Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation

Overview

MURI Annual Review Meeting

Randy Moses

November 3, 2008
Research Goal

- Develop an integrated systems theory that jointly treats information fusion, control, and adaptation for automatic target exploitation (ATE).
  - Multiple, dynamic sensors
  - Multiple sensing modes
  - Resource-constrained environments
Research Framework

ATE Objectives
Sensor Resources

Optimal, Robust Information Fusion
- Graphical Models
- Performance Measures
- Information State Propagation
- Contextual Models
- Learning and Adaptation

Dynamic Sensor Resource Management
- Dynamic sensor allocation
- Efficient sensor management algorithms
- Multi-level planning
- Performance uncertainty

Adaptive Front-End Signal Processing
- Decision-directed Imaging and Reconstruction
- Modeling and Feature Extraction
- Statistical Shape Estimation

Features and Uncertainties
Priors and Learned Statistics
Measurement Constraints
Value of Information

ATE Objectives
Sensor Resources

ATR/ATE Inferences
and Confidences
Inference-rooted metrics provide the common language across the system.
Information Fusion: Key Research Questions

**ATE Objectives**

- Sensor Resources

**Optimal, Robust Information Fusion**

- Graphical Models
- Performance Measures
- Information State Propagation
- Contextual Models
- Learning and Adaptation

**ATR/ATE Inferences and Confidences**

**Features and Uncertainties**

**Adaptive Front-End Signal Processing**

- Decision-directed Imaging and Reconstruction
- Modeling and Feature Extraction
- Statistical Shape Estimation

**Priors and Learned Statistics**

**Value of Information**

- Dynamic Sensor Resource Management

**Constraints**

**Performance Prediction**

- to support sensor management

**What are the ‘right’ performance measures and bounds for FE and Sensor Mgmt?**

**MURI: Integrated Fusion, Performance Prediction, and Sensor Management for Automatic Target Exploitation**

- How to effectively direct front-end signal processing?
Signal Processing: Key Research Questions

**Feature sets and feature uncertainties that permit fusion across modalities**

**Adaptive Front-End Signal Processing** (R. Moses, lead)
- Decision-directed Imaging and Reconstruction
- Modeling and Feature Extraction
- Statistical Shape Estimation

**Problem formulations that admit context, priors and directed queries**

- Physics-based feature representations
- Decision-directed imaging and reconstruction
- Feature uncertainty characterization
- Statistical shape estimation
- Adaptation and Learning
Sensor Management: Key Research Questions

**ATE Objectives**

- Sensor Resources

**Optimal, Robust Integration**

- Fusion
  - Graphical Models
  - Performance Measures
  - Information State Propagation
  - Contextual Models
  - Learning and Adaptation

**Dynamic Sensor Resource Management**

- D. Castañón, lead
  - Integrate ATE performance based on graphical models
  - Manage evolution of “information state” in support of ATE missions

**Active sensor control that incorporate ATE performance metrics**

- Multi-modal, heterogeneous platforms

**Scalable real-time algorithms for theater-level missions**

- Robust to inaccurate performance models

- Modeling and Feature Extraction
- Statistical Shape Estimation

**Measurement Constraints**

**Value of Information**

- Dynamic sensor allocation
- Efficient sensor management algorithms
- Multi-level planning
- Performance uncertainty
MURI Payoff

Goal: Develop an integrated theory for ATE systems that combines information fusion, platform control, signal processing, and adaptation.

Research Outcomes:
- An integrated theoretical framework for dynamic information exploitation systems.
- Theoretical foundations for adaptivity and learning in complex inference systems.
- New algorithms and performance metrics for coupled signal processing, fusion, and platform control.

Payoff:
- Systematic design tools for end-to-end design of multi-modal, multi-platform ATE systems.
- Active platform control to meet ATE objectives.
- System-level ATE performance assessment methods.
- Adaptive, dynamic ATE systems.
MURI Team

UNIVERSITY TEAM:
- Ohio State University (lead)
  - Randy Moses (PI)
  - Lee Potter
  - Emre Ertin
- Massachusetts Institute of Technology
  - Alan Willsky
  - John Fisher
  - Mujdat Çetin (also Sabanici U.)
- Boston University
  - David Castaño
  - Clem Karl
- University of Michigan
  - Al Hero
- Florida State University
  - Anuj Srivastava

AFOSR:  David Luginbuhl → Doug Cochran
AFRL POC:  Greg Arnold
Year 1 Meeting Feedback

- Strongly positive on team expertise and interactions.
- Strongly supportive of research plan.
- Maintain emphasis on fundamental research.
  - Assumptions that maintain relevance.
- Maintain research continuity and relevance.
  - Complementary research problem statements, compatibility across the team.
  - Scalability
  - Performance Prediction

