CPS: SYNERGY: COLLABORATIVE RESEARCH: CNS-1239021

A CYBER-PHYSICAL INFRASTRUCTURE FOR THE "SMART CITY"

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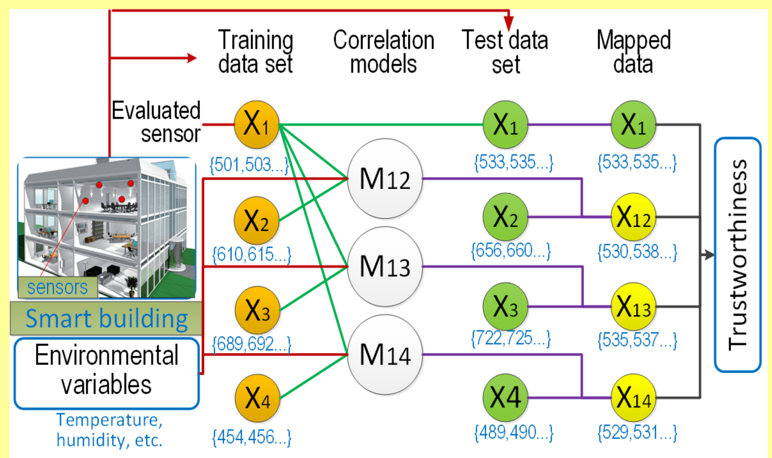
ELECTRICAL & COMPUTER ENGINEERING CNS-1239102
MECHANICAL & AEROSPACE ENGINEERING CNS-1239030

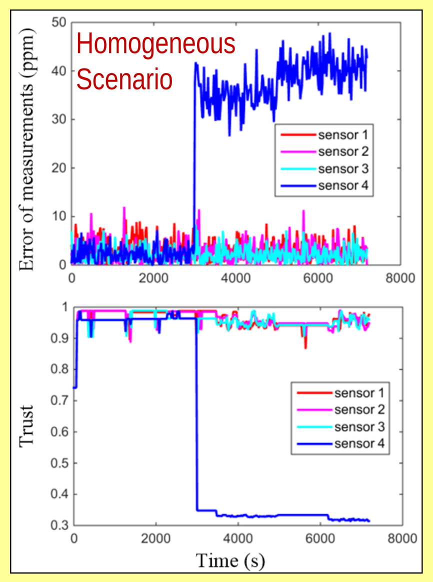
SELECTED RESEARCH TASKS

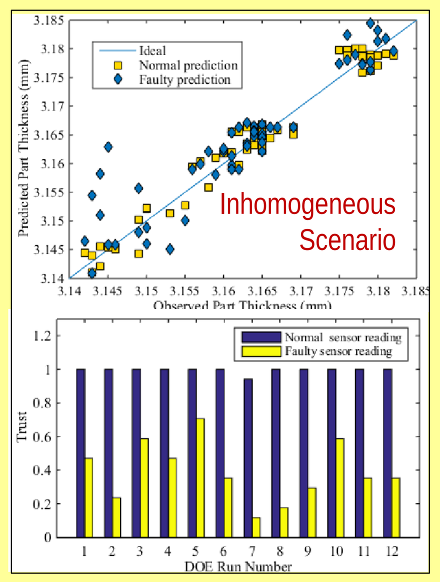
TRUSTWORTHINESS EVALUATION FOR SENSING

- Trustworthy sensing is the physical foundation for CPS systems monitoring and control;
- Developed an analytical platform for trustworthiness evaluation of sensor data, based on correlation and redundancy of spatially distributed sensors:
  - ✓ Homogeneous sensors: evaluate trustworthiness of sensor at any location using its geometrical correlation with sensors in the neighborhood;
  - ✓ Inhomogeneous sensors: map sensor data of different physical nature to a common quantity and evaluate trustworthiness of sensors through an inverse operation.
- Introducing a new measure for quantifying sensor performance:

Sensor Trustworthiness as probability: $\pi(z_i;\hat{z}_i) = P(|z_i - \hat{z}| < \sigma)$ Given sensor data z and estimated ground truth $\hat{z}$



