MITMECHE

Battelle

Hunter-Prey

An Open-Source Adversarial Competition to Promote Cooperative Autonomous Research

MOOS-DAWG Conference 2013

Presented by:

LT Arthur Anderson, USN

Alon Yaari

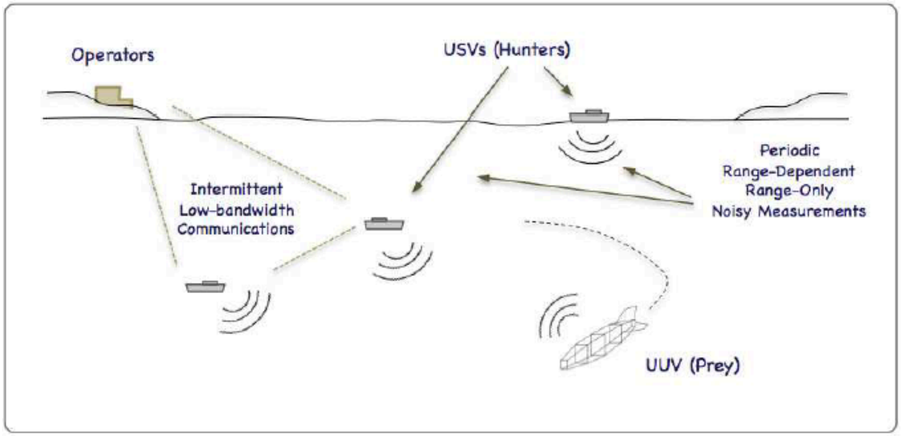
Dr. Michael Benjamin

Background

- Research is derived from a collaborative research project funded by *Battelle* and the *Laboratory for Autonomous Marine Sensing Systems*

The "Hunter-Prey" Project

The project creates a scenario in which two or more Unmanned Surface Vehicles (USV's) will be looking for and prosecuting a single Unmanned Underwater Vehicle (UUV) attempting to traverse across a designated area and back again.



Project Goals

Further the research on collaborative multi-vehicle missions

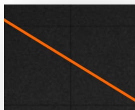
- Particularly with regard to communicating over low-bandwidth, intermittent communications

Set up a competition environment for participants beyond the principal researchers to participate in

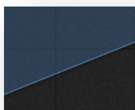
Develop a new set of axes upon which to evaluate autonomous missions

Environmental Overview

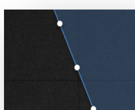
Operating Field Boundary

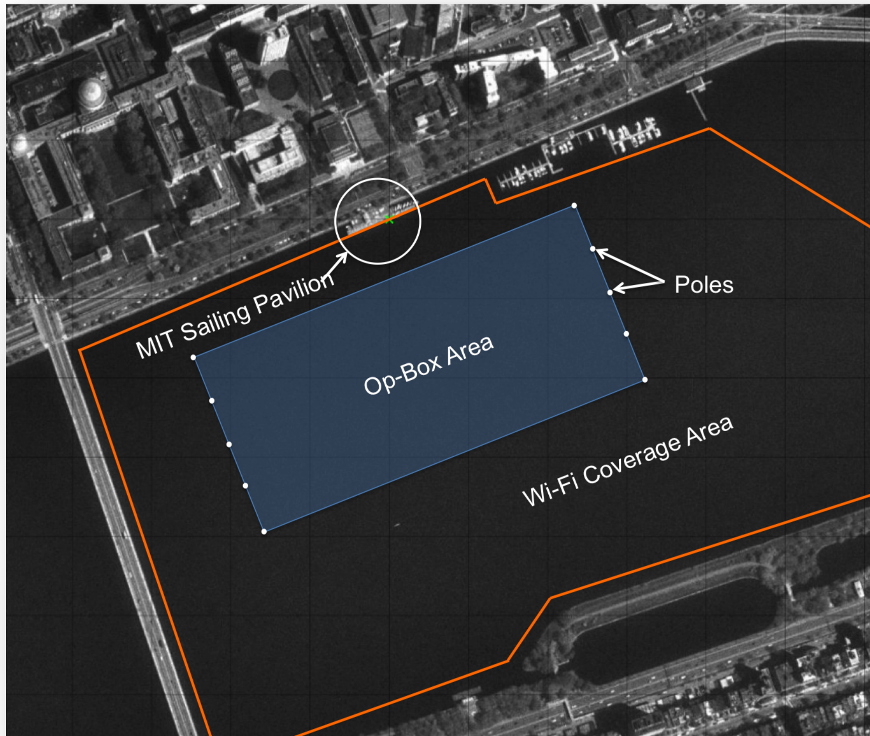


Scenario Field Boundary



Virtual Pole Positions (start / end points)

