MOOS Integration and Sea Tests of a Novel Reacquire/Identify Algorithm

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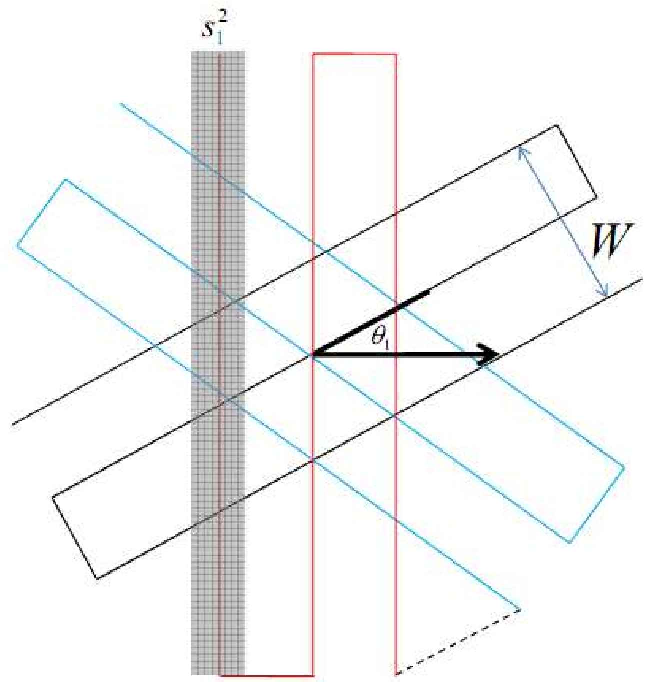
Outline

- **Clustered Reacquire/Identify Problem Overview**
  - *Brief* overview of NSWC Solution
  - Performance statistics
- **MOOS-IvP Implementation**
  - Stand-alone MOOS Module
  - Dynamic Helm Behavior Submodule
- **MOOS-equipped REMUS Sea Tests**

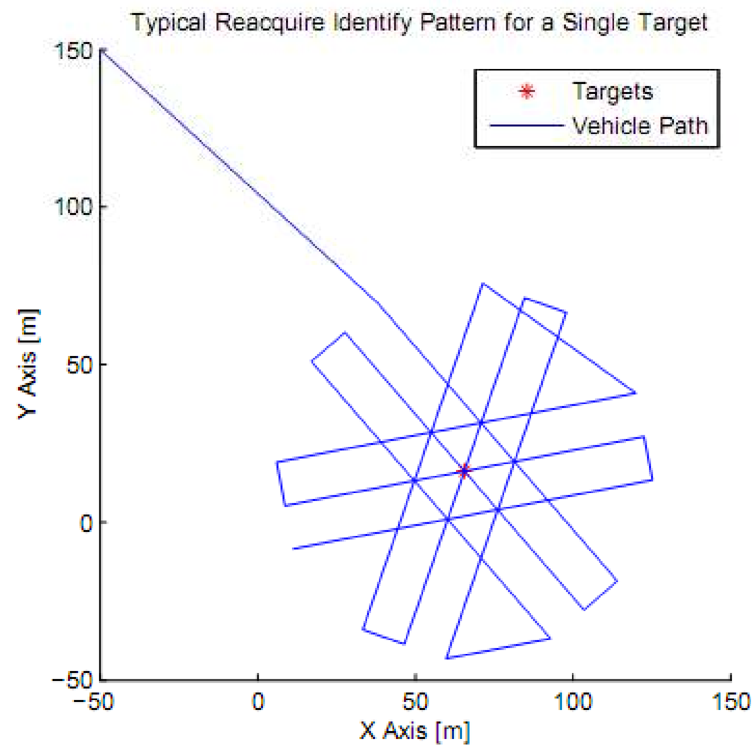
Problem Overview

- **Given:**
  - ***N Target Position Estimates***
  - Task: Cover targets from ***M aspects***
- **Terminology**
  - Aspect (colored)
  - Swath (shaded)
  - Aspect Angle



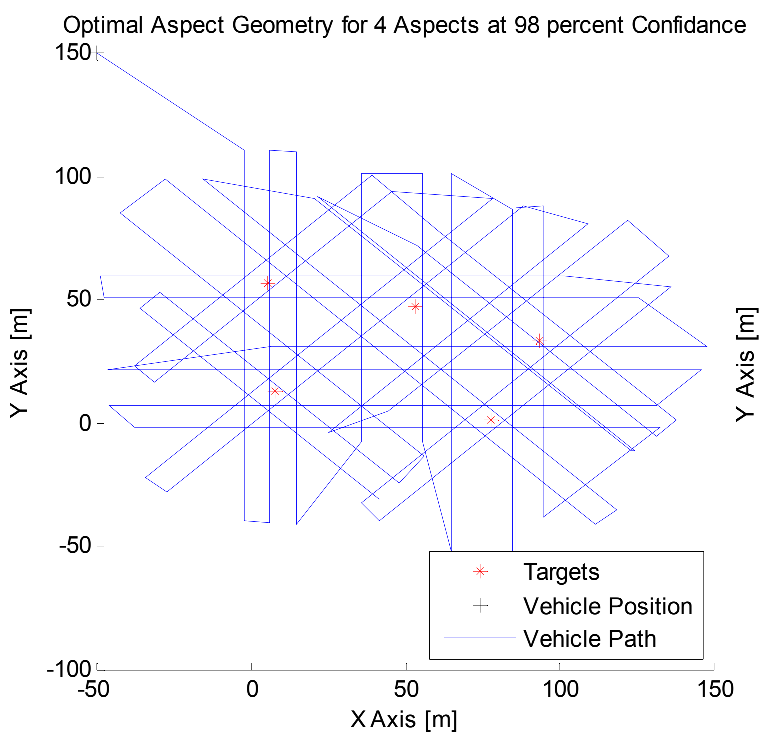
Problem Overview

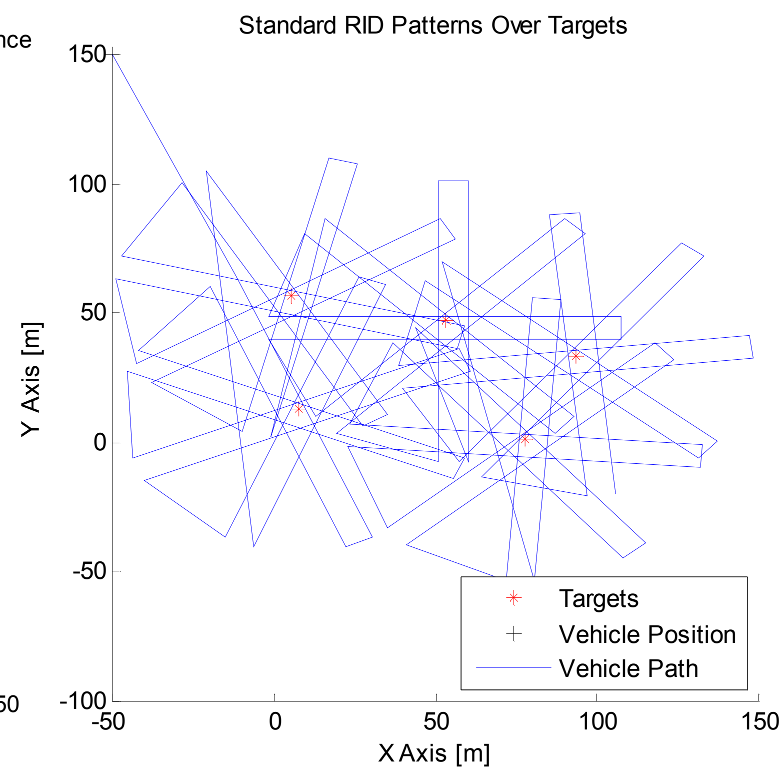
- **Standard Search**
  - Treats targets individually
  - Does not take advantage of cluster geometry
  - **Time consuming**
- **Custom Operator Search**
  - Not Standardized
  - Experience based
  - No performance guarantees



Standard vs. Clustered RID Patterns

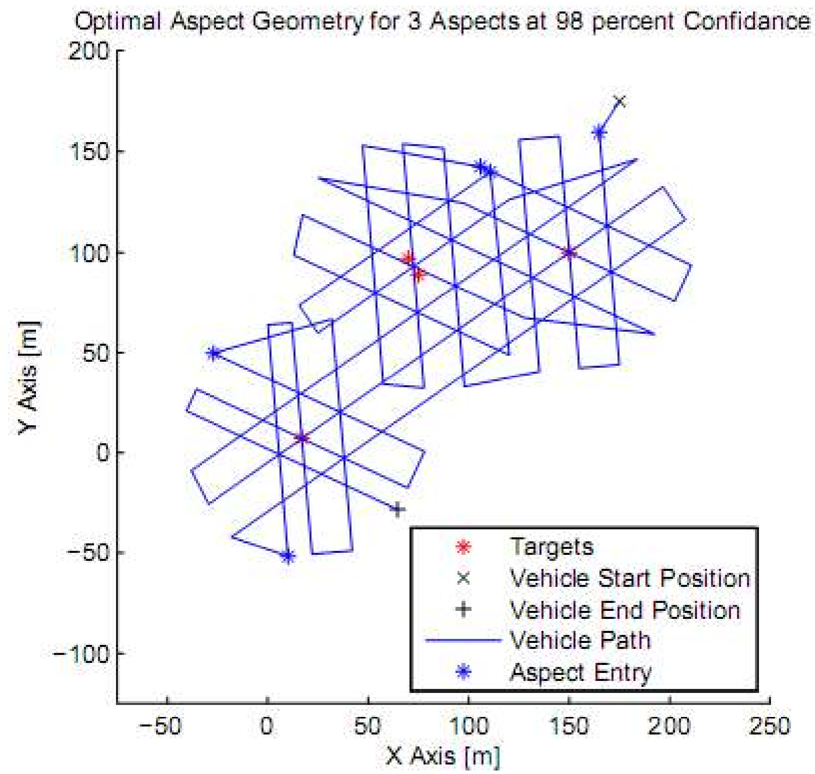
- 5 Targets, 4 Aspects.