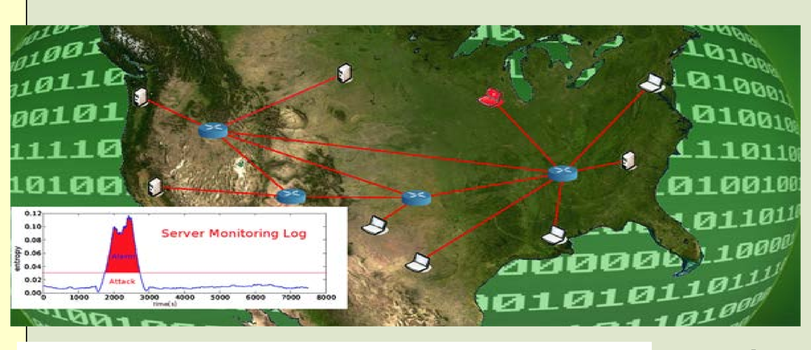


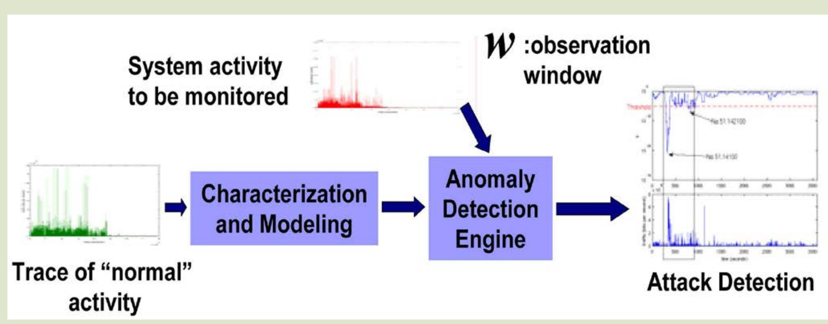


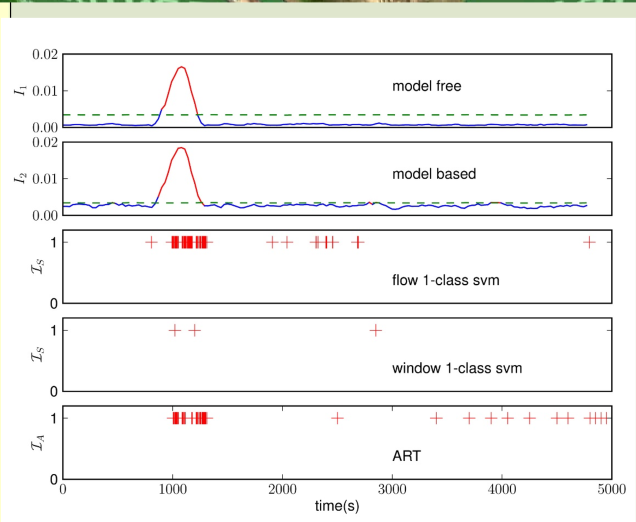
Application: *occupancy sensing* for energy efficiency optimization in buildings

Wang and Gao, CIRP CMS, 2015 Wu et al. I2MTC, 2016

ANOMALY DETECTION FOR CPS SECURITY



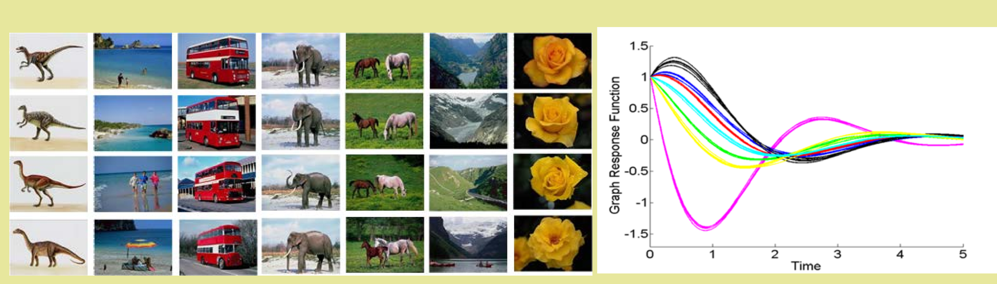




- Anomaly detection is more suited to detect novel anomalies vs. signature-based methods
- Developed a series of complementary approaches:
  - Statistical methods using model-free and Markovian models, including methods that can handle time-varying traffic
  - Machine learning methods leveraging Support Vector Machines (SVMs) in an unsupervised setting
  - Classification-based methods leveraging the biologically-inspired Adaptive Resonance Theory (ART).
- Validated using real and synthetic anomalies

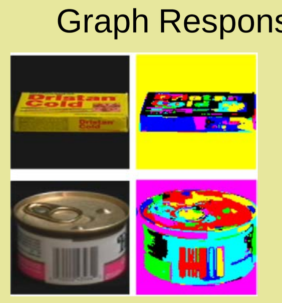
Wang & Paschalidis, TCNS 2015, Wang, Rossell, Cassandras, Paschalidis, CDC 2013.