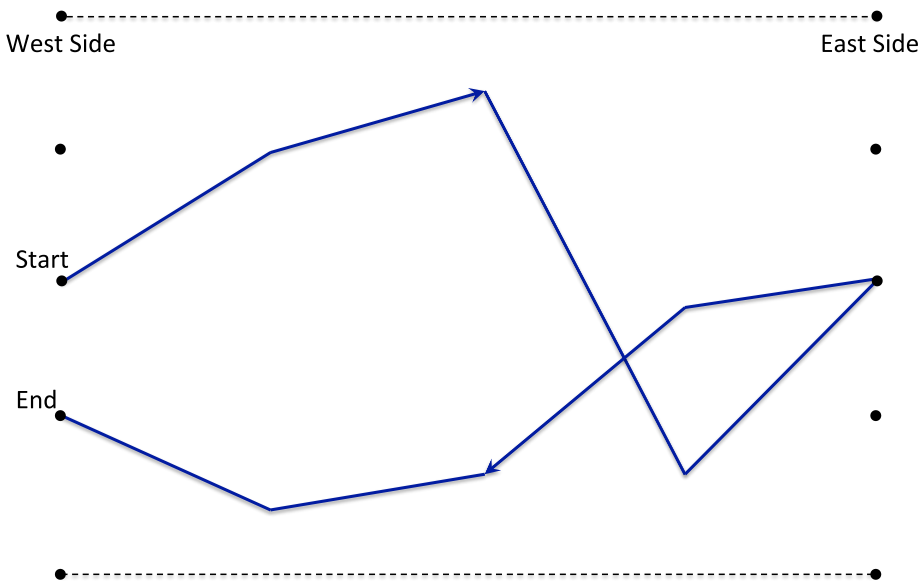




USV - Kingfisher M200

UUV – Bluefin 9

UUV



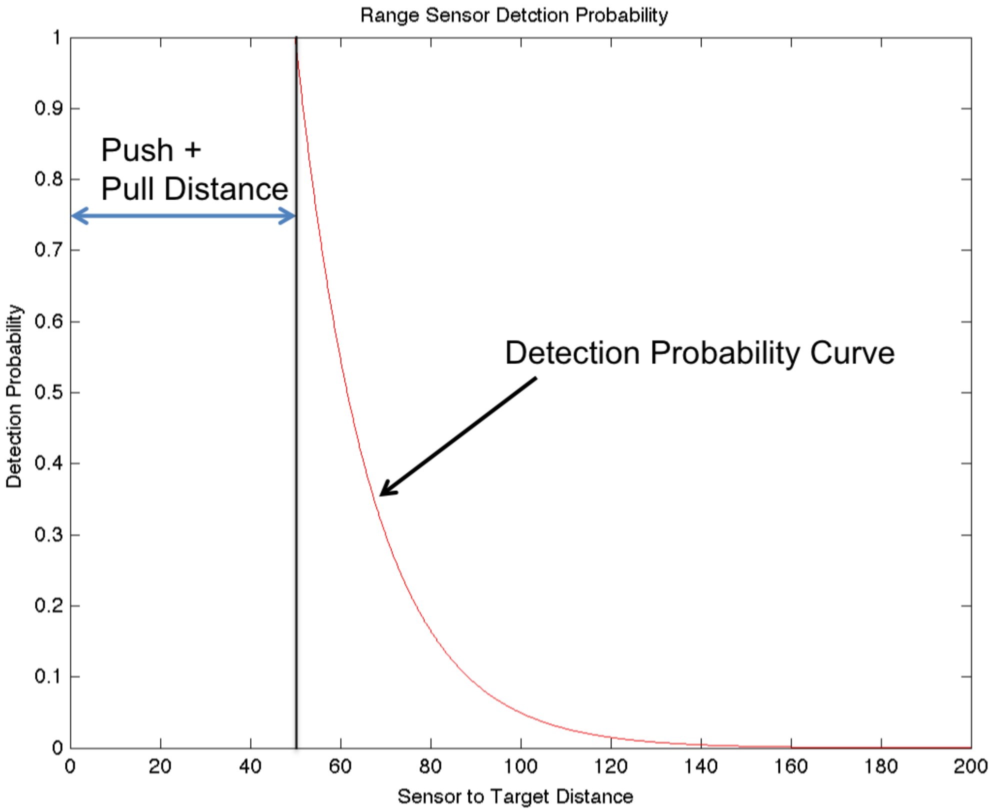
- UUV attempts to traverse across op-box and back
- UUV receives USV locations at each ping
  - Via shoreside during simulation
  - Via *pAcomms* with actual vehicles

USV - Range Sensor Rules

- Pings can be limited by:
  - Range
  - Arc Coverage
  - Time Between Pings

- Probability of Detection:

$$Probability = e^{\left(\frac{3(Max-d)}{Max}\right)}$$



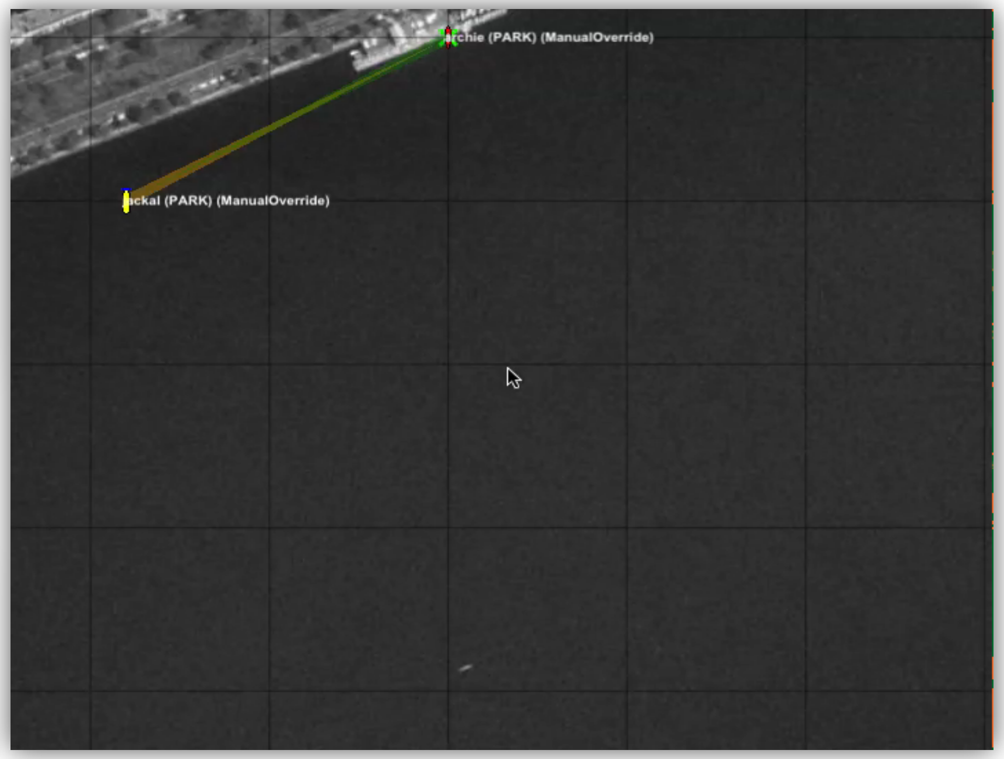
Background and Goals | Overview and Rules | Sample Solution | Project Information | Conclusions