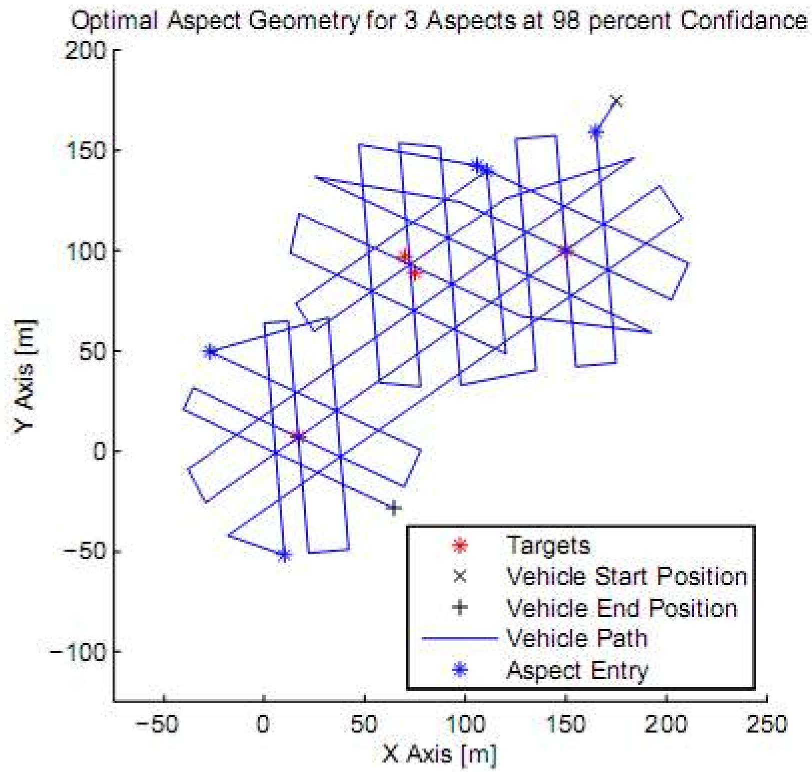
Problem Overview

- Clustered RID Questions
  - What is the optimal initial aspect angle?
  - How do we choose the number/location of swaths?



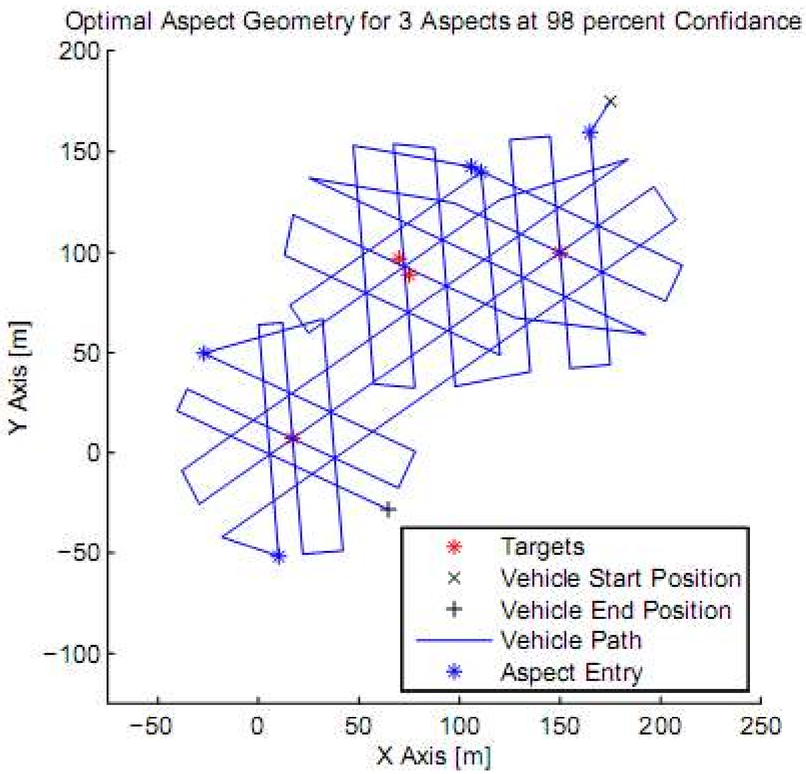
Algorithm Overview

NSWC Solution: PROPS



Algorithm Overview

- **What is PROPS?**
  - Probabilistic Reacquire/identify Optimal Path Selection algorithm
  - Covers multiple targets in a given aspect (faster)
  - Groups swaths for shortest travel time
  - Probabilistically determines number of sweeps required

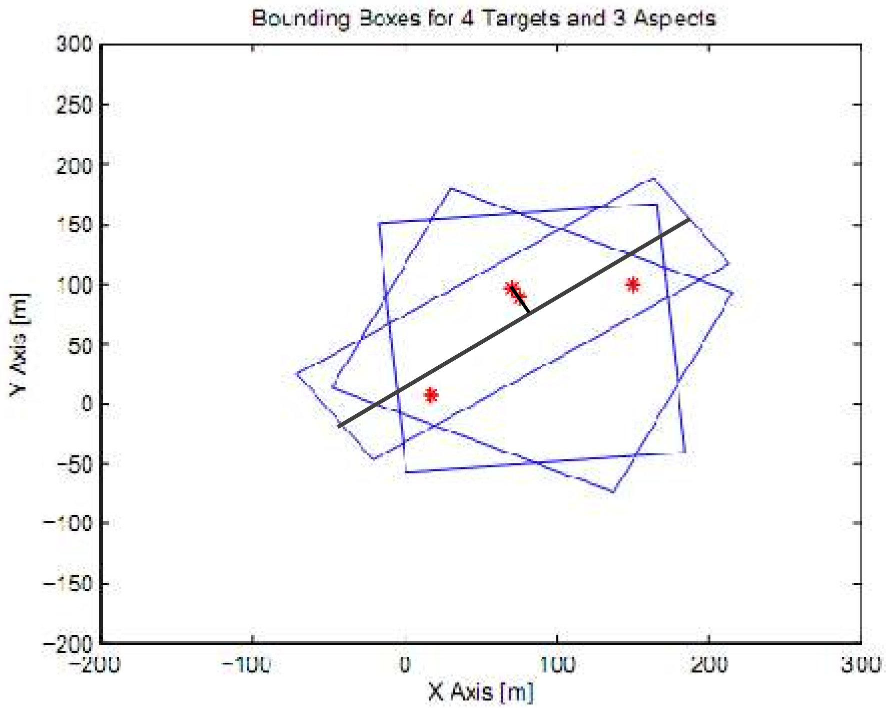


Algorithm Overview

- Choosing the aspect angle
  - Analysis & monte carlo simulations suggest minimizing width of primary aspect approximately minimizes overall number of swaths
  - Found via ***normalized minimax regression***
  - Useful for large numbers of targets
- Choosing the swaths in an aspect
  - Iterative aspect planning algorithm

Aspect Angle

- **Normalized Minimax Regression**
  - Standard regression penalizes y direction error
  - NMR penalizes L_2 distance from furthest target to aspect line

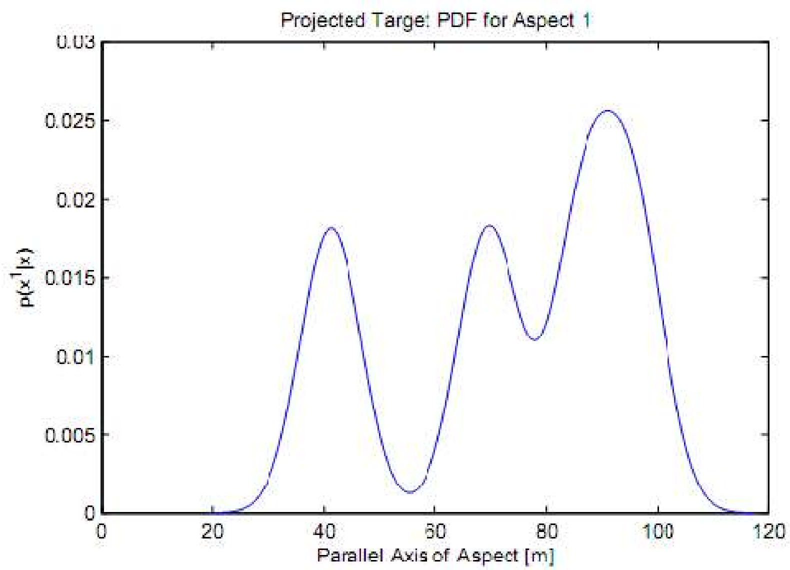


$$\mathbf{s}^* = \arg\min_{\mathbf{s}} \max_{i=1\ldots N} \frac{1}{2} \frac{(z_i - ax_i + b)^2}{a^2 + 1}$$

$$s = \begin{bmatrix} a \\ b \end{bmatrix}$$ Aspect slope and offset

$$\hat{\mathbf{x}}_i = \begin{bmatrix} x_i \\ z_i \end{bmatrix}$$ Target Estimate