GRAPH RESPONSE FUNCTIONS FOR FEATURE EXTRACTION AND CLASSIFICATION IN MONITORING CPS EQUIPMENT

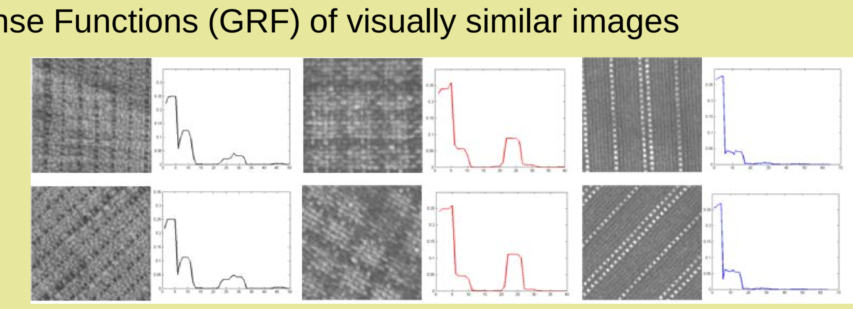


- Structure-preserved graph generation for image
- Graph response function based image feature
- Robust to rotation/affine transform/noise
- Robust to small change of view point
- Executable on small devices

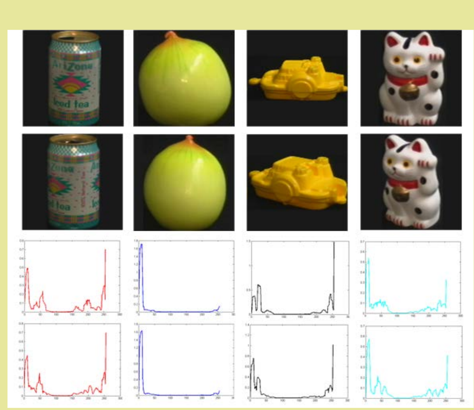
Graph Response Functions (GRF) of visually similar images



Structure-preserved graph generation



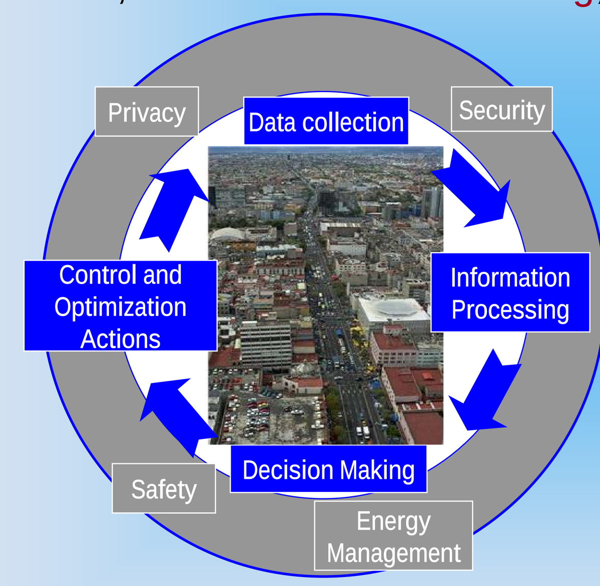
GRF-based rotational invariant texture feature



GRF spectrum is robust to small change of view point

RESEARCH OBJECTIVES

- Establish a Cyber-Physical Infrastructure for urban environments
- Address fundamental problems that involve data collection, resource allocation, real-time decision making, safety, and security



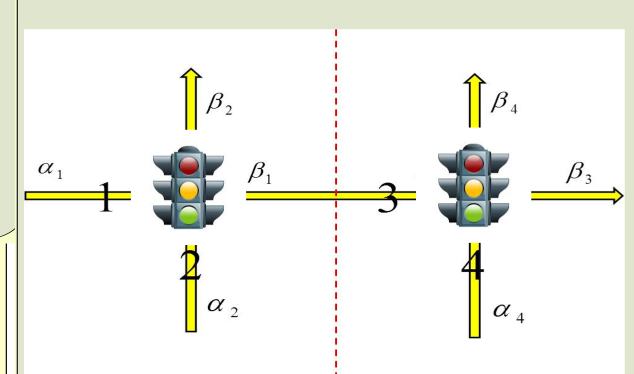
APPLICATIONS

- Traffic Light Control
- "Smart Parking"
- Electric Vehicle Management
- Urban Sensor Networks
- …

RESEARCH TASKS

1. **Sensing and Data Acquisition :**
   - **Energy Harvesting**
   - **Dynamic Voltage Scheduling**
   - **Static and Dynamic Data Collection**
   - **Trustworthiness of Sensing Data**
   - **CPS Security**
2. **Decision Support :**
   - **Dynamic Resource Allocation/Optimization**
   - **Event-Driven Control, Communication, Optimization**
   - **Constrained Flow Network Design and Analysis**
   - **Software Defined Networks for CPS Applications**

