DDDAMS-based Border Surveillance and Crowd Control via UVs and Aerostats

**Sponsor:**
Air Force Office of Scientific Research
FA9550-17-1-0075
Program Manager: Dr. Erik Blasch

**PIs:** Young-Jun Son¹, Jian Liu¹, Jyh-Ming Lien²
**Students:** S. Lee¹, Y. Yuan¹, H. Na¹, H. Yang¹

¹Systems and Industrial Engineering, University of Arizona
²Computer Science, George Mason University

**PI Contact:** son@sie.arizona.edu; 1-520-626-9530

AFOSR DDDAS PI Meeting Sep. 7th, 2017
Agenda

• Problem Definition and Modeling Framework

  • Model Description and Implementation via Sensors

• Systems Software
Border Surveillance and 3-Level Framework

3-Level Physical Framework

High altitude level (HAL)

Low altitude level (LAL)

Surface level (SL)

3-Level Information Framework
Major Challenges in Border Surveillance

• 3-D Surveillance System for aerial and ground targets

• Effective detection, recognition and identification of targets

• Heterogeneous data from complex targets by 3 levels of sensors

• Multi-level information aggregation

• Active or pro-active surveillance strategies

• Realistic scenarios and model validation based on data collection from our research partners (AFRL, Raytheon, University Partners …)
3-Level Measurement System in Border Surveillance

3-Levels

- High altitude level (HAL)
- Low altitude level (LAL)
- Surface level (SL)

Sensors

- SAR Image
- EO/IR Image
- Lidar Image
- Thermal Images
- Spectral Image

Measurement Data

- Magnetic Data
LiDAR Data Processing

A Velodyne HDL64 LiDAR integrated with a golf cart for **outdoor** scanning

A Velodyne HDL32 LiDAR integrated with a powered wheelchair for **indoor** scanning

Registered LiDAR data captured on George Mason Campus

LiDAR+Photos = Better Localization [Arsalan, Kosecka, Lien, ICRA 2015]
DDDAMS Framework
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DDDAMS Framework: Target DRI

(Detection, Recognition, Identification)
Target DRI (1): Detection

- **Goal**: Discover the presence of a person, object, or phenomenon

- **Sensing technologies**: Cameras (UAV, UGV), Seismic Sensors
- **Algorithms**: Motion detection, Control Charts

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Target DRI (2): Recognition

- **Goal:** Determination of the *nature* of a detected person, object or phenomenon, and its class or type

- **Algorithms:** Wavelet decomposition, Classification

**Target DRI (3) : Identification**

- **Goal:** Discrimination between recognizable objects as being **friendly** or **enemy**

- **Algorithms:** Information-aggregation method, Extended BDI (Belief-Desire-Intention) framework

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Crowd Detection Module ➞ UAV

**Goal:**

Moving Target Detection via Sliding Window

§1. Feature extraction: Good features to track

§2. Feature tracking: Optical flow

§3. Image registration: RANSAC, Homography

§4. Background elimination: Absolute differences

§5. Targets segmentation: Motion history, Dilation-erosion


Individual Detection/Recognition Module → UGV

- **Goal:** HOG (Histogram Oriented Gradient) based Target D/R

  - **Gradient computation:**
    - 3x3 derivative mask
    - $[-1, 0, 1]$  

  - **Orientation binning:**
    - Weighted voting over cells
    - 6x6 pixel cells

  - **HOG over des. blocks:**
    - Grouping cells into blocks
    - 3x3 cell blocks

  - **Block normalization:**
    - L2-norm

  - **Classify the target:**
    - OpenCV classifier

References:
Detection ➔ Ground Seismic Sensor

- **Goal**: Target Detection based on Control Charts
- **Detect presence of an object**

![Graphs showing normal and target appearances with detected spikes](image)

**System Components:**
- Geophone
- Amplifier
- Gateway
- Software
**Goal:** Target’s Characteristics Recognition (e.g., walking/running)

**Challenge:** Raw data are noisy and mathematically inseparable

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**Recognition → Ground Seismic Sensor**

- **Training Data**
  - Walking
  - Running

- **Knowledge**
  - Walking Wavelets: 0.5s/Period
  - Running Wavelets: 0.33s/Period

- **Wavelet Coefficients**
  \[ C = \begin{bmatrix} C_{run} \\ C_{walk} \end{bmatrix} \]

- **Model:** Wavelet decomposition

- **Regression**

- **Feature Extraction Methods:**
  - Fisher's Discriminant Analysis
  - SVM Classifier

- **New Observation**
### Behavioral Models of Drug Traffickers

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<thead>
<tr>
<th>Decision 1</th>
<th>Decision 2</th>
<th>Decision 3</th>
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<td><strong>Selection at Departure</strong></td>
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<td>Rugged Road</td>
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<td><strong>En-Route Planning</strong></td>
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<td>Hiding/Avoiding</td>
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<td>Sudden Direction Change</td>
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**Goal:** Target identification via behavior models of drug traffickers and ground patrol agents under varying environmental conditions.