Aspect Planning

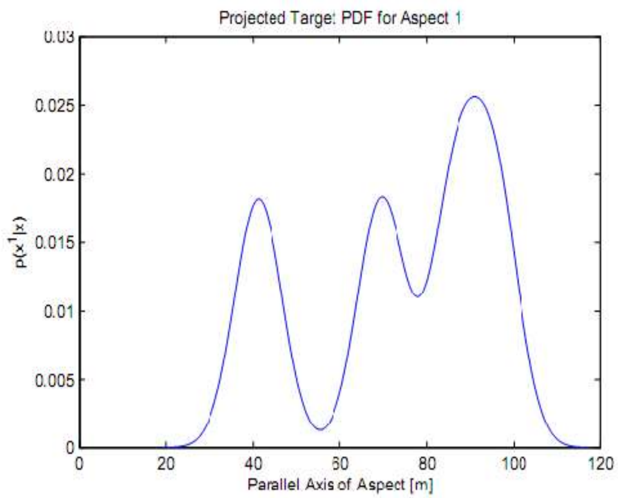


- Gaussian Mixture PDF of target locations

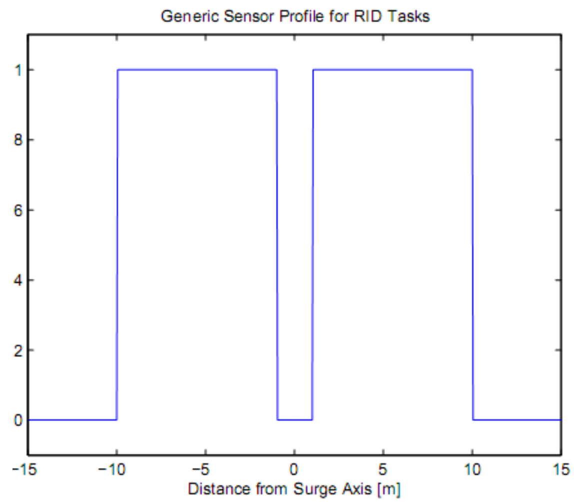
$$p(x \mid \hat{\mathbf{x}}_{1\ldots N}) = \frac{1}{N}\sum_{i=1}^{N} Normal(\tilde{x}_i, \sigma_i)$$

$\tilde{x}_i$ Target *i*'s *x* coordinate in the direction of the aspect

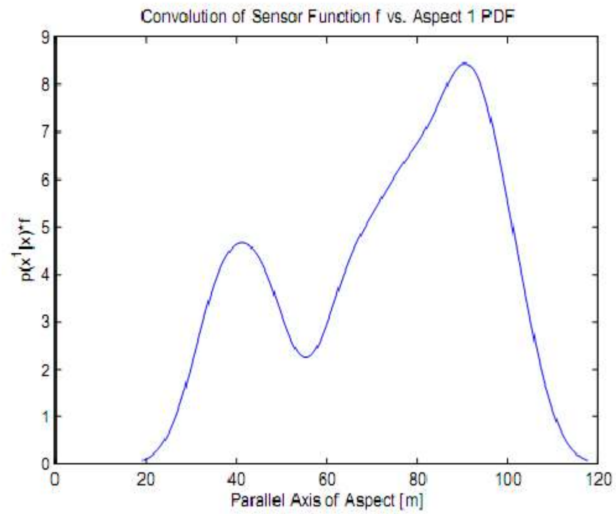
Aspect Planning



Density Function



Sensor Profile

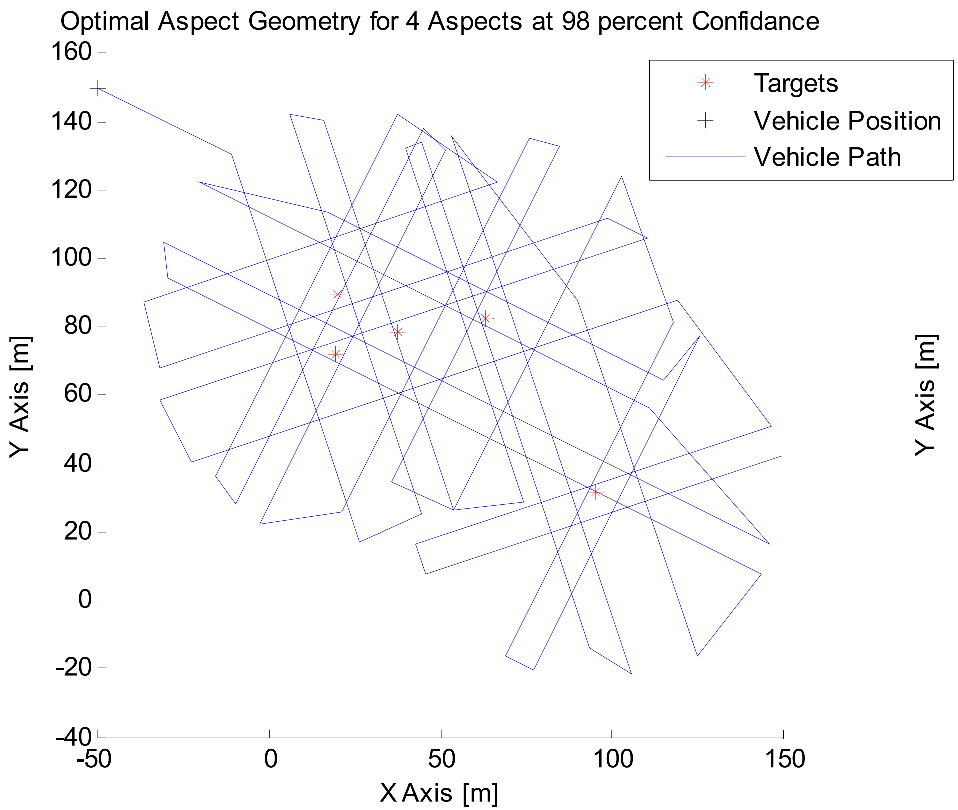


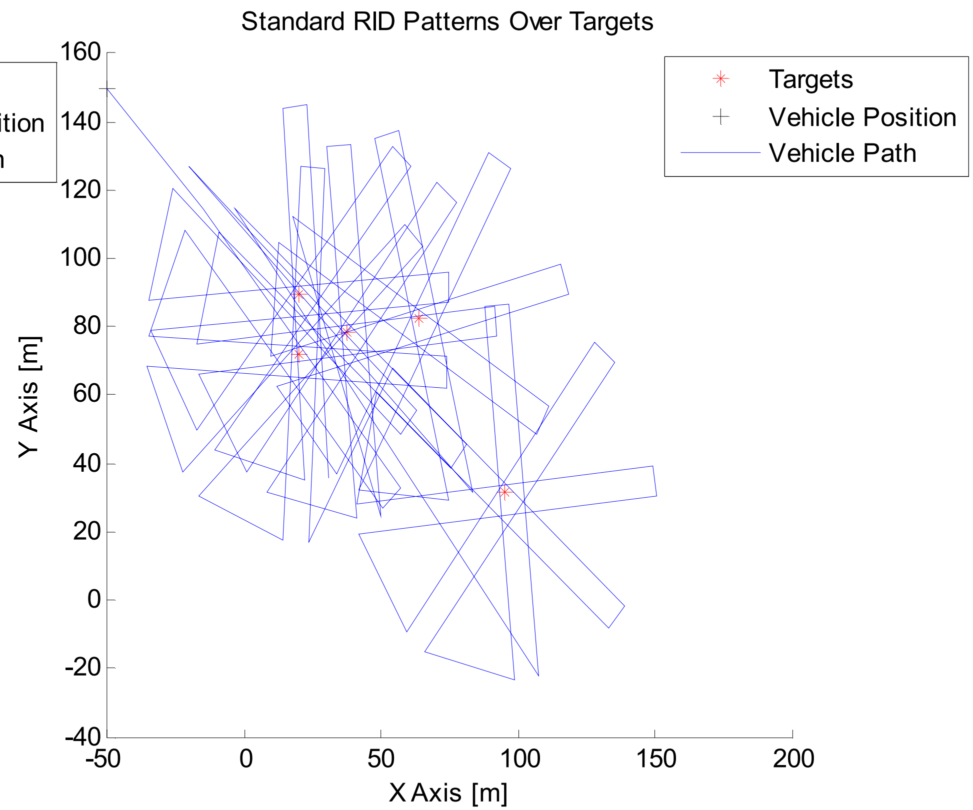
Convolution

- Objective function
  - Convolution of sensor profile and target Gaussian mixture
  - Choose swath that optimizes this function
  - Recalculate PDF
  - Calculate probability of missing a target and iterate
  - Stop when desired threshold probability is reached