ADAPTIVE *QUASI-DYNAMIC* TRAFFIC LIGHT CONTROL



Traffic light control:

$(\theta_{n\min}, \theta_{n\max}),\quad n = 1,\ldots,4$ GREEN light cycles

$s_n,\quad n = 1,\ldots,4$ Thresholds: switch n to GREEN if $x_n > s_n$ and current GREEN at m has exceeded $\theta_{n\min}$

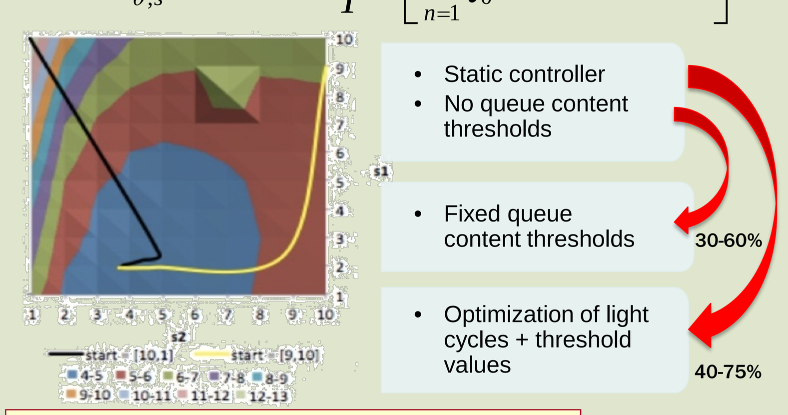
OBJECTIVE: minimize weighted vehicle backlog:

$$\min_{\theta,s} J(\theta,s) = \frac{1}{T} E\left[\sum_{n=1}^{4}\int_0^T w_n x_n(\theta,s,t)\,dt\right]$$

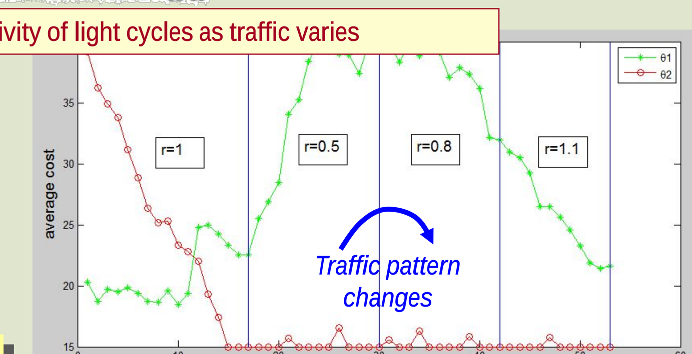
- Model as Stochastic Hybrid System
- Use Infinitesimal Perturbation Analysis (IPA) to estimate $\nabla J(\theta_n)$ on line
- Gradient based adaptive scheme:

$$\theta_{n+1} = \theta_n + \eta_n \hat{\nabla} J(\theta_n)$$

- IPA estimators are independent of stochastic traffic flow characteristics
- IPA estimators are event-driven, scalable in the number of observed events – not limited by added system complexity, state space dimensionality
- Simple implementation: timers, counters



Adaptivity of light cycles as traffic varies



Fleck and Cassandras, IEEE TCST, 2016

SELECTED RESEARCH TASKS

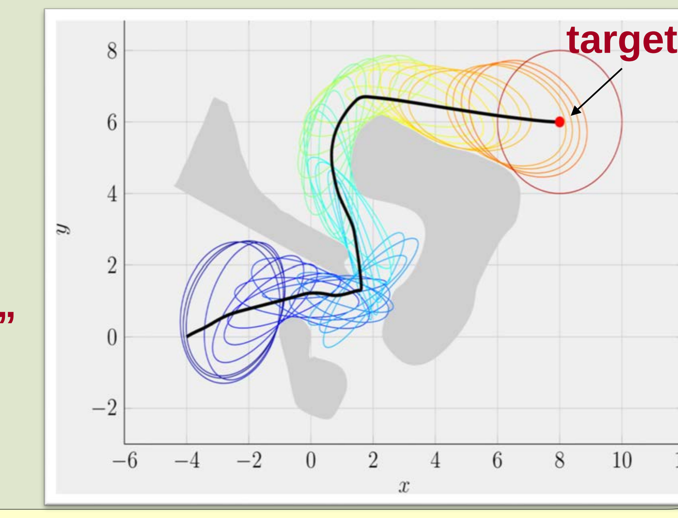
DRONES FOR SURVEILLANCE AND EMEREGNCY RESPONSE

