Flexible Resource Assignment in Sensor Networks: A Hybrid Reasoning Approach

Geeth de Mel 1, Murat Sensoy 1, Wamberto Vasconcelos 1, Alun Preece 2
1 University of Aberdeen
2 University of Cardiff

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Outline

- Introduction
  - Problem and Motivation
- Approach
  - Capability Inference
  - Capability-Asset Matching
- Future work
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Introduction: Problem

- Resource assignment in sensor networks involves assignment of sensing assets to tasks such that the assigned assets sufficiently and effectively cover the information needs of tasks.
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Introduction: Problem

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\[ T_1 \rightarrow S_1, \quad T_2 \rightarrow S_4 \]
Coalitions are formed to achieve collective goals.

Due to the nature of coalitions and the environments they operate on, asset-task assignment is even more complicated.

- Different partners
  - Ownership issues, Policy issues etc.
- Heterogeneity of the sensing assets
  - Quantitative and Qualitative attributes
- Assets are scarce and high in demand
- Multiple tasks to accomplish simultaneously
- Highly dynamic environment (assets failures, situation changes etc)
Introduction: In a Coalition
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TASK 1
Identify enemy vehicles

TASK 2
Enemy activity in the region

TASK 3
Detect suspicious vehicles
Introduction: In a Coalition

- Task 3: Detect suspicious vehicles
- Task 7: Rescue trapped civilians
- Task 2: Enemy activity in the region
- Task 6: Injured people to identify
- Task 1: Identify enemy vehicles
- Task 5: Detect vehicles in a dusty road
- Task 4: Area surveillance (main supply route)
- Task 8: Aerial surveillance

Adopted from EKAW 2008 - Slide credit: Diego Pizzocaro, University of Cardiff
Introduction: Approach

- Need to infer different capabilities that could be used to satisfy tasks.
  - *Acoustic* or *imagery* data could be used to detect a vehicle.

- Need to decide what types of assets are capable of satisfying the information requirements of each task.
  - Logically sounding pairs of assets and tasks. They match in-terms of the requirements advertised by the tasks and the capabilities provided by the assets.
  - If a *radar* is capable of performing the tasks, then a *synthetic aperture Radar* (SAR) is also capable of performing the task.
Capability Inference

- Requirements are specified at a high level.
  - Detect vehicle movement near the city centre.
  - Detect human activity in the city centre.
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Capability Inference
# Capability Inference

## National Image Interpretability Rating Scales (NIIRS)

### NIIRS 1 [over 9.0 m GRD]

<table>
<thead>
<tr>
<th>Visible NIIRS</th>
<th>Radar NIIRS</th>
<th>Infrared NIIRS</th>
<th>Multispectral NIIRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detect a medium-sized port facility and/or distinguish between taxi-ways and runways at a large airfield.</td>
<td>Detect the presence of aircraft dispersal parking areas.</td>
<td>Distinguish between runways and taxiways on the basis of size, configuration or pattern at a large airfield.</td>
<td>Distinguish between urban and rural areas.</td>
</tr>
<tr>
<td></td>
<td>Detect a large cleared swath in a densely wooded area.</td>
<td>Detect a large (e.g., greater than 1 square kilometer) cleared area in dense forest.</td>
<td>Identify a large wetland (greater than 100 acres).</td>
</tr>
<tr>
<td></td>
<td>Detect, based on presence of piers and warehouses, a port facility.</td>
<td>Detect large ocean-going vessels (e.g., aircraft carrier, super-tanker, KIROV) in open water.</td>
<td>Detect meander flood plains (characterized by features such as channel scars, oxbow lakes, meander scrolls).</td>
</tr>
<tr>
<td></td>
<td>Detect lines of transportation (either road or rail), but do not distinguish between</td>
<td>Detect large areas (e.g., greater than 1 square kilometer) of marsh/swamp.</td>
<td>Delineate coastal shoreline.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Detect major highway and rail bridges over water (e.g., Golden Gate, Chesapeake Bay).</td>
</tr>
</tbody>
</table>

NIIRS: [http://www.fas.org/irp/imint/niirs.htm](http://www.fas.org/irp/imint/niirs.htm)
Capability Inference

**Radar**

**NIIRS**

Detect the presence of aircraft dispersal parking areas.

Detect a large cleared swath in a densely wooded area.

Detect, based on presence of piers and warehouses, a port facility.

Detect lines of transportation (either road or rail), but do not distinguish between

**Visible NIIRS**

Detect a medium-sized port facility and/or distinguish between taxi-ways and runways at a large airfield.

**Multispectral NIIRS**

Distinguish between urban and rural areas.

Identify a large wetland (greater than 100 acres).

Detect meander flood plains (characterized by features such as channel scars, oxbow lakes, meander scrolls).

Delineate coastal shoreline.

Detect major highway and rail bridges over water (e.g., Golden Gate, Chesapeake Bay).

Delineate extent of snow or ice cover.