Standard vs. Clustered RID Patterns

- Comparison plots for 5 Targets, 4 Aspects

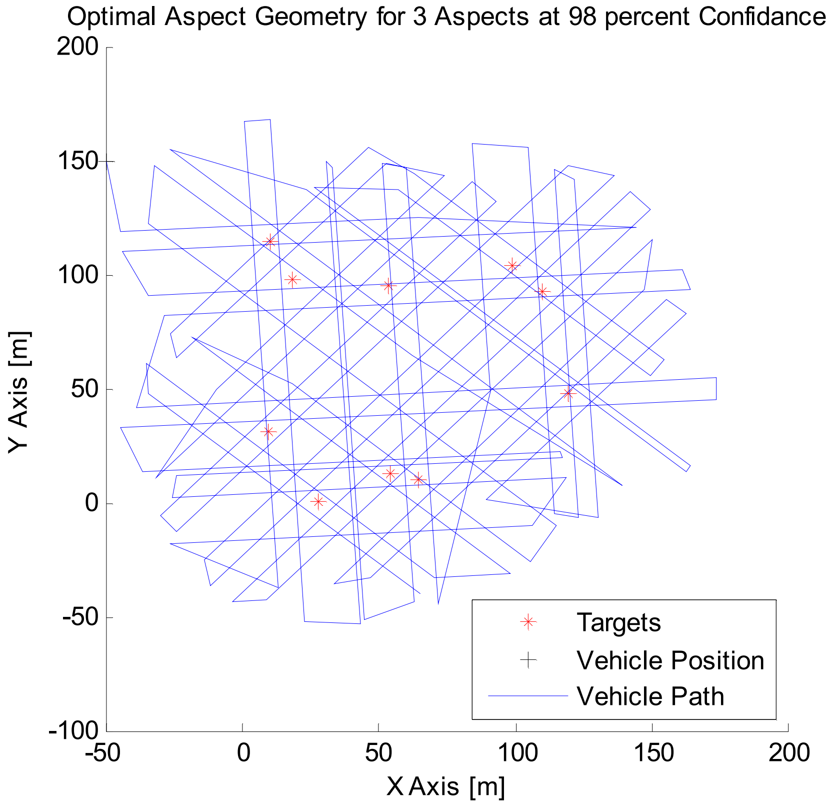


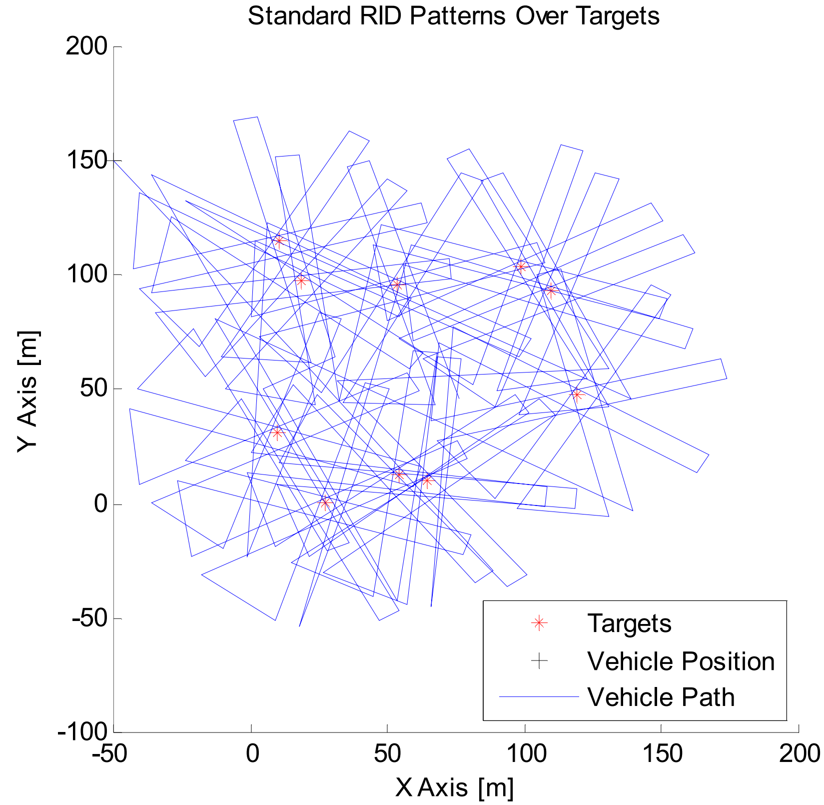


- Clustered path requires 68.8% of standard path’s distance

Algorithm Results

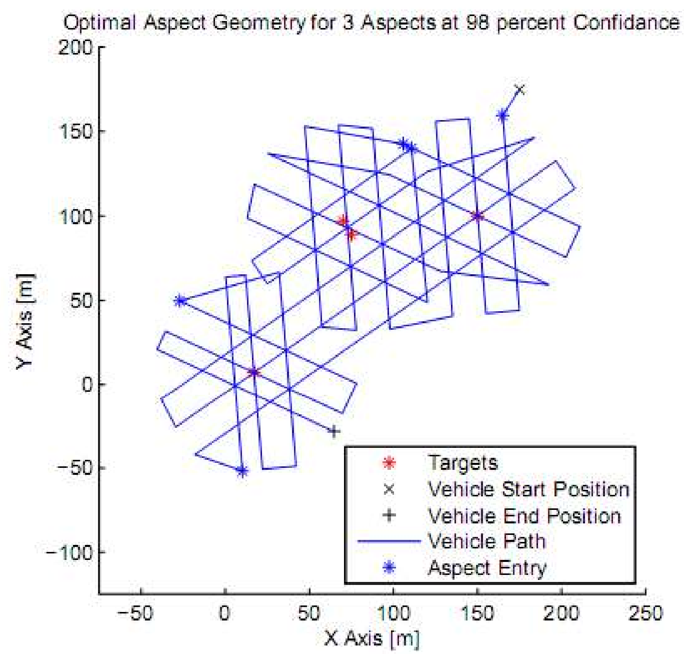
- Comparison plots for 10 Targets, 3 Aspects





- Clustered path requires 74% of standard path's distance.

Algorithm Results



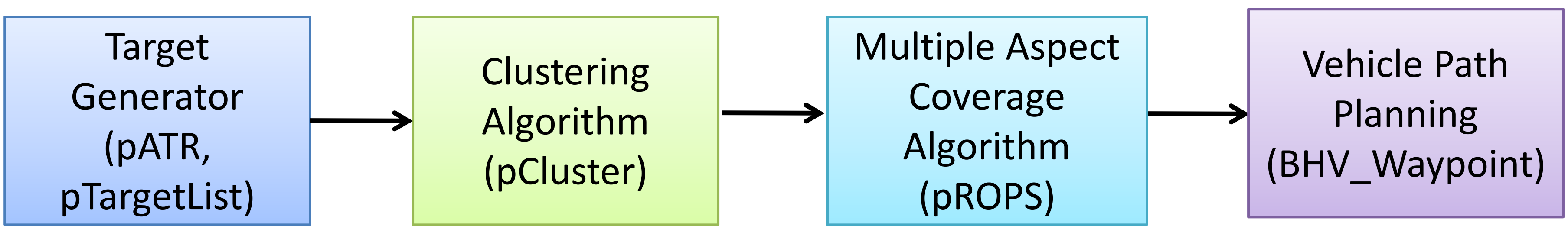
- On average, PROPS algorithm requires
  - 16% less distance traveled
  - 30% fewer turns
  - Probability guarantees

MOOS-IvP Implementation

- **Current Builds**
  - Static MOOS Module
    - Independent MOOS module
    - Triggered using posts to MOOS Database
  - Dynamic Helm Behavior Submodule
    - Submodule of BHV_RIdentify
    - Uses pattern format found in MOOS-IvP-MCM Library

Stand-alone MOOS Module Process Flow

- Part of NSWC UCCI Implementation

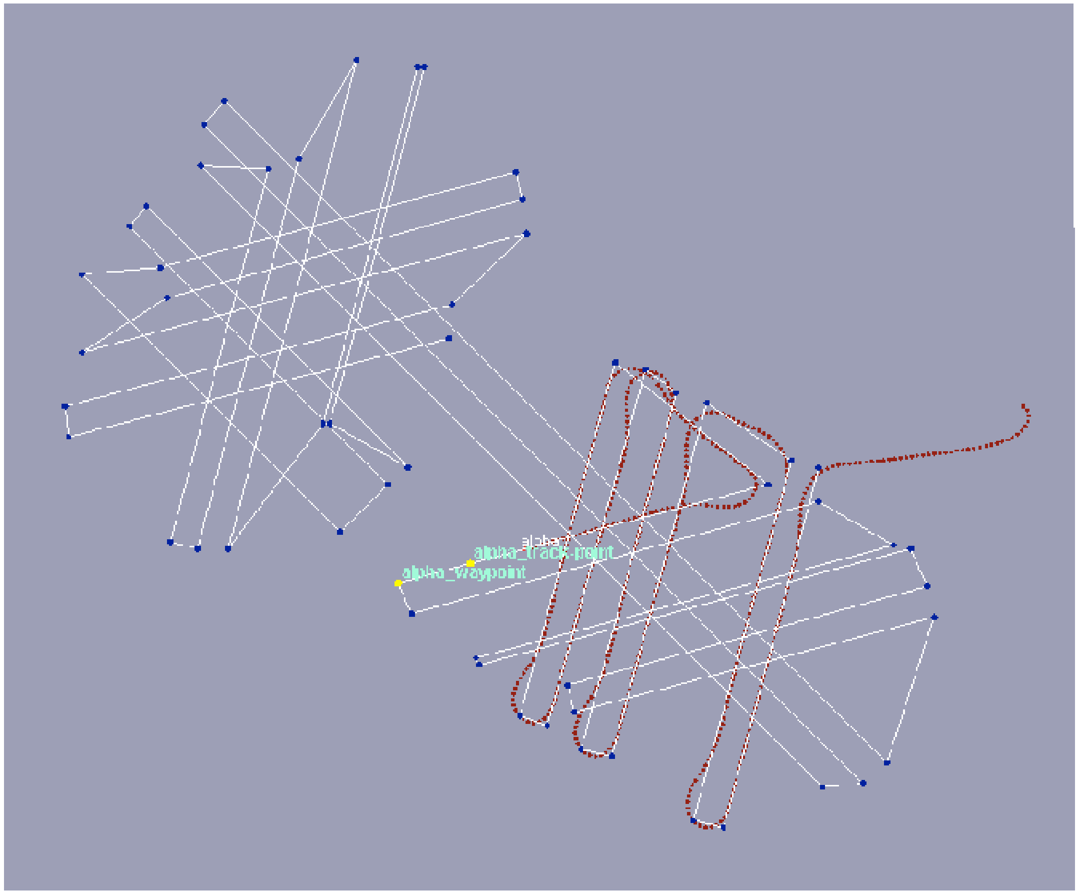


pROPS Processing

- pRIDManager posts clusters of targets to MOOS Database
- pROPS
  - listens for target list
  - Processes target list and returns waypoint list for vehicle
  - Posts waypoint list to MOOS Database