- **Hiding**
- **Direction Change**
Extended Belief-Desire-Intention (EBDI) Framework

Bratman, 1987
Rao and Georgeff, 1998
Zhao and Son, 2008

Identification → Fusion of Sensor Data

- **Goal:** Target’s Identification (e.g., Friend/Foe)
- **Challenge:** Fusion of different sensor data (UAV vision and seismic)
Superhuman Vision via Information Fusion

DDDAS in border patrol’s computing unit

- **Task**: Augment patroller agent’s vision system with real-time imagery data collected by UAVs and the patrol agent.

- **Inputs**:
  - (1) Low-resolution but less-occluded image/3D data from UAV
  - (2) High-resolution but much-occluded captured by the border patrol

- **Output**: Fused and registered data captured by the UAV to images captured by the border patrol agents.

- **Method**: The key in enhancing the border patrol's vision is in finding the correspondences between the features extracted from the images captured by the UAV and the patrol agents and identifying occluded objects in patrol agents’ view.
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Agent-based Hardware-in-the-loop Simulation

Physics Based Simulation for Data Generation

Real Pictures from UAV

Generated Pictures from Simulation
Physics Based Simulation for Data Generation

• **Goal:** Visionary data generation using various simulation objects.
Detection module $\rightarrow$ (Simulated) UAV

- **Goals:** Applying detection algorithm using data from simulated UAV.
Detection module ➔ (Simulated) UGV

- **Goal:** Applying HOG detection algorithm to simulated data from UGV.
• Summary of Effort
  – AF relevance to autonomous systems; collaborative/cooperative control; sensor-based processing; multi-scale simulation technologies; cognitive modeling

• Key Focus of Scientific Research
  – Active or pro-active border surveillance strategies
  – Multi-level information aggregation involving heterogeneous data from 3 levels of sensors
  – Handling latency in detection, recognition, & identification of targets

• Other performers on project
  – Y. Son (UA), J. Liu (UA), J. Lien (George Mason)
  – Students: S. Lee, Y. Yuan, H. Na, H. Yang
• Accomplishments
  – Developed/refined a DDDAMS-framework for a 3 level border surveillance system
  – Developed preliminary models and algorithms for target DRI, group prediction, and mission control
  – Hardware in the loop simulation (agent; physics simulation)

• Awards
  – (PhD graduate at U of Arizona) Dr. Sara Minaeian, August 2017 (Joined Siemens)
  – (Best paper award in “Service and Work Systems” track) S. Lee (PhD student) and Y. Son, “Extending Decision Field Theory to a Multi-agent Decision-making with Forgetting,” Proceedings of 2016 IISE Annual Meeting, Anaheim
• Reporting


  – Minaeian, S., Liu, J., & Son, Y.-J. Effective and Efficient Detection of Moving Targets from a UAV’s Camera. Submitted to Intelligent Transportation Systems, IEEE Transaction on, Special Issue on Robust & Efficient Vision Techniques for Intelligent Vehicles, (Under Review)

  – Minaeian, S., Liu, J., & Son, Y.-J. Effective and Efficient Multi-target Data Association via Dynamically Adjusted Affinity Scores, (to be submitted to a journal in September, 2017)

Coordination/Synergy

- Exploring collaboration and access to aerostat data with Raytheon (no access yet)

- Discussed collaboration opportunities with Tathagata Mukherjee (Intelligent Robotics, Inc) at the 2017 PI meeting in Dayton, and will schedule follow-up meetings together with Eduardo Pasiliao at AFRL

Exposure/Use by other groups

- Hardware-in-the-loop demos to visitors (STEM students, summer students, visitors from industry and other universities)
Acknowledgements

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PI Contacts:
son@sie.arizona.edu; 1-520-626-9530
jianliu@email.arizona.edu; 1-520-621-6548
jmlien@cs.gmu.edu; 1-703-993-9546