USV - Range Sensor Rules

Managed by process *uFldContactRangeSensor*

Range Pulse “pings”

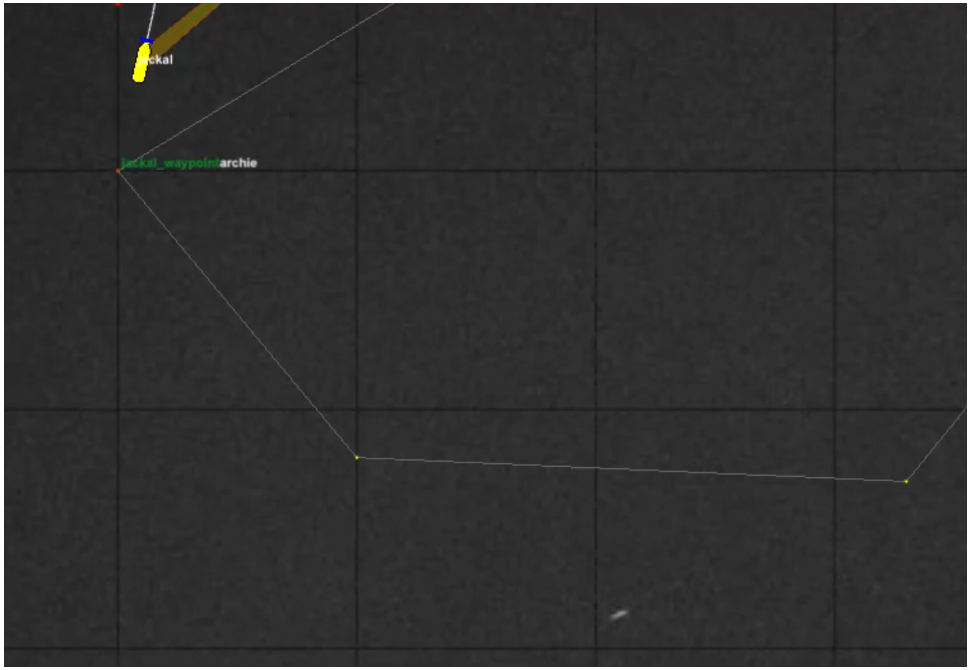
Returned ranges to
pinging vehicle



Background and Goals | Overview and Rules | Sample Solution | Project Information | Conclusions

USV - Depth Charge Rules

- Simulated by *uFldDepthChargeManager*
- Each vehicle begins with a set number of depth charges
- Vehicle drops depth charge, characterized by:
  - Charge Delay
  - Charge Range



- Refills can be done at sailing pavilion when depth charges are exhausted

USV - Communications

- Managed by *uFldMessageHandler*
  - *Future competitions may implement pAcomms as an alternative*

- Inter-vehicle messages subject to limited bandwidth
  - Initially, 100 characters per minute
  - Scenarios may increase or decrease this limit

Scoring*

- USV’s each start with 200 points
- Mission over when depth charge “hits” UUV
- Points are removed from the USV such that
  - 1 point for every 10 seconds after the first 200 seconds
  - 5 points for every missed depth charge
  - 50 points for near USV-USV collisions (< 3 meters)
  - All points are lost if UUV completes traverse

*Rules are subject to change at actual competition

Scenario Considerations

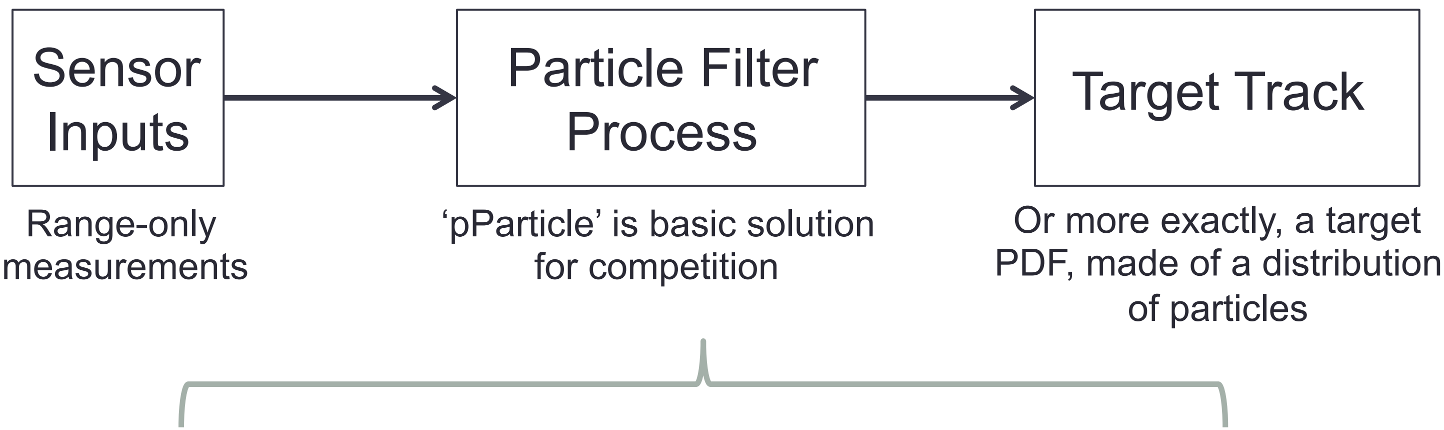
- USV Considerations
  - Surface vessel collision avoidance
  - Translating range information into a target track
    - A simple, non-optimized particle filter (*pParticle) is provided*
  - Limited inter-vehicle communications
  - Strategies for vehicle cooperation
  - Managing depth charge drops and refills
- UUV Considerations
  - Path selection
  - Evasion tactics

Straw-man Solution

- A straw-man basic (but complete) solution was developed as a baseline for competition.
- Users may use this to build their solutions from.
- Solution was tested using regression code in order to test parameters
  - Make problem not too easy or too hard
  - Regression code (regress.py) developed by Mario Bollini

Tracking with a Particle Filter

- A means of developing a target solution with range-only measurements
- A basic, non-optimized particle filter is provided with the sample solution



Uses particles or "guesses" for the target track.
Guesses improve as sensor information comes in.