MOOS-IvP Implementation

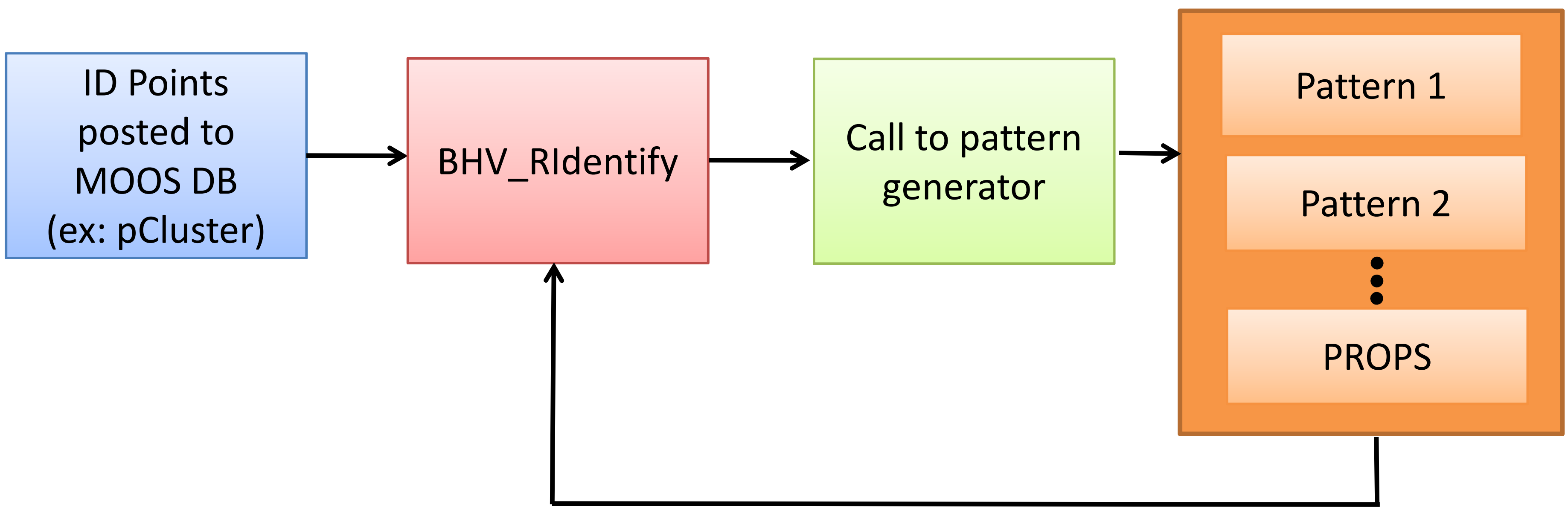
pMarine Viewer Output



Behavior Submodule

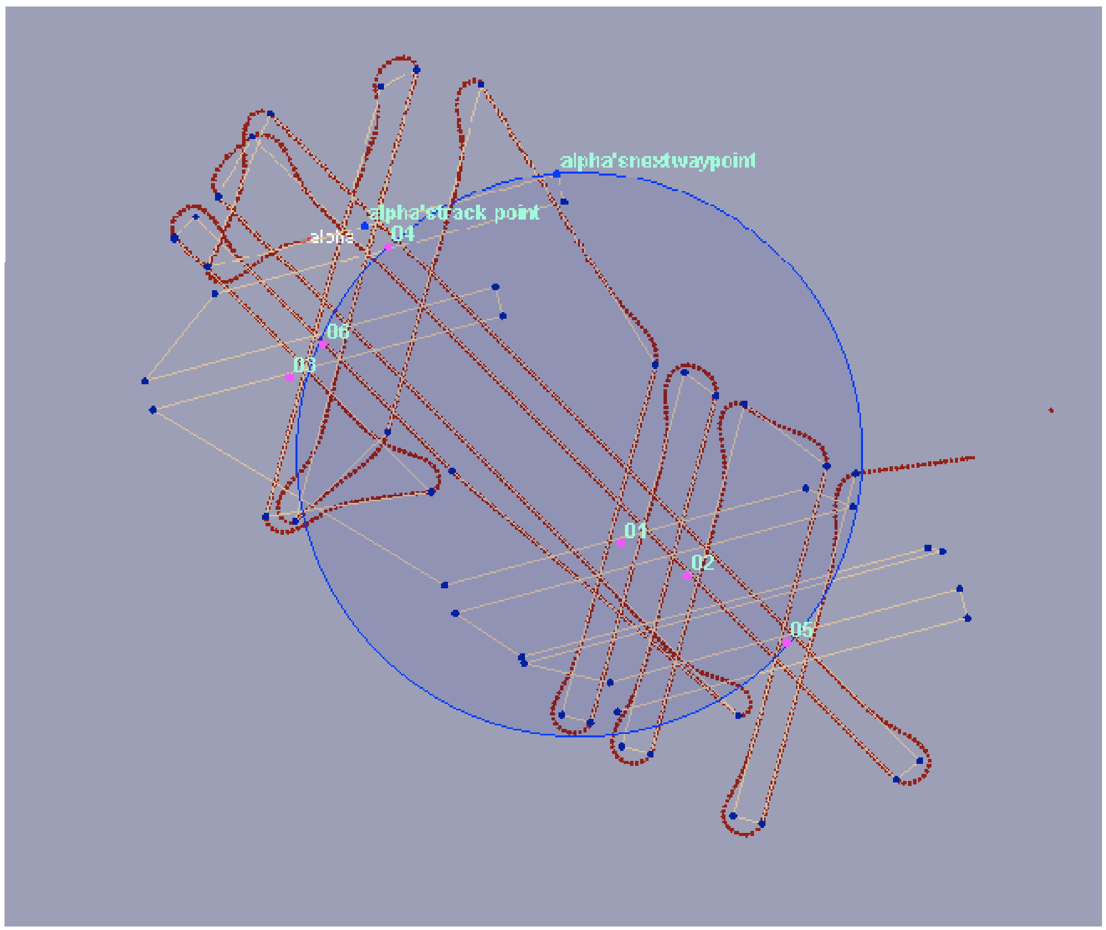
- BHV_RIdentify
  - Part of the MOOS-IvP-MCM Library
  - Creates standard RID pattern
  - Allows for customized patterns via patternGenerator
- PGEN_PROPS
  - BHV_RIdentify pattern implementing PROPS
  - Takes advantage of the BHV_Ridentify
    - Clustering
    - Unique RID Objective functions

