonidas Spinoulas, Oliver Cossairt, Guido Schuster, and Aggelos K. Katsaggelos
University of Applied Sciences of Eastern Switzerland; Northwestern University, USA

We present a prototype compressive video camera that encodes scene movement using a translated binary photomask in the optical path. The encoded recording can then be used to reconstruct multiple output frames from each captured image, effectively synthesizing high speed video. The use of a printed binary mask allows reconstruction at higher spatial resolutions than has been previously demonstrated. In addition, we improve upon previous work by investigating tradeoffs in mask design and reconstruction algorithm selection. We identify a mask design that consistently provides the best performance across multiple reconstruction strategies in simulation, and verify it with our prototype hardware. Finally, we compare reconstruction algorithms and identify the best choice in terms of balancing reconstruction quality and speed.

Quantitative Aspects of Single Molecule Microscopy
Raimund J. Ober, Amir Tahmasbi, Sripad Ram, Zhiping Lin, and E. Sally Ward
Texas A&M, USA

Single molecule microscopy is a relatively new optical microscopy technique that allows the detection of individual molecules such as proteins in a cellular context. This technique has generated significant interest among biologists, biophysicists and biochemists, as it holds the promise to provide novel insights into subcellular processes and structures that otherwise cannot be gained through traditional experimental approaches. Single molecule experiments place stringent demands on experimental and algorithmic tools due to the low signal levels and the presence of significant extraneous noise sources. Consequently, this has necessitated the use of advanced statistical signal and image processing techniques for the design and analysis of single molecule experiments. In this tutorial paper, we provide an overview of single molecule microscopy from early works to current applications and challenges. Specific emphasis will be on the quantitative aspects of this imaging modality, in particular single molecule localization and resolvability, which will be discussed from an information theoretic perspective. We review the stochastic framework for image formation, different types of estimation techniques and expressions for the Fisher information matrix. We also discuss several open problems in the field that demand highly non-trivial signal processing algorithms.
Journal Updates:

July 2015

Automatica

Minimax control over unreliable communication channels

*Volume 59, September 2015, Pages 182–193*

**Jun Moon, Tamer Başar**

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**Abstract**

In this paper, we consider a minimax control problem for linear time-invariant (LTI) systems over unreliable communication channels. This can be viewed as an extension of the $H_\infty$ optimal control problem, where the transmission from the plant output sensors to the controller, and from the controller to the plant are over sporadically failing channels. We consider two different scenarios for unreliable communication. The first one is where the communication channel provides perfect acknowledgments of successful transmissions of control packets through a clean reverse channel, that is the TCP (Transmission Control Protocol). Under this setting, we obtain a class of output feedback minimax controllers; we identify a set of explicit threshold-type existence conditions in terms of the $H_\infty$ disturbance attenuation parameter and the packet loss rates that guarantee stability and performance of the closed-loop system. The second scenario is one where there is no acknowledgment of successful transmissions of control packets, that is the UDP (User Datagram Protocol). We consider a special case of this problem where there is no measurement noise in the transmission from the sensors. For this problem, we obtain a class of corresponding minimax controllers by characterizing a set of (different) existence conditions. We also discuss stability and performance of the closed-loop system. We provide simulations to illustrate the results in all cases.

Complete stability analysis of a heuristic approximate dynamic programming control design

*Volume 59, September 2015, Pages 9–18*

**Yury Sokolov, Robert Kozma, Ludmilla D. Werbos, Paul J. Werbos**

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IntControl LLC, Arlington, and CLION, The University of Memphis, USA

**Abstract**

This paper provides new stability results for Action-Dependent Heuristic Dynamic Programming (ADHDP), using a control algorithm that iteratively improves an internal model of the external world in the autonomous system based on its continuous interaction with the environment. We extend previous results for ADHDP control to the case of general multi-layer neural networks with deep learning across all layers. In particular, we show that the introduced control approach is uniformly ultimately bounded (UUB) under specific conditions on the learning rates, without explicit constraints on the temporal discount factor. We demonstrate the benefit of our results to the control of linear and nonlinear systems, including the cart–pole balancing problem. Our results show significantly improved learning and control performance as compared to the state-of-the-art.
Stabilization of networked control systems with both network-induced delay and packet dropout (brief paper)

*Volume 59, September 2015, Pages 194–199*

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**Abstract**

This paper is concerned with the mean-square stabilization problem for discrete-time networked control systems (NCSs). It is assumed that control signal is sent to plant over a lossy communication channel, where network-induced delay and packet dropout occur simultaneously. A necessary and sufficient stabilizing condition is developed in terms of the unique positive-definite solutions to some coupled algebraic Riccati equations (CAREs). The contributions of this paper are twofold. First, an existence theorem of the maximum packet dropout rate is proposed. Second, for one-dimensional single-input system and the decoupled multi-input system, it is shown that the NCS is stabilizable iff the network-induced delay and the packet dropout rate satisfy some simple algebraic inequalities. If the network-induced delay is known a priori, the maximum packet dropout rate is given explicitly in terms of network-induced delay and unstable eigenvalues of the system matrix. If the packet dropout rate is known a priori, the maximum allowable delay bound is also given explicitly.