USV Logic - pHunterPrey

5 Modes, selected by conditional logic statements

Start

Action
- Head to starting positions

Condition
- If current time is less than start time

Resupply

Action
- Head to base for resupply, and stay until resupplied

Conditions
- If number of charges on board is zero.
- If other vehicle is not resupplying

Search

Action
- Conduct a loiter pattern at center of the op box

Condition
- If reports on vehicle are not current - specified number of reports not within a certain time frame

Track

Action
- Maintain a constant bearing and distance to target

Condition
- Vehicle reports are current
- Own vehicle is furthest from target vehicle

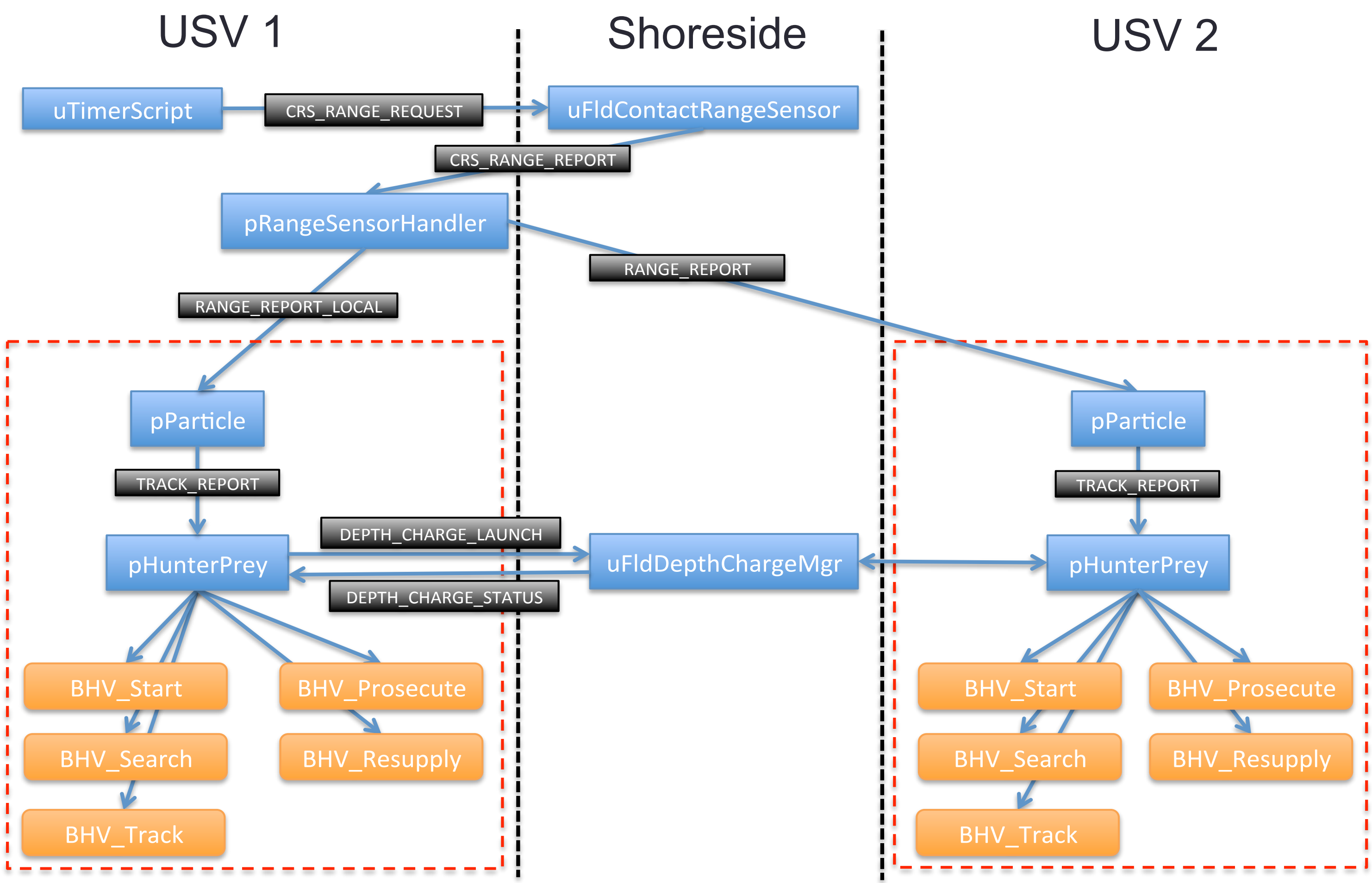
Prosecute

Action
- Maintain a constant bearing and distance to target

Condition
- Vehicle reports are current
- Own vehicle is closest to target vehicle


First Contact made by Archie
Archie and Betty pulse their range-only sensors to search for Jackal
Archie and Betty start at 2 end poles
After three "hits" Jackal is acquired
Jackal starts from one of five random starting poles
Betty Drops her depth charges when in range, and after a successful hit, the vehicles return home.
Archie maneuvers into a tracking position, while Betty moves in to prosecute.
betty

USV Logic Architecture



Project Details

- To be released this Fall 2013
- Hunter-Prey information will be posted
  - http://moos-ivp.org
- Ongoing info available by joining the mailing list
  - http://lists.csail.mit.edu/mailman/listinfo/hunter-prey
- Points of contact:
  - Michael Benjamin mikerb@mit.edu
  - Alon Yaari ayaari@mit.edu
  - Arthur Anderson arthura@mit.edu

Closing Remarks

- Objective to obtain creative and innovative solutions.
- There may be future iterations of this project.
- Goal is to include an automatic submission system

Questions and Comments

My Research

1. Formulation of the problem.
2. The development of a “straw-man” solution.
   - Not optimized, but a useable solution
   - Development and understanding of range only tracking algorithms
3. Running a design of experiments to determine how adjusting the problem parameters affect the probability of success.