Pattern Generation Algorithm Flow



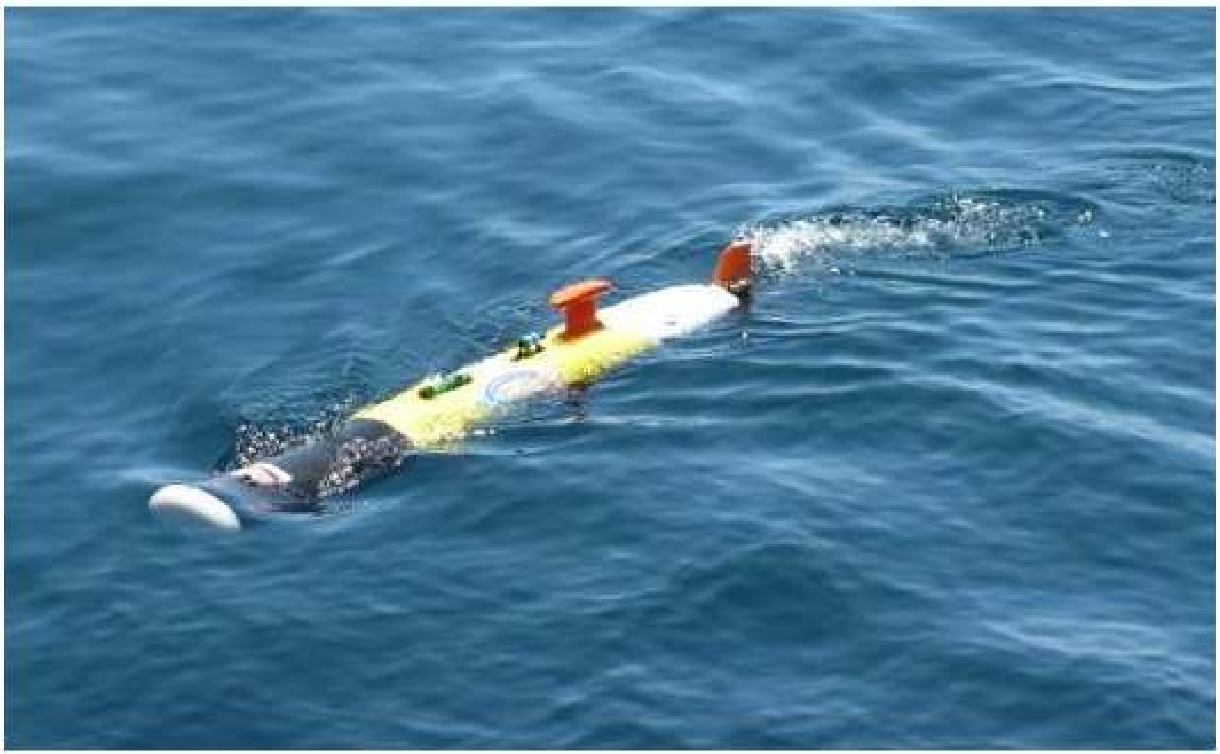
MOOS-IvP Implementation

pMarine Viewer Output

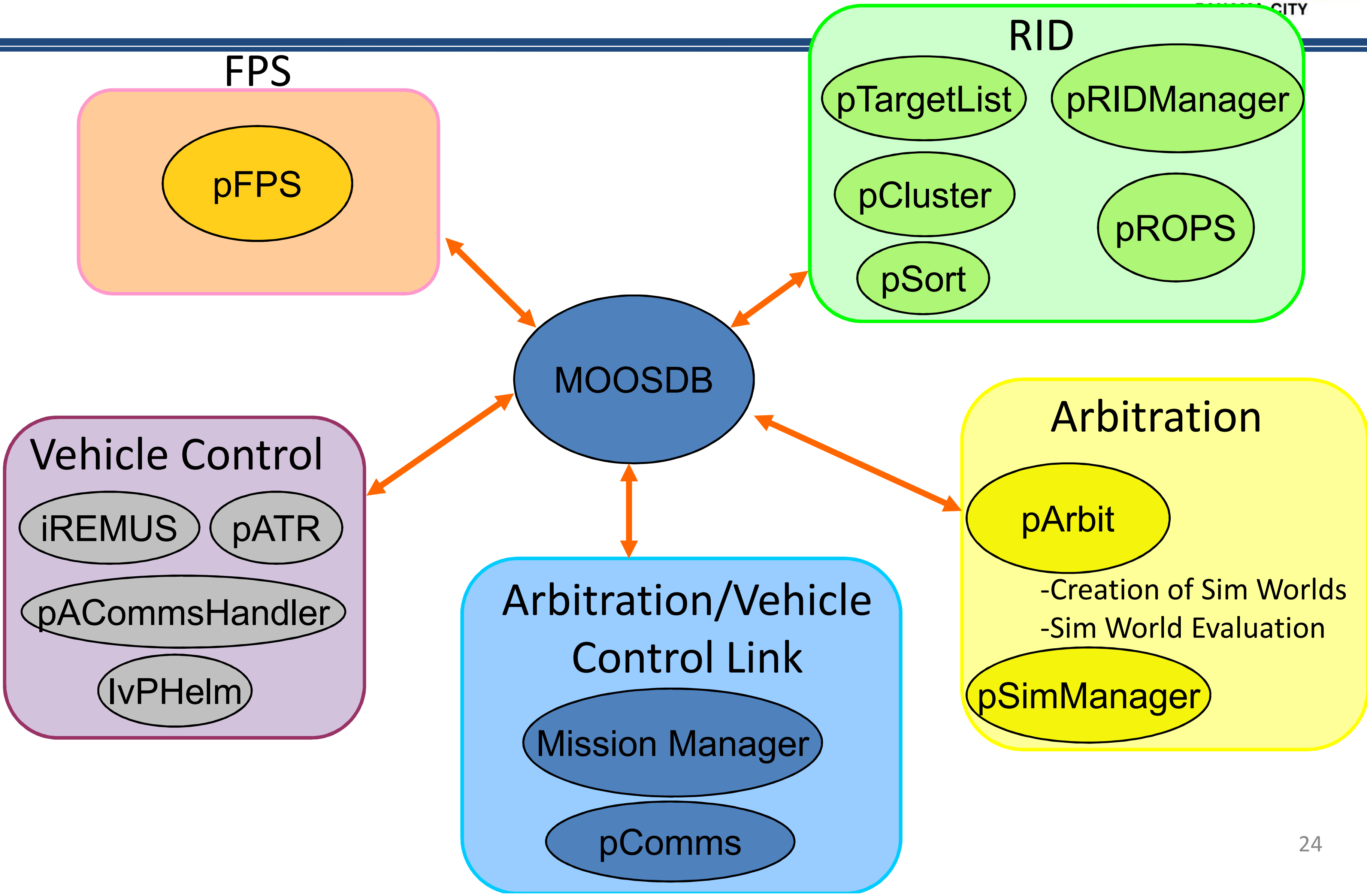


Sea Tests

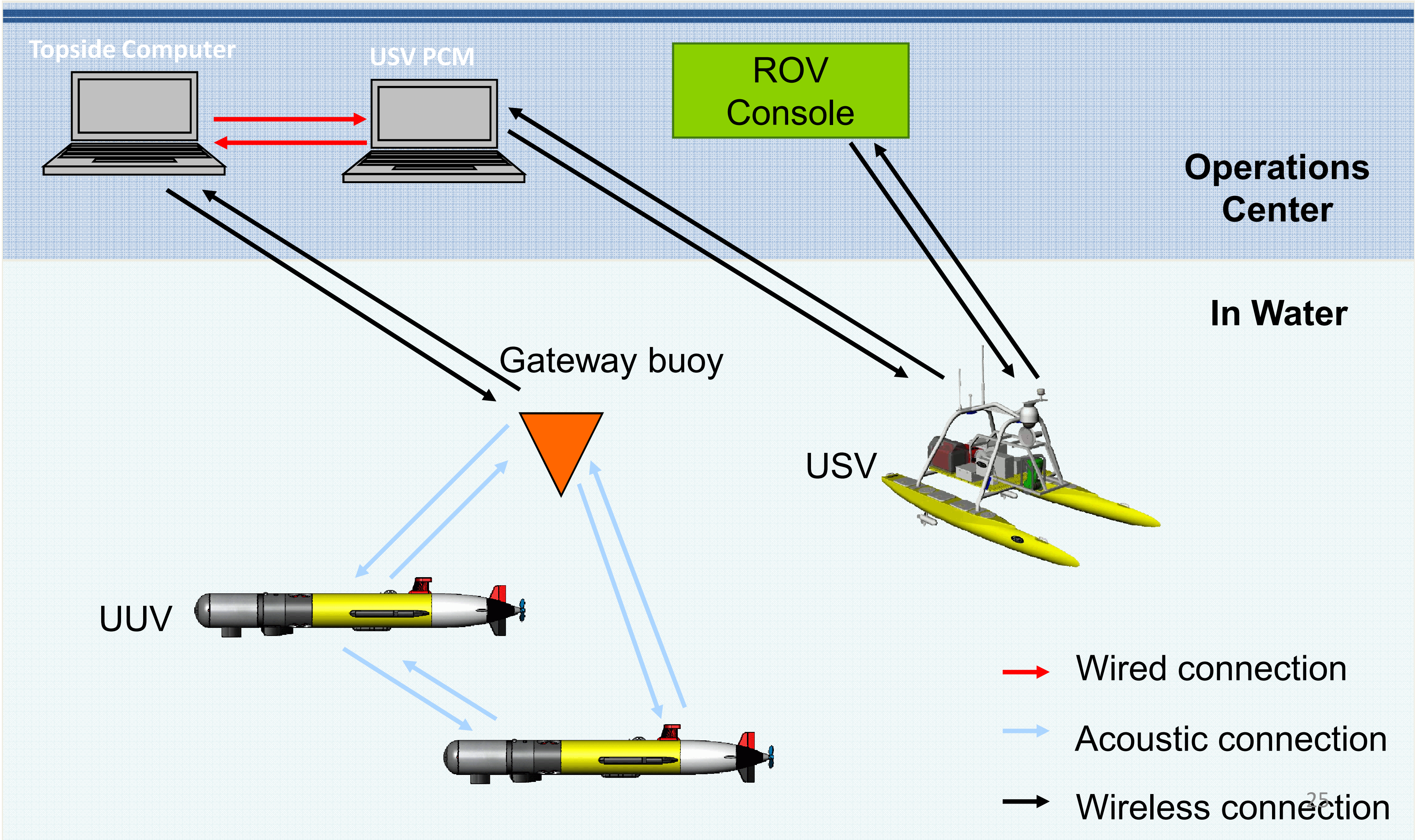
- REMUS 100 AUV
  - Backseat-driver onboard computer
  - Equipped with Open Suse Linux