Year 2 Advances

- Regularized Tomography for Sparse reconstruction
  - Sparse apertures – monostatic and multistatic
  - Sparse ‘objects’ (targets or scenes)
  - Anisotropy characterization
  - 3D Reconstruction for wide angle and circular SAR
  - Decision-directed reconstruction
  - Lots of cross-pollination

- Shape Statistics for Curves and Surfaces
  - Shape Analysis
    - Shape distribution; not just point estimates
  - Bayesian classification from shapes
  - Bayesian shape estimation from EO/IR images
Year 2 Advances II

Sensor Management
- Multiplatform information-theoretic dynamic sensor management using integer optimization
- Adaptive dynamic sensor management algorithms and performance bounds for radar search, detection and classification
- Multi-Radar resource management with guaranteed uncertainty metrics

Scalable Inference
- Lagrangian relaxation and multiresolution methods for tractable inference in graphical models
- New graphical model-based algorithms for multi-target, multi-sensor tracking
- Learning Graphical Model structures directly for discrimination
- GM-based distributed PCA and hyperspectral image discrimination
- Graphical models to extract dynamic behavior modes
MURI Students

- 11 graduate students and 1.5 postdocs supported by the MURI.
- 14 graduate students and 1 postdoc working on the MURI team with outside support (e.g. fellowships) or partial funding.
- 7 PhD and 8 MS degrees awarded

- People
- Publications
- On-line research collaboration space
- Resources
Synergy Examples: Joint Data Collections

- **October 2007: Layered Sensing over OSU Campus**
  - AFRL: 3 airborne imaging sensors
  - AFRL and OSU: rooftop sensors
  - OSU: acoustic, seismic, microsensor radar ground sensors

- **November 2007: Follow-up layered sensing collection**
  - Rooftop and Ground sensors
  - Richer set of people tracking scenarios

- **August 2008: AFRL Radar/EO sensing**
  - Our MURI provided
    - test targets, stationary and moving vehicles, “sweat equity”
    - INS measurements of moving targets; Location ground truthing
    - Acoustic and Seismic ground sensing
    - Moving vehicle test plans
  - Data to benefit multiple university programs
    - MURI, AFOSR DCT program, ATR Center research
Test Reflectors

- Urban propagation measurements
  - Top hats
    - Isotropic even bounce return
    - 11.1 dBsm (48 inch base; 16x12.5 cylinder)
  - Quad corners
    - Quasi-isotropic odd bounce return
    - 10.0 dBsm (5 inch squares)
  - Bruderhedral at 45 degrees
    - Wide beam cross-polarization return
    - 5 dBsm
    - Loan from SET Corp
Phase Alignment Reflectors

- 14 Quad-corners
  - 37.2 dBsm
Civilian Vehicles
Today’s Presentations

ATE Objectives
Sensor Resources

Optimal, Robust Information Fusion

Optimal, Robust Information Fusion in Uncertain Environments (Willsky)

Features and Uncertainties

Adaptive Front-End Signal Processing

Inference-Aware Feature Extraction and Reconstruction (Çetin, Ertin, Karl, Moses, and Potter)

Front-End Processing Research on Shape Analysis (Fisher, Srivastava, Willsky)

ATR/ATE Inferences and Confidences

Graphical Models for Resource-Constrained Hypothesis Testing and Multi-Modal Data Fusion (Castañón, Fisher, Hero)

Dynamic Sensor Resource Management

Progress in Sensor Management for Integrated Surveillance (Castañón, Fisher, Hero)

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<tr>
<th>Time</th>
<th>Event</th>
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<tr>
<td>8:30 - 9:00</td>
<td>Intro and Overview (Moses)</td>
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<tr>
<td>9:00 - 9:40</td>
<td>Optimal, Robust Information Fusion in Uncertain Environments (Willsky)</td>
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<tr>
<td>9:40 - 10:25</td>
<td>Inference-Aware Feature Extraction and Reconstruction (Potter)</td>
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<td>10:25 - 10:45</td>
<td>Break</td>
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<td>10:45 - 11:15</td>
<td>Shape Analysis Research (Srivastava)</td>
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<td>11:55 - 12:50</td>
<td>Lunch - <strong>Blackwell Ballroom</strong></td>
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<td>12:50 - 1:30</td>
<td>Progress in Sensor Management for Integrated Surveillance (Castañón )</td>
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<td>1:30 - 2:00</td>
<td>Summary (Moses)</td>
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<td>Government caucus</td>
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<td>Feedback and Discussion</td>
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