Literature Comparison

Cooperative positioning using range-only measurements between two AUV's. 2010.

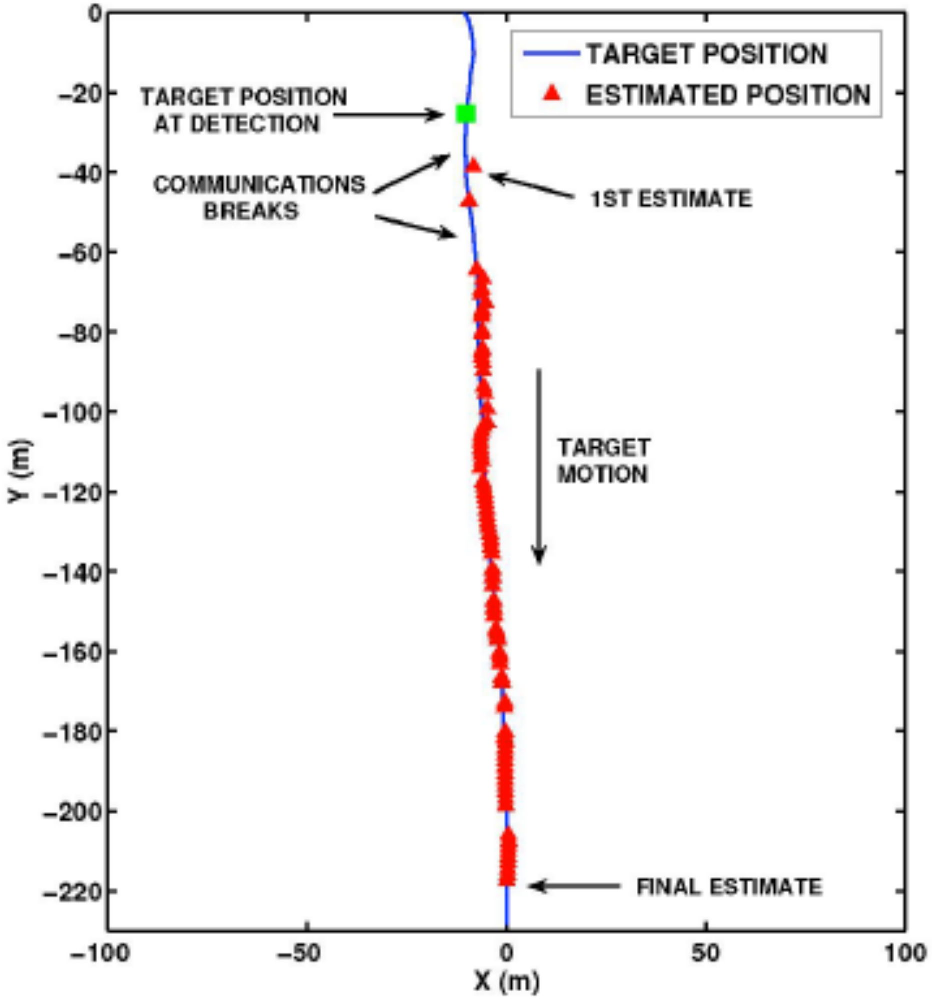
Gao Rui and Mandar Chitre.

Cooperative Target Tracking in a distributed Autonomous Sensor Network. 2006.

Michael R. Benjamin and Donald P Eikstadt.

In previous studies, the common metric for success and analysis was position error. In practice, however, position estimation is not as important as overall mission success rates.

"What can it do?"



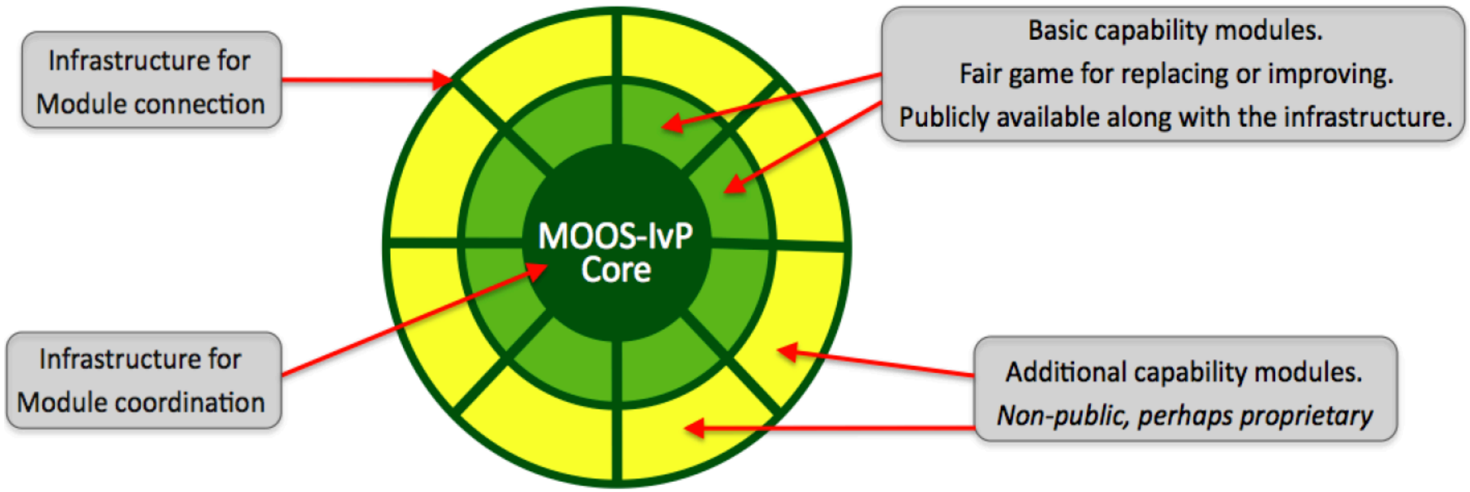
Code Architecture

Code Architecture:

MOOS-IvP is a set third-party, open source C++ modules that provide autonomy for robotic platforms.

