## 30th (Pearl Anniversary) Southern California Control Workshop

Cymer Conference Center, Structural and Mechanical Engineering Building UC San Diego, June 3, 2016

akfast	8:30-9:00
Chair: Solmaz Kia	Session I
tegic Air Traffic Planning with an Aggregate Route Model sandro Bombelli (UC Irvine)	9:00-9:25
erentially Private Distributed Convex Optimization via Functional Perturbation n Nozari (UC San Diego)	9:25-9:50
r Model Identification of Opportunistic Navigation with Cellular CDMA Signals Khalife (UC Riverside)	9:50-10:15
Adaptive Control of Compact Reverse Osmosis Systems y Gao (UCLA)	10:15-10:40
d Talks	10:40-11:00
ee Break	11:00-11:30
Chair: Bob Bitmead	Special Sessi
ok back into the history of the Southern California (Nonlinear) Control Workshop oslav Krstic	11:30-11:45
damental Trade-offs in Robust Control with Heterogeneous Uncertainty er Başar (University of Illinois at Urbana-Champaign)	11:45-12:30
ch e	12:30-13:30 13:30-13:45
Chair: Andy Teel	Session II
Price-Discrimination Help Influence Social Behavior? ip Brown (UC Santa Barbara)	13:45-14:10
omata Theory Meets Approximate Dynamic Programming: Optimal Control with Temporal Logi straints Papusha (Caltech)	14:10-14:35
out Feedback Control of the One-Phase Stefan Problem non Koga (UC San Diego)	14:35-15:00
n Learning and Performance via Assign/Appraise Dynamics jun Mei (UC Santa Barbara)	15:00-15:25
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ing for Help with the Right Question by Predicting Human Visual Performance g Cai (UC Santa Barbara)	15:50-16:15
tiscale Modeling and Operation of PECVD of Thin-Film Solar Cells at Crose (UCLA)	16:15-16:40
ust Control over Delayed and Quantized Feedback with Applications to Human Sensorimotor Cont e Nakahira (Caltech)	16:40-17:05
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for Control Systems and Dynamics

## ABSTRACTS

Title: Strategic Air Traffic Planning with an Aggregate Route Model

Speaker: Alessandro Bombelli, UC Irvine

Adviser: Ken Mease, UC Irvine

**Abstract:** An aggregate route model for strategic traffic air traffic flow management is presented. It is an Eulerian flow model, describing the flow between segments of unidirectional point-to-point routes. Flight trajectory data are compared using similarity measures. Spatial similarity is determined using the Frechet distance and temporal similarity by average ground speed. Agglomerative hierarchical clustering is used to cluster routes. The optimal number of cluster is determined comparing performances of four different indexes. The traffic flow along aggregate routes is modeled as a network whose dynamics are described by a discrete linear time-invariant system. The traffic flow controls considered are ground holding and pre-departure rerouting. The strategic planning problem is posed as minimizing a weighted linear combination of controls, subject to sector capacity constraints and takes the form of an integer linear programming problem.

Title: Differentially Private Distributed Convex Optimization via Functional Perturbation

Speaker: Erfan Nozari, UC San Diego

Adviser: Jorge Cortés, UC San Diego

Abstract: A common and implicit assumption in the development of most distributed coordination algorithms is the honesty and trustworthiness of all the agents, upon which they can freely share their information to achieve their common objective. Therefore, although security issues of such algorithms have received considerable attention thus far, until very recently, little work had been done to incorporate privacy considerations into distributed coordination algorithms. In this talk, I first review the notion of differential privacy and show how "data" can be deliberately contaminated with carefully chosen noise to preserve its privacy when released. We will see that this notion is so general that can be utilized in almost every context. Then, we will focus on the particular problem of distributed convex optimization as one of the most important multi-agent coordination problems. We discuss and compare the two wide-spread methods of privacy preservation in this scenario, namely, the perturbation of inter-agent messages or objective functions, and this motivates our novel approach to this problem called functional perturbation. We will then see how this approach can be used to solve the private distributed optimization problem, and address the issues and difficulties that may arise as a result.