- UAVs can observe traffic and deploy rapidly in case of accidents and disasters to guide 1st responders and deliver supplies
- Concentrated on path planning, aiming at reaching a target area while avoiding obstacles (e.g., buildings) or no-fly zones
- Developed a new method for robust model predictive control that can accommodate uncertainties due to limitations in the UAV sensors

Use of Quadrotors for surveillance and emergency response in smart cities

A Quadrotor navigating to the target while avoiding no-fly zones through a sequence of "safe" ellipsoids

Ataei & Paschalidis, CDC 2015

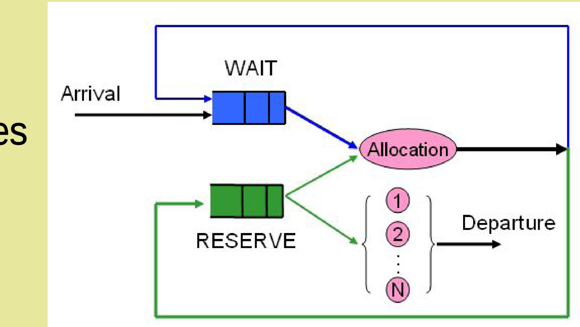


DYNAMIC RESOURCE ALLOCATION: "SMART PARKING" SYSTEM

- MOTIVATION: 30% of vehicles in urban downtown areas are cruising for a parking spot. Average driver needs 7.8 minutes to find one.
- "Smart Parking" System assigns and reserves optimal parking spaces based on driver objective function:

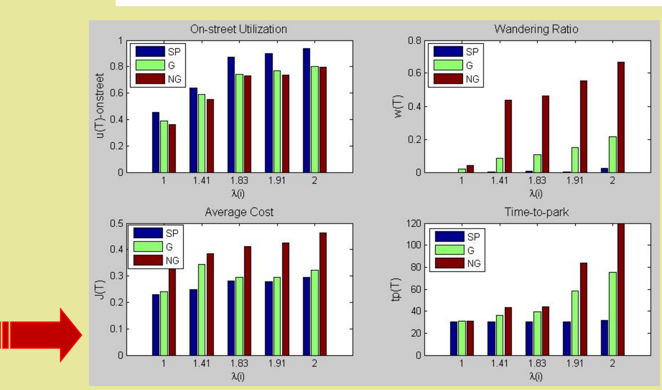
$$J_{ij}(k) = \lambda_i \frac{M_{ij}(k)}{M_i} + (1-\lambda_i)\frac{D_{ij}}{D_i}$$

weight → walking distance → parking cost



- Optimal allocation made by solving MILP problem over time
- "Smart Parking" provides quality and fairness guarantees
- Simulation case study based on parking at Boston U. campus: Smart Parking vs Parking Guidance systems

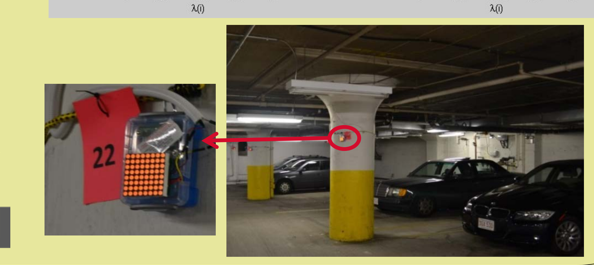
win-win Situation
- Higher (10-20%) and more balanced parking utilization
- Up to 50% reduction in parking time under heavy traffic
- % drivers searching for parking reduced to < 10%



DEPLOYMENT AT BU PARKING FACILITY

"BU Smart Parking" iPhone App

Geng and Cassandras, IEEE TITS, 2013



CONNECTING CYBER & PHYSICAL INFRASTRUCTURES THROUGH A CLOUD PLATFORM

SCOPE: Smart-city Cloud-based Open Platform and Ecosystem

A. Bestavros (PI), C. Cassandras, L. Hutyra, and E. Terzi. SCOPE: A Smart-city Cloud-based Open Platform and Ecosystem. NSF PFI:BIC Award #1430145, 2014.

SCOPE is a cloud computing platform that exposes the digital pulse of the City of Boston, allowing innovators to develop smart services that leverage a unique ecosystem of technology, organizations, and big-data assets. SCOPE integrates cyber-physical and data management/mining capabilities into an open cloud architecture, targeting services and applications in transportation and mobility, energy and environmental sustainability, public safety, and urban planning.