UUV SCM/RID Details



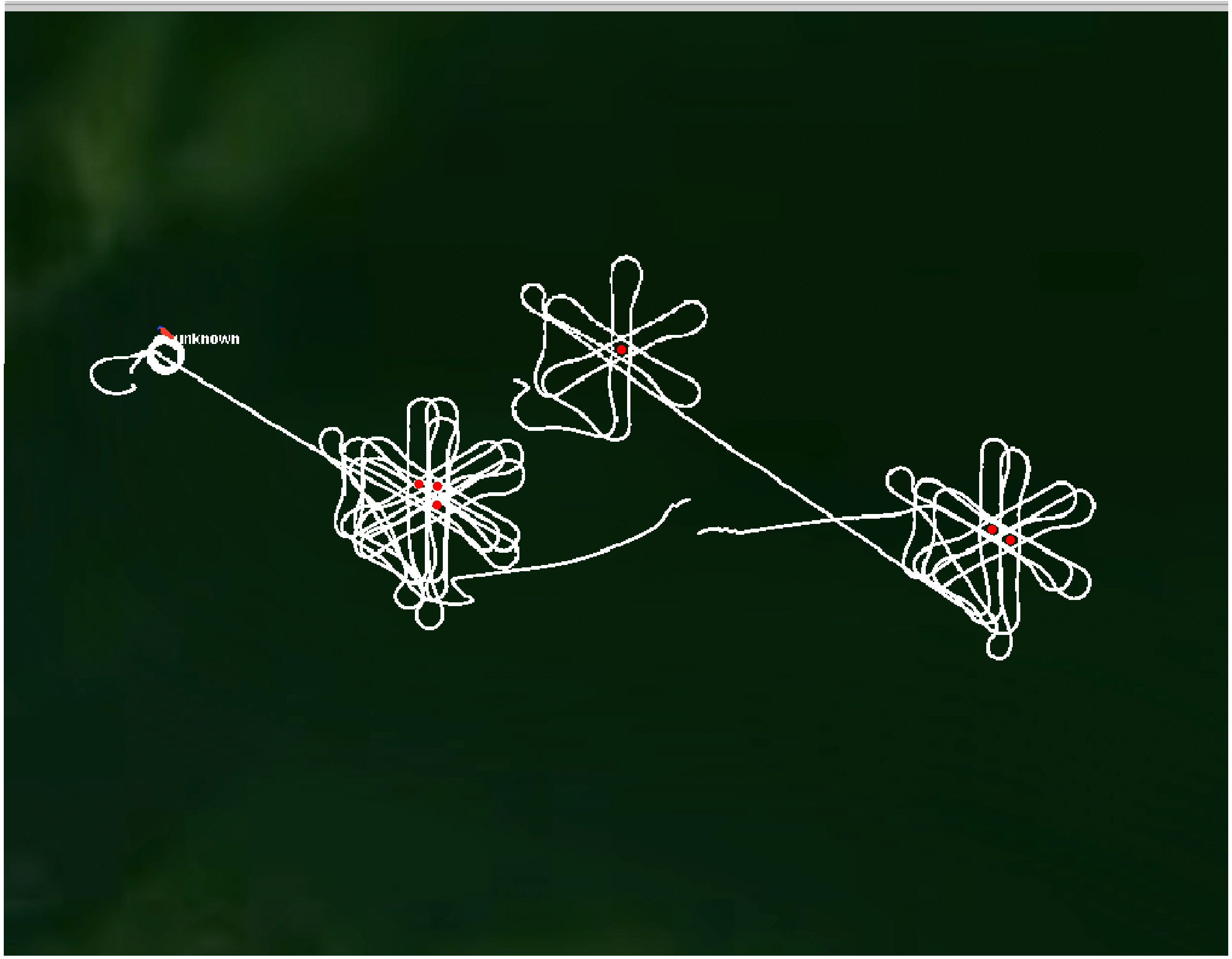
Demonstration Setup



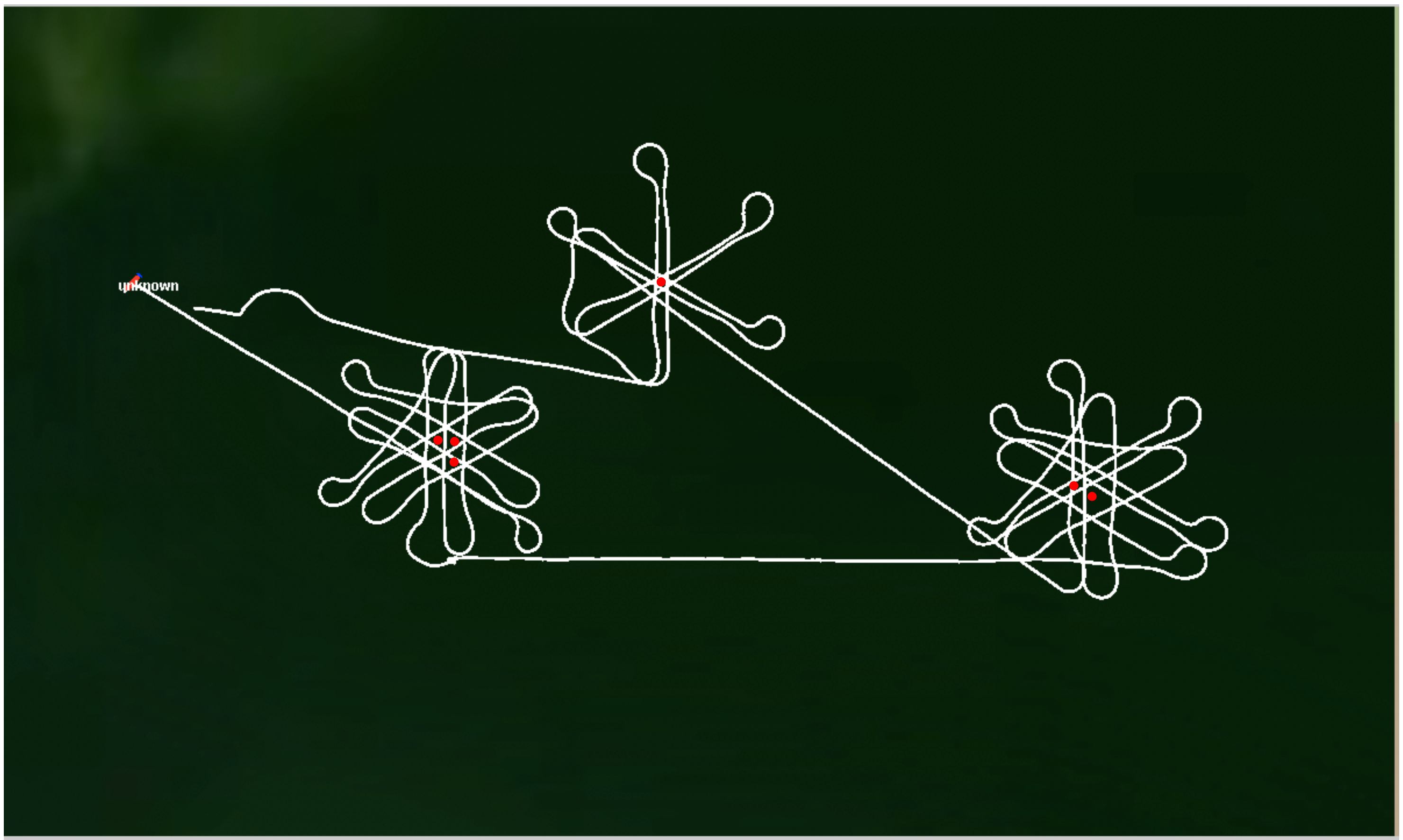
Sea Tests

- Same target points used in all tests
  - 3 clusters of 1, 2, and 3 simulated targets
  - 3 Aspects
- pROPS MOOS Module was sea tested in March 2010
- 2 Baseline RID tests conducted in June 2010
  - Standard Star Pattern over each target
  - Human operator attempting to minimize time/turns