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Capability Inference
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- 3 main interpretation task (IT) types

  - Detect
  - Distinguish
  - Identify

- Knowledge base created from NIIRS knowledge corpus

\[ FIT(T,W,F,C,I,V) \]

- **T** = Type of the interpretation task to perform (detect, distinguish, or identify)
- **W** = \{W_i\} is a set of Detectables that can be observed from the image
- **F** = \{F_j\} is a set of Detectables which are features of W
- **C** = Represents the context of the detectables
- **I** = Type of NIIRS
- **V** = Value of NIIRS
Capability Inference

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Detect, based on presence of piers and warehouses, a port facility

\[
FIT(\text{detect},[\text{Port}],[\text{Pier,Warehouse}],[\ ],\text{image(Radar)},1)
\]

Detect a large cleared area in dense forest

\[
FIT(\text{detect},[\text{ClearedArea}],[\ ],[\text{DenseForest}],\text{image(Infrared)},1)
\]
Capability Inference
Capability Inference

- Rules to capture the knowledge and forward chaining to find required NIIRS values to perform the tasks.

\[
\begin{align*}
\text{detect}(x_j, i_j, v_j) & \leftarrow \text{distinguish}(x_j, i_j, v_j) \\
\text{distinguish}(x_j, i_j, v_j) & \leftarrow \text{identify}(x_j, i_j, v_j) \\
\text{detect}(x_j, i_j, v_j) & \leftarrow \text{FIT}(\text{detect}, w, f, c, i_j, v_j) \land x_j \in w \\
\text{identify}(x_j, i_j, v_j) & \leftarrow \text{FIT}(\text{identify}, w, f, c, i_j, v_j) \land x_j \in w \\
\text{distinguish}(x_j, i_j, v_j) & \leftarrow \text{FIT}(\text{distinguish}, w, f, c, i_j, v_j) \land x_j \in w
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Capability Inference

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\begin{align*}
detect(x_j, i_j, v_j) & \leftarrow distinguish(x_j, i_j, v_j) \\
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identify(x_j, i_j, v_j) & \leftarrow FIT(identify, w, f, c, i_j, v_j) \land x_j \in w \\
distinguish(x_j, i_j, v_j) & \leftarrow FIT(distinguish, w, f, c, i_j, v_j) \land x_j \in w
\end{align*}
\]

?- detect(largeAirliner,Results).
Results = [(image(infrared),2),(image(radar),2),(image(visible,3))]

?- detect(smallAirliner,Results).
Results = [(image(infrared),3)]

?- distinguish([largeAirliner,smallAirliner],Results).
Results = [(image(infrared),3)]
Capability-Asset Matching
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- Knowledge represented via ontologies.
  - Sensors and platforms
  - Sensing capabilities provided by assets.
  - Information requirements of tasks
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• Semantic matchmaking to evaluate the fitness-for-purpose of collections of asset types to the information requirements of a task.
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Dr. Mario Gomez, ACITA 2007
System Architecture

- Rule System
  - Acoustic KB
  - Imagery KB
- Mission Script
- Reasoner
  - < requirements >
  - < tasks >
  - < capabilities >
  - < packages >
- ISTAR
- Sensor Catalog
- Sensor Infrastructure
• **Packages**: A collection of all possible assets types that could satisfy tasks.
Rescue Hostages
Sabotage Dirty Bomb
Tracking Insurgents
Main Supply Route Surveillance

Details :: Main Supply Route Surveillance

Commander's Intent: Protect main supply route (MSR) which is under threat by insurgents
Description: ...

Operations

Interpretation Tasks
- Detect_Vehicle

Add Task

Intelligence Requirements

Add Requirements

Operational Requirements

Add Requirements

Recommended Assets
1. I_Robot_Packbot with AcousticArray
2. Raven with DaylightTV LLTV
3. I_GNAT with EO_Camera
4. I_GNAT with SAR
5. Predator_A with SAR
6. Predator_A with TV_Camera
7. Reaper with DaylightTV
8. Reaper with SAR
9. Global_Hawk with SAR
10. Global_Hawk with...
Future work

- More research on the rule-based derivation of capabilities.
  - Applicability of the SWRL for the rule system and performance evaluation.
  - Introduce more knowledge sources.
  - Constraints (weather, terrain, etc.) and policies.

- Explanations
  - Justify recommendations.
  - If there is no feasible solution, suggest constraints that can be removed/weakened to open up possible recommendations.

- Logic-based rule engine for asset-task matching (First-order-logics).
• Capability inference process is crucial to provide flexibility to the assignment process.

• Ontology centric approach is important to cope with heterogeneity of the sensing assets and of tasks.

• We have implemented prototype versions of the rule system and the first integrated hybrid reasoning systems to identify the fit-for-purpose assets.

• Positive feedback from the UK and US users.
Acknowledgment

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- Dr. Mario Gómez Martínez, Artificial Intelligence research Institute (IIIA), Spain
Thanks for listening.

Q?