**System & Control Letters**

Distributed resource coordination in networked systems described by digraphs

*Volume 82, August 2015, Pages 33–39*

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**Abstract**

We consider a multicomponent system in which each component can receive/transmit information from/to components in its immediate neighborhood. Communication links between components are not required to be bidirectional, so that the information exchange between components in the system is in general described by a directed graph (digraph). Each component can contribute a certain amount of some resource (of the same type for each component), and the objective is for the components to distributively compute their individual resource contribution so as to collectively provide a requested amount of the resource. A further constraint is that each component’s contribution is upper and lower bounded by locally known capacity constraints. In order to solve this resource coordination problem, we propose a distributed linear iterative algorithm in which each component maintains a set of values that are updated to be weighted linear combinations of its own previous value(s) and the values of the components it receives information from. Since the original choices of weights used by the components to perform the linear updates may not allow the components to solve the problem, the weights are allowed to adapt (also in a distributed fashion) as the algorithm progresses. Convergence of the proposed algorithm to a feasible solution is established analytically and demonstrated via examples.
An iterative method for suboptimal control of linear time-delayed systems

Volume 82, August 2015, Pages 40–50

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Abstract

This article presents a new approach for solving the Optimal Control Problem (OCP) of linear time-delay systems with a quadratic cost functional. The proposed method can also be used for designing optimal control time-delay systems with disturbance. In this study, the Variational Iteration Method (VIM) is employed to convert the original Time-Delay Optimal Control Problem (TDOCP) into a sequence of nonhomogeneous linear two-point boundary value problems (TPBVPs). The optimal control law obtained consists of an accurate linear feedback term and a nonlinear compensation term which is the limit of an adjoint vector sequence. The feedback term is determined by solving Riccati matrix differential equation. By using the finite-step iteration of a nonlinear compensation sequence, we can obtain a suboptimal control law. Finally, Illustrative examples are included to demonstrate the validity and applicability of the technique.

Leader–follower consensus of linear multi-agent systems with unknown external disturbances

Volume 82, August 2015, Pages 64–70

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Abstract

This paper addresses the leader–follower consensus tracking problem for multi-agent systems with identical general linear dynamics and unknown external disturbances. First, a distributed extended state observer is proposed, where both the local states and disturbance of each agent are estimated simultaneously by using the relative output information between neighbors. Then a consensus algorithm is proposed for each agent based on the relative estimated states between neighbors and its own disturbance estimate. It is shown that, with the proposed observer-based consensus algorithm, the leader–follower consensus problem can be solved. Finally, we present a simulation example to demonstrate the effectiveness of the proposed algorithm.
**Persistent Monitoring of Events With Stochastic Arrivals at Multiple Stations**

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**Abstract**

This paper introduces a new mobile sensor scheduling problem involving a single robot tasked to monitor several events of interest that are occurring at different locations (stations). Of particular interest is the monitoring of transient events of a stochastic nature, with applications ranging from natural phenomena (e.g., monitoring abnormal seismic activity around a volcano using a ground robot) to urban activities (e.g., monitoring early formations of traffic congestion using an aerial robot). Motivated by examples like these, this paper focuses on problems in which the precise occurrence times of the events are unknown a priori, but statistics for their interarrival times are available. In monitoring such events, the robot seeks to: 1) maximize the number of events observed and 2) minimize the delay between two consecutive observations of events occurring at the same location. This paper considers the case when a robot is tasked with optimizing the event observations in a balanced manner, following a cyclic patrolling route. To tackle this problem, first, assuming that the cyclic ordering of stations is known, we prove the existence and uniqueness of the optimal solution and show that the solution has desirable convergence rate and robustness. Our constructive proof also yields an efficient algorithm for computing the unique optimal solution with $O(n)$ time complexity, in which $n$ is the number of stations, with $O(\log n)$ time complexity for incrementally adding or removing stations. Except for the algorithm, our analysis remains valid when the cyclic order is unknown. We then provide a polynomial-time approximation scheme that computes for any $\epsilon > 0$ a $(1+\epsilon)$-optimal solution for this more general, NP-hard problem.

**Multiobjective Path Planning: Localization Constraints and Collision Probability**

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**Abstract**

We present a novel path planning algorithm that, starting from a probabilistic roadmap, efficiently constructs a product graph used to search for a near optimal solution of a multiobjective optimization problem. The goal is to find paths that minimize a primary cost, such as the path length from start to goal, subject to a bound on a secondary cost such as the state estimation error covariance. The proposed algorithm is efficient as it relies on a scalar metric, related to the largest eigenvalue of the error covariance, and adaptively quantizes the secondary cost, yielding a product graph whose number of vertices and edges provides a good tradeoff between optimality and computational complexity. We further show how our approach can be extended to handle constraints on the probability of collision avoidance specified at every vertex along the path. Numerical examples show 1) how the computed paths change as a function of the specified bound on the secondary costs, and 2) the tradeoff between accuracy and computational efficiency of the proposed approach compared with methods where the product graph is built by quantizing the secondary cost uniformly.
Persistent Homology for Path Planning in Uncertain Environments

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Abstract

We address the fundamental problem of goal-directed path planning in an uncertain environment represented as a probability (of occupancy) map. Most methods generally use a threshold to reduce the grayscale map to a binary map before applying off-the-shelf techniques to find the best path. This raises the somewhat ill-posed question, what is the right (optimal) value to threshold the map? We instead suggest a persistent homology approach to the problem—a topological approach in which we seek the homology class of trajectories that is most persistent for the given probability map. In other words, we want the class of trajectories that is free of obstacles over the largest range of threshold values. In order to make this problem tractable, we use homology in $\mathbb{Z}_2$ coefficients (instead of the standard $\mathbb{Z}$ coefficients), and describe how graph search-based algorithms can be used to find trajectories in different homology classes. Our simulation results demonstrate the efficiency and practical applicability of the algorithm proposed in this paper.