Title: Error Model Identification of Opportunistic Navigation with Cellular CDMA Signals

Speaker: Joe Khalife, UC Riverside

Adviser: Zak Kassas, UC Riverside

Abstract: Over the past decade, research in navigation via signals of opportunity (SOPs) has revealed their potential as an alternative or a complement to global navigation satellite system (GNSS). Recent work in navigation using cellular code division multiple access (CDMA) signals revealed errors inherent to cellular CDMA systems that are not harmful for communication purposes but severely degrade the navigation performance. Such errors result from discrepancies between the clock biases of different sectors of the same base transceiver station (BTS). In this talk, these discrepancies are characterized and their effect on the navigation solution is studied. First, a linear time-invariant (LTI) stochastic dynamic model capturing the error between the clock biases of different sectors of the same BTS is developed and validated. Next, the statistics of the noise process driving this error are characterized. Our experimental results consistently show the discrepancy between the sectors clock biases to evolve according to a random walk dynamics with a Laplacian-distributed step-size. Then, the optimal incorporation of the proposed model into the navigation solution is discussed, and experimental results showing reduction in the navigation solution error are presented. Finally, useful bounds on the navigation performance in the presence of these discrepancies are derived, and experimental data demonstrating that these bounds are never violated is presented.

Title: Self-Adaptive Control of Compact Reverse Osmosis Systems

Speaker: Larry Gao, UCLA

Adviser: Panagiotis D. Christofides, UCLA

Abstract: Lack of access to sources of potable water is a huge problem in many parts of the world today. In rural communities within California, up to 250,000 people are unable to use their water for mundane uses such as for cooking or showering due to high levels of contaminants. Reverse Osmosis (RO) desalination has become the leading method for utilizing otherwise unusable water sources, such as seawater or brackish water. Today in California, RO desalination plants are operating in cities like Carlsbad and San Diego to provide water for their respective communities. However, large-scale plants such as the ones existing in Carlsbad and San Diego are not practical for the agricultural communities spread out over Central Valley. There is a need for distributed RO systems capable of automated operation. To optimize such systems for use by remote communities, a combination of novel system design and robust self-adaptive control were developed and implemented in order to reduce the maintenance/operation cost, as well as to simplify operation and reduce the required amount of human interface. Several pilot-scale plants were designed and constructed by a team of UCLA graduate student researchers and were deployed in several field studies. Various novel design and control concepts were developed, integrated, then tested. It was demonstrated that a combination of these approaches led to a significant improvement in the efficiency of RO systems.

Title: Fundamental Trade-offs in Robust Control with Heterogeneous Uncertainty

**Special Faculty Speaker:** Tamer Başar, Director, Center for Advanced Study; Swanlund Endowed Chair; CAS Professor of Electrical and Computer Engineering; Coordinated Science Laboratory; University of Illinois at Urbana-Champaign

**Abstract:** The paradigm of networked control systems, where the feedback loop is closed over heterogeneous networks, has opened up a vast number of opportunities for applications in different fields while creating also a number of challenges with regard to reliability, robustness, and security of control operations. This talk will address these challenges, where networks providing sensor measurements to controller(s) and those carrying control signals to the plant as well as the plant itself are vulnerable to stochastic as well as adversarial disturbances and sporadic failure of channel connectivity. The question of interest is the extent to which the plant, measured in terms of a performance metric, can tolerate such disturbances and failures, which themselves are also quantified in terms of some appropriate metrics.

Following a general overview of networked control problems, the talk will focus on linear-quadratic systems, with normbounded deterministic (adversarial) disturbance inputs and hybrid stochastic uncertainty, both of which impact network channels, where the latter is characterized by additive Gaussian noise and Bernoulli type failures. Explicit results for both the estimation problem and the control problem will be discussed under the TCP (Transmission Control Protocol) type information structure (which leads to certainty-equivalance, but not to separation of estimation and control), and the trade-offs between control performance, disturbance energy, and channel failure rates (that is, channel reliability) will be quantified. Under the UDP (User Datagram Protocol) type packet loss acknowledgment process, on the other hand, there is no certainty- equivalance, but still some trade-off results can be obtained. The talk will conclude with a discussion of future directions of research in this topical area and the challenges that lie ahead.