Prolific Software that has been run on over a dozen platforms, and is being used at both ONR and DARPA.

Great tool for rapid-prototyping of autonomy scenarios



Tracking with a Particle Filter

Step 1: Initialization

A range report r_t is received, N particles generated such that:

Positions generated:

$$\mathbf{x}_i = [x_i, y_i, z_i]^T$$

$$x_i = r_t \sin(\phi_i)\cos(\theta_i)$$
$$y_i = r_t \sin(\phi_i)\sin(\theta_i)$$
$$z_i = r_t \cos(\phi_i)$$

For random:

$$-\frac{\pi}{2} \le \phi_i \le 0$$
$$0 \le \theta_i \le 2\pi$$

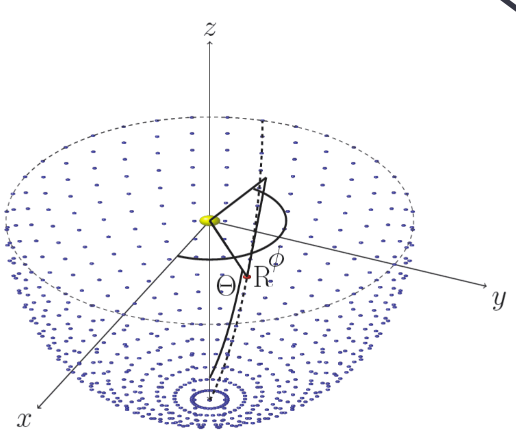
Velocities generated:

$$\dot{\mathbf{x}}_i = [\dot{x}_i, \dot{y}_i, \dot{z}_i]^T$$

$$\dot{x}_i = v_i \sin(\Phi_i)\cos(\Theta_i)$$
$$\dot{y}_i = v_i \sin(\Phi_i)\sin(\Theta_i)$$
$$\dot{z}_i = v_i \cos(\Phi_i)$$

For random:

$$0 \le v_i \le v_{\max}$$
$$0 \le \Theta_i \le 2\pi$$
$$\frac{\pi}{2} - \Phi_{\max} \le \Phi_i \le \frac{\pi}{2} + \Phi_{\max}$$



Each particle defined:

$$\zeta_t^i = \begin{bmatrix} \mathbf{x}_i \\ \dot{\mathbf{x}}_i \end{bmatrix}$$

for i = 1,2,… N

Tracking with a Particle Filter

2. Advance Particles (Prediction)

Advance the particles to their new state after time Δt, and insert random noise into velocity:

$$v_i^{t-1} = \sqrt{\dot{x}_i^2 + \dot{y}_i^2 + \dot{z}_i^2}$$

$$\Theta_i^{t-1} = \tan^{-1}\left(\frac{\dot{x}_i}{\dot{y}_i}\right)$$

$$\Phi_i^{t-1} = \tan^{-1}\left(\frac{\dot{z}_i}{\sqrt{x_i^2 + \dot{y}_i^2}}\right)$$

→

$$v_i^t = v_i^{t-1} + v_{noise}$$

$$\Theta_i^t = \Theta_i^{t-1} + \Theta_{noise}$$

$$\Phi_i^t = \Phi_i^{t-1} + \Phi_{noise}$$

→

$$\dot{x}_i^t = v_i \sin(\Phi_i)\cos(\Theta_i)$$

$$\dot{y}_i^t = v_i \sin(\Phi_i)\sin(\Theta_i)$$

$$\dot{z}_i^t = v_i \cos(\Phi_i)$$

Calculate the new positions:

$$x_i^t = x_i^{t-1} + \dot{x}_i^{t-1}\Delta t$$

$$y_i^t = y_i^{t-1} + \dot{y}_i^{t-1}\Delta t$$

$$z_i^t = z_i^{t-1} + \dot{z}_i^{t-1}\Delta t$$

New positions and new velocity vectors with noise.

$$\zeta_t^i = A\zeta_{t-1}^i$$

Tracking with a Particle Filter

3. Calculate the Weights

A range report r_t is received at time t, and weights are calculated.

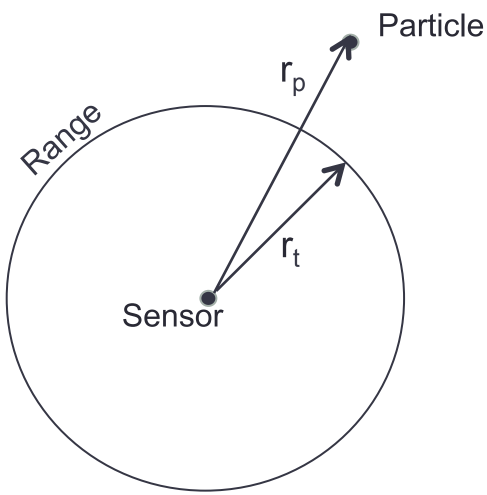
$$w_i^t = w_i^{t-1} \frac{p\left(r_t \middle| \varsigma_t^i\right) p\left(\varsigma_t^i \middle| \varsigma_{t-1}^i\right)}{q\left(\varsigma_t^i \middle| \varsigma_{0:t-1}^i, r_t\right)}$$

and if $p\left(\varsigma_t^i \middle| \varsigma_{t-1}^i\right) = q\left(\varsigma_t^i \middle| \varsigma_{0:t-1}^i, r_t\right)$

$$w_i^t = w_i^{t-1} p\left(r_t \middle| \varsigma_t^i\right)$$

Sources of Error?

1. Particle Guess vs. Target Location
2. Range Measurement error
3. Sensor location (GPS) error
4. Sensor time delay



By CLT, probability approximated as:

$$p\left(r_t \middle| \varsigma_t^i\right) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

μ = sensor range r_t
x = range to particle r_p
σ = set range variance

Finally, normalize the weights.