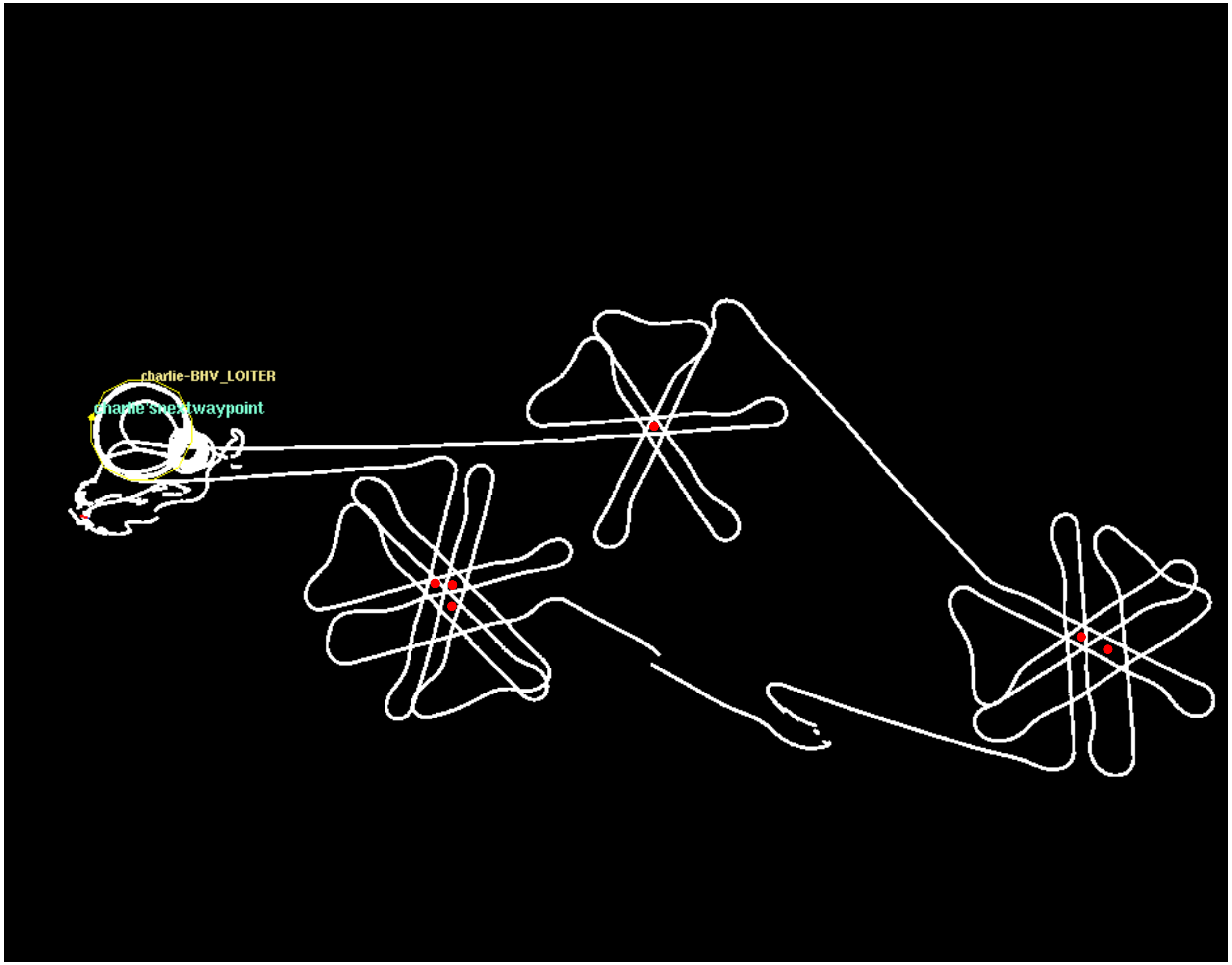
Standard Star Pattern



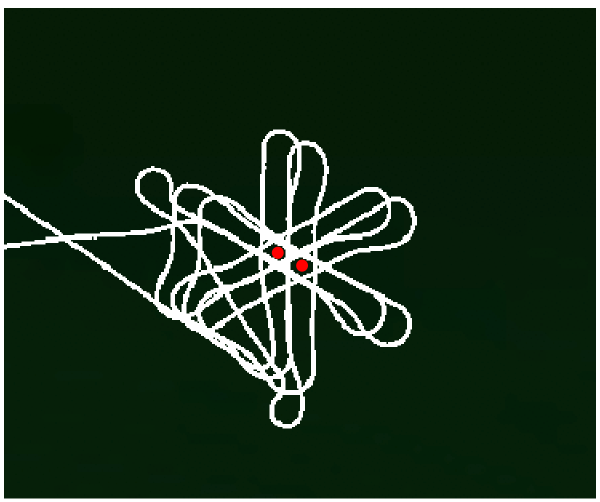
Operator-generated Star Pattern



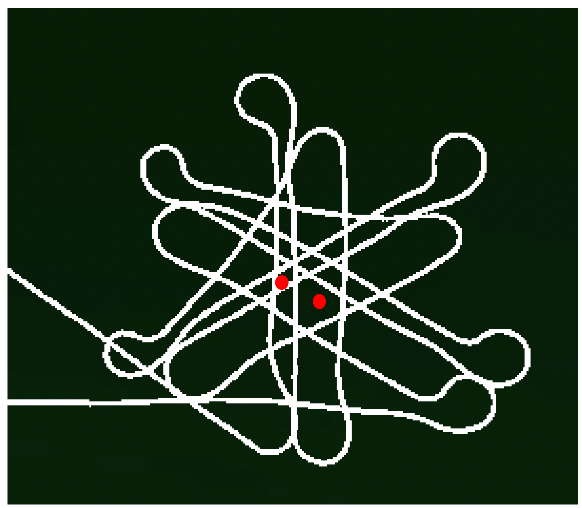
PROPS-generated Star Pattern



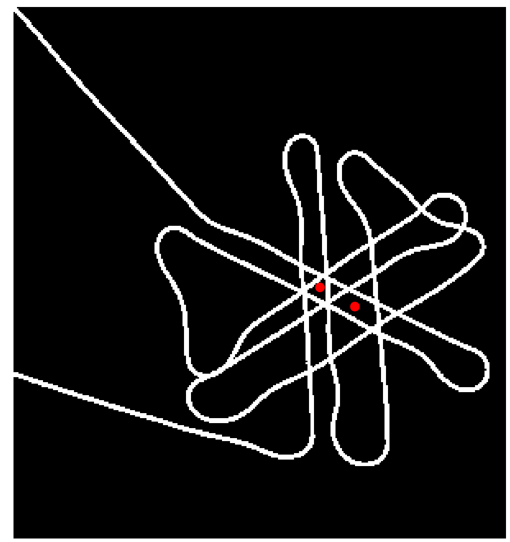
2-Target Comparison



Standard RID



Human-generated RID



PROPS RID

Results

- After Post-Processing & Normalization
  - Standard Pattern: 46.6 minutes
  - Human-operator Pattern: 37.6 minutes
    - Additionally required 11 minutes of operator analysis
  - PROPS Pattern: 36.7 minutes
- PROPS required 78.7% of the time required by the standard pattern

Conclusions

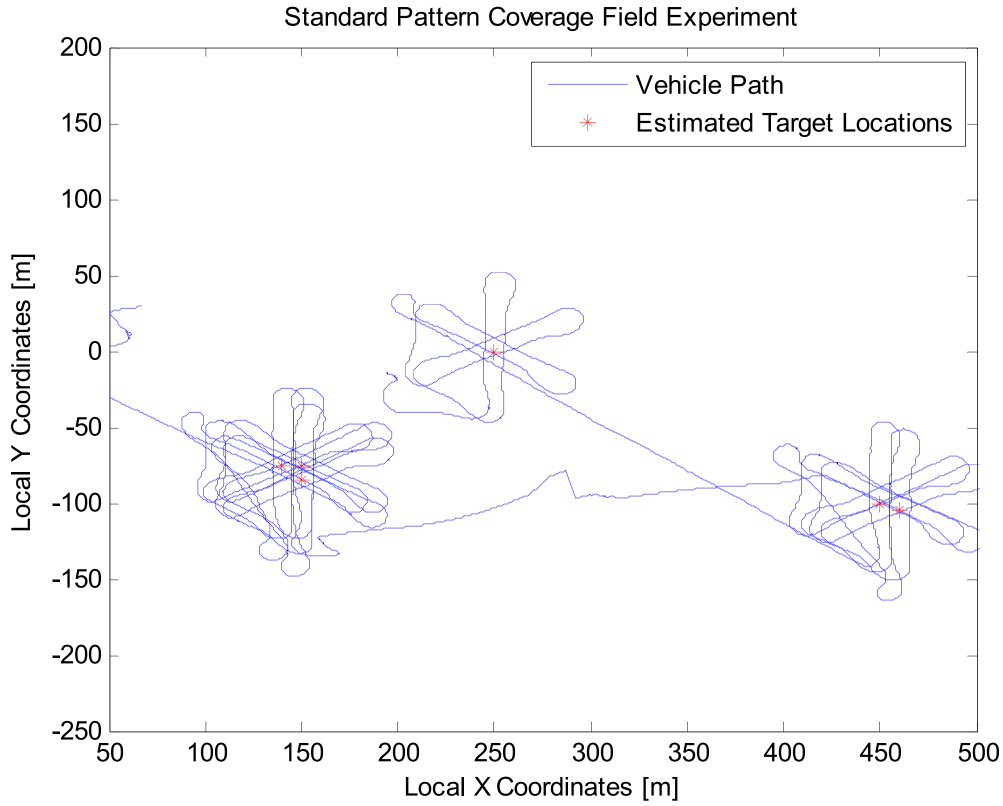
- Developed an algorithm to optimize the clustered Reacquire/Identify problem
  - 16% more efficient than standard RID methods for travel distance
  - 30% more efficient in number of turns
  - Probabilistic performance guarantees
- Implemented using two approaches in MOOS-IvP
- Sea tests demonstrate functionality and overall efficiency versus standard RID and human optimization

Future Work

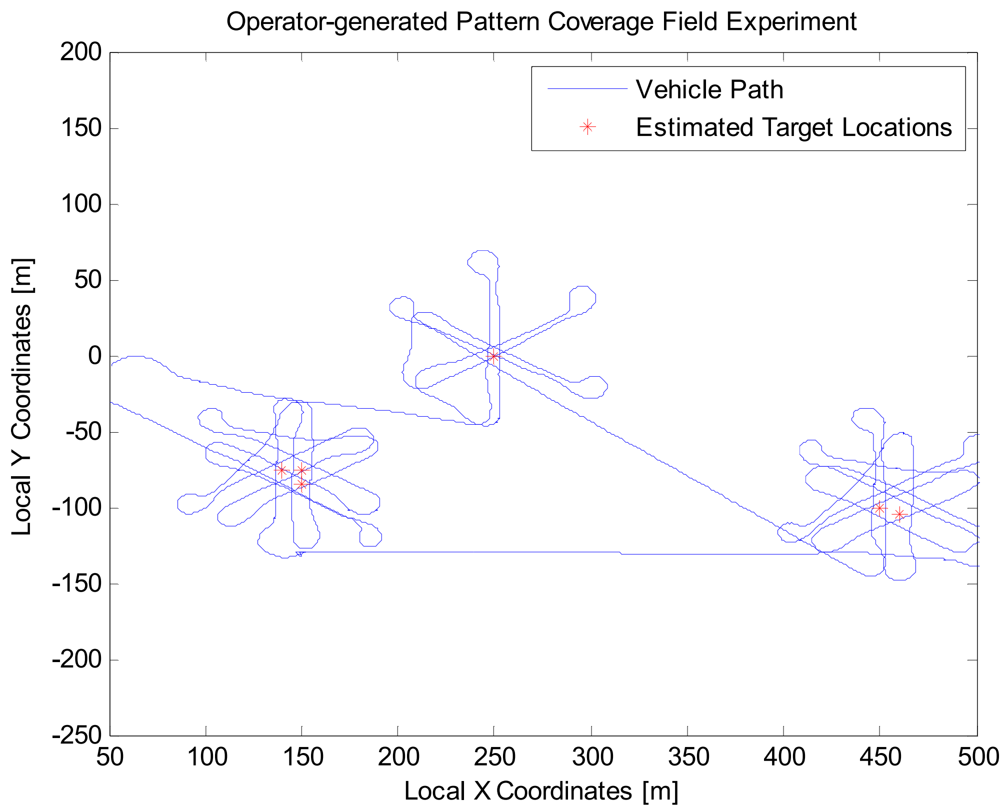
- Sea test PROPS dynamic helm behavior pattern
- Fully vet the PROPS algorithm for inclusion in MOOS-IvP-MCM library
- Perform overall demonstration of UCCI project

Questions?

Standard Star Pattern



Operator-generated Pattern



PROPS-generated Pattern