Title: Can Price-Discrimination Help Influence Social Behavior?

Speaker: Philip Brown, UC Santa Barbara

Adviser: Jason Marden, UC Santa Barbara

**Abstract:** Engineered systems with a significant social component often perform suboptimally; in the context of traffic routing in transportation networks, drivers' individual delay-minimizing route choices can lead to system-level overcongestion. Road pricing has been studied as a means to align drivers' incentives with those of the system designer. These pricing schemes typically charge every driver the same price, which has limitations if the driver population is highly diverse in price-sensitivity. Accordingly, we introduce a stylized model of price-discrimination, and show that if a system designer can coarsely disaggregate the driver population according to price-sensitivity, charging different tolls to different users may yield considerable performance gains. We will present a series of preliminary theoretical results demonstrating the potential benefits of price discrimination, including a general methodology by which off-the-shelf nondiscriminatory pricing schemes can be robustly adapted to a discriminatory setting. We conclude with a discussion of how such a system could be implemented. Title: Automata Theory Meets Approximate Dynamic Programming: Optimal Control with Temporal Logic Constraints

Speaker: Ivan Papusha, Caltech

Adviser: Richard Murray, Caltech

**Abstract:** We investigate the synthesis of optimal controllers for continuous-time and continuous-state systems under temporal logic specifications. We consider a setting in which the specification can be expressed as a deterministic, finite automaton (the specification automaton) with transition costs, and the optimal system behavior is captured by a cost function that is integrated over time. Specifically, we construct a dynamic programming problem over the product of the underlying continuous-time, continuous-state system and the discrete specification automaton. This dynamic programming formulation relies on the optimal substructure of the additive transition costs over the product of the system and specification automaton. Furthermore, we propose synthesis algorithms based on approximate dynamic programming for both linear and nonlinear systems under temporal logic constraints. We show that, for linear systems under co-safe temporal logic constraints, this approximate dynamic programming solution reduces to a semidefinite program.

Title: Output Feedback Control of the One-Phase Stefan Problem

Speaker: Shumon Koga, UC San Diego

Adviser: Miroslav Krstic, UC San Diego

**Abstract:** When a solid-liquid material (e.g. ice and water) is melting or freezing, the solid-liquid interface is moving due to its phase transition. Such a problem is formulated by the one-phase Stefan problem, which refers to a thermal diffusion partial differential equation (PDE) defined on a time varying spatial domain whose dynamics is actuated by the heat flux at the interface. In this presentation, a backstepping observer and an output feedback control law designed for the stabilization of the one-phase Stefan Problem will be addressed. We propose a backstepping observer allowing to estimate the temperature profile along the melting zone based on the available measurement, namely, the solid phase length. The designed output feedback controller ensures the exponential stability of the reference errors and estimation errors of moving interface and the H1-norm of the temperature profile with keeping physical constraints when the initial estimation is chosen to satisfy some explicitly given conditions.

Title: Team Learning and Performance via Assign/Appraise Dynamics

Speaker: Wenjun Mei, UC Santa Barbara

Adviser: Francesco Bullo, UC Santa Barbara

**Abstract:** In this talk we will propose models of team learning in groups of individuals who collectively execute a sequence of tasks. The individuals' actions are determined by individual skill levels and networks of interpersonal appraisals and influence. The closely-related proposed models have increasing complexity, starting with a centralized manager-based assignment and learning model, and finishing with a social model of interpersonal appraisal, assignments, learning, and influences. We will show how rational optimal behavior arises along the task sequence and discuss conditions of suboptimality. Our models are grounded in replicator dynamics from evolutionary games, influence networks from mathematical sociology, and transactive memory systems from organization science.