MITMECHE

Tracking with a Particle Filter

4. Resampling

To avoid estimation degeneration, new particles are generated based on the newly calculated weight distribution if enough particles have a low weight.

$$N_{eff} = \frac{1}{\sum_{i=1}^{N}\left(w_i^2\right)} \qquad N_{threshold} = \frac{N}{2}$$

If $N_{eff} < N_{threshold}$ resample

Resampling Process:

Draw N new particles from the old particles based on the distribution of their weights to replace the old set.

Then the weights for the new particles are reset to equal:

$$w_i = 1/N$$

Particle Filter

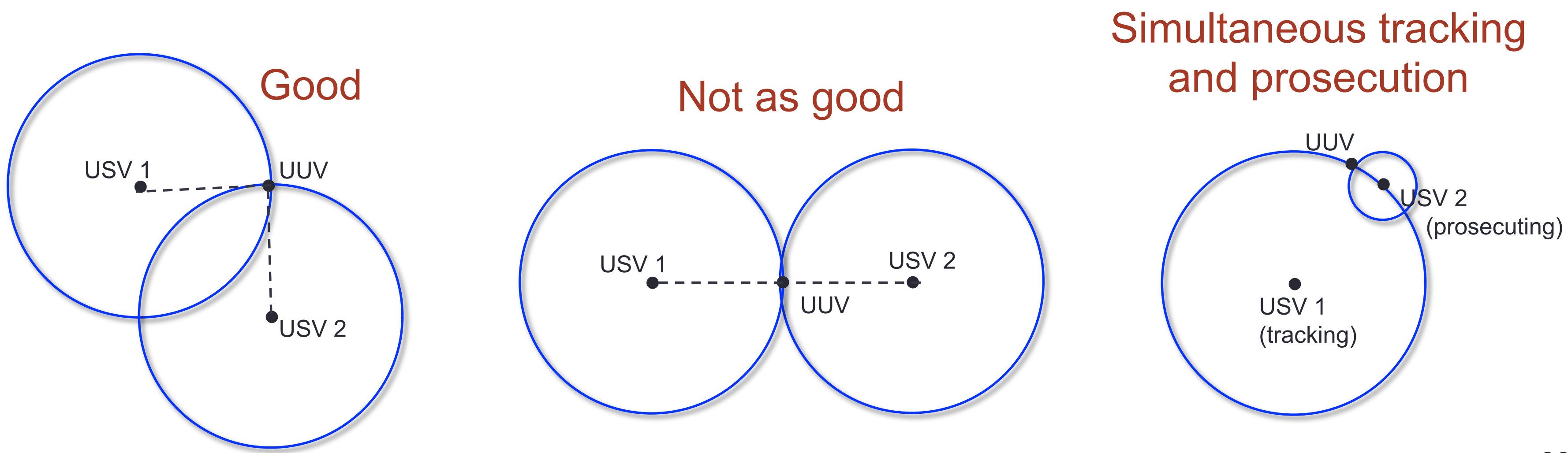
- Distribution of the particles represents the pdf of the target

Vehicle positioning for tracking optimization

1. Vehicles must be within range of sensor
2. Safety of vehicles – Collision avoidance
3. Resupplies of depth charges must be managed
4. One vehicle may need to prosecute

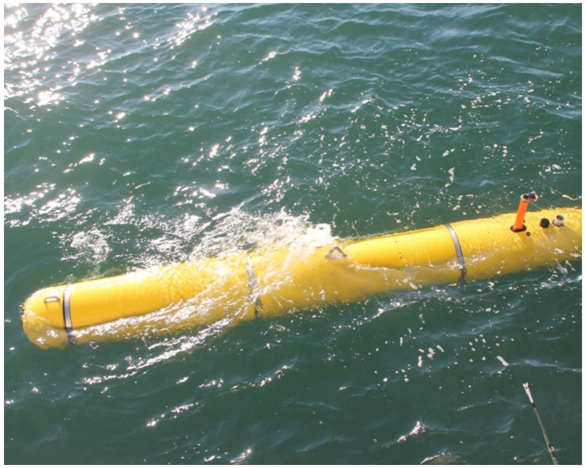
Other Particle Filter Considerations

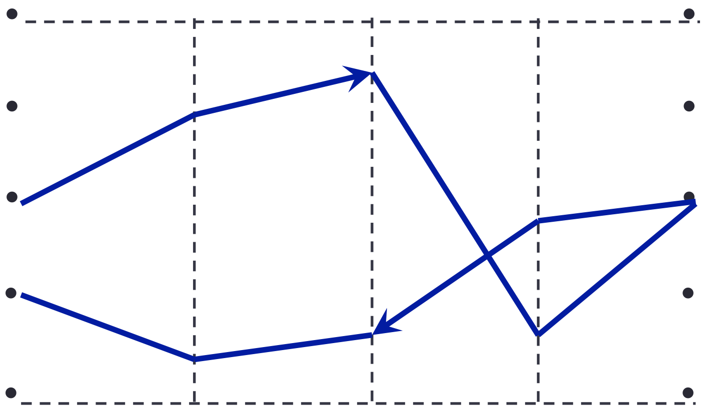
1. UUV depth assumed shallow and constant – making problem 2 dimensional
2. Reserve particles for target track changes



The Problem - UUV

- UUV Logic:
  - 5 starting and ending "poles" created at the ends of an operational box, or "op-box"
    - The UUV must start at one of the 5 poles, traverse to one of the end poles on the east side, then traverse back to any pole on the west
  - Two mechanism to avoid USV's:
    1. Regular UUV path changes planned at a ¼, ½, and ¾ of the way across the op-box, there and back
    2. Path avoidance when UUV senses a USV nearby (from USV's range "pings")