Title: Asking for Help with the Right Question by Predicting Human Visual Performance

Speaker: Hong Cai, UC Santa Barbara

Adviser: Yasamin Mostofi, UC Santa Barbara

**Abstract:** In this talk, we consider robotic surveillance tasks that involve visual perception. The robot has a limited access to a remote operator to ask for help. However, humans may not be able to accomplish the visual task in many scenarios, depending on the sensory input. We propose a machine learning-based approach that allows the robot to probabilistically predict human visual performance for any visual input. Based on this prediction, we then present a methodology that allows the robot to properly optimize its field decisions in terms of when to ask for help, when to sense more, and when to rely on itself. The proposed approach enables the robot to ask the right questions, only querying the operator with the sensory inputs for which humans have a high chance of success. Furthermore, it allows the robot to

autonomously locate the areas that need more sensing. We then run a number of robotic surveillance experiments on our campus as well as a larger-scale evaluation with real data/human feedback in a simulation environment.

Title: Multiscale Modeling and Operation of PECVD of Thin-Film Solar Cells

Speaker: Grant Crose, UCLA

Adviser: Panagiotis D. Christofides, UCLA

**Abstract:** In this work, we focus on the development of a multiscale modeling and run-to-run control framework with the purpose of improving thin film product quality in a batch-to-batch plasma-enhanced chemical vapor deposition (PECVD) manufacturing process. Specifically, at the macroscopic scale, gas-phase reaction and transport phenomena yield deposition rate profiles across the wafer surface which are then provided to the microscopic domain simulator in which the complex microscopic surface interactions that lead to film growth are described using a hybrid kinetic Monte Carlo algorithm. Batch-to-batch variability has prompted the development of an additional simulation layer in which an exponentially weighted moving average (EWMA) control algorithm operates between serial batch deposition sequences to adjust the operating temperature of the PECVD reactor to overcome drift in the electron density of the plasma. Application of the run-to-run (R2R) control system developed here is shown to reduce offset in the product thickness from 5% to less than 1% within 10 batches of reactor operation. Finally, we propose an extension of the EWMA algorithm to four independent, radial wafer zones in order to improve thickness uniformity in the presence of spatially non-uniform species concentrations. It is demonstrated that the produced thin films can be driven to the desired thickness set-point of 300 nm in less than 10 batches in the presence of both electron density drift and non-uniform deposition rate profiles.

Title: Robust Control over Delayed and Quantized Feedback with Applications to Human Sensorimotor Control

Speaker: Yorie Nakahira, Caltech

Adviser: John Doyle, Caltech

**Abstract:** The modern view of the nervous system as layering distributed computation and communication for the purpose of sensorimotor control and homeostasis has much experimental evidence but little theoretical foundation, leaving unresolved the connection between diverse components and complex behavior. As a simple starting point, we address a fundamental tradeoff when robust control is done using communication with both delay and quantization error, which are both extremely heterogeneous and highly constrained in human and animal nervous systems. This yields surprisingly simple and tight analytic bounds with clear interpretations and insights regarding hard tradeoffs, optimal coding and control strategies, and their relationship with well known physiology and behavior. These results are similar to reasoning routinely used informally by experimentalists to explain their findings, but very different from those based on information theory and statistical physics (which have dominated theoretical neuroscience).

**Title:** Higher-Order Averaging Analysis of the Nonlinear Time-Periodic Dynamics of Hovering Insects/Flapping-Wing Micro Air Vehicles

Speaker: Ahmed Hassan, UC Irvine

Adviser: Haithem Taha, UC Irvine

**Abstract:** Because of the wing oscillatory motion, the flight dynamics of biological flyers as well as their man-made mimetic vehicles, flapping-wing micro-air-vehicles (FWMAVs), is typically represented as a nonlinear time-periodic system (NLTP). Moreover, its equilibrium configurations (e.g., hovering) are represented by periodic orbits. In this work, we combine tools from geometric control theory and averaging to perform higher-order averaging analysis on the NLTP dynamics of FWMAVs near the hovering equilibrium. The objective is to achieve balance at hover; that is, to ensure a periodic solution whose velocities have zero-mean values.