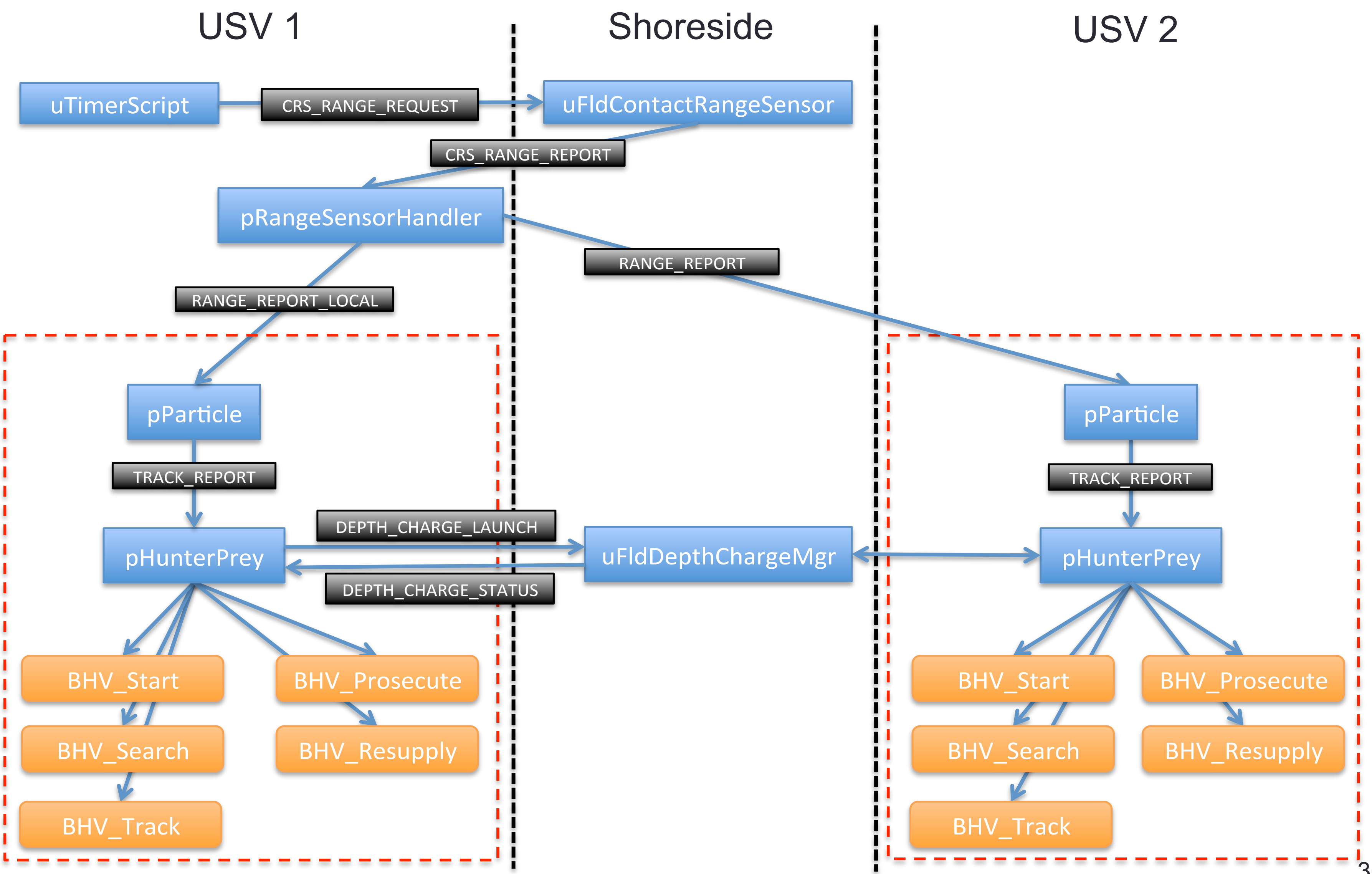


The Problem - USV

- The USV's must start the problem at the upper and lower corners of the east side of the op-box.
- At the start of the competition, the USV's may "ping" to attempt to get a range from the vehicle to the UUV
  - Pings can be limited in:
    1. Range
    2. Arc Coverage
    3. Time Duration Between Pings

- USV's are given a set number of depth charges, which may be dropped with fixed time delay and range, which represent successful prosecution of a submarine

USV Logic Architecture



USV Logic - pHunterPrey

5 Modes, selected by conditional logic statements

Start

Action:
- Head to starting positions

Condition:
- If current time is less than start time

Resupply

Action
- Head to base for resupply, and stay until resupplied

Conditions:
- If number of charges on board is zero.
- If other vehicle is not resupplying

Search

Action:
- Conduct a loiter pattern at center of the op box

Condition:
- If reports on vehicle are not current - specified number of reports not within a certain time frame

Track

Action
- Maintain a constant bearing and distance to target

Condition
- Vehicle reports are current
- Own vehicle is furthest from target vehicle

Prosecute

Action
- Maintain a constant bearing and distance to target

Condition
- Vehicle reports are current
- Own vehicle is closest to target vehicle


First Contact made by Archie
Archie and Betty pulse their range-only sensors to search for Jackal
After three “hits” Jackal is acquired
Betty Drops her depth charges when in range, and after a successful hit, the vehicles return home.
Archie maneuvers into a tracking position, while Betty moves in to prosecute.
betty

Same Scenario,
Now with a Particle Filter


jackal

My Contributions

- Creation of the code that governs the logic of the UUV, USV's and communication between them
  - pHunterPrey, pUUVPath
  - Including and configuring CutRange, Trail, Waypoint and behaviors
- Modifications to existing particle filter (pParticle) code to accommodate Hunter-Prey scenario.
- Communications sharing between vehicles
  - Range Reports, Mode, Node Reports
- Modifications to uFldContactRangeSensor to limit range sensor to arcs

MITMECHE

My Future Work

Develop a Design of Experiments to test how the parameters affect the problem

- Sensor Range – 3 variables
- Sensor Frequency – 2 variables
- USV Speed – 3 variables
- UUV Speed – 3 variables
- Depth Charge Range – 3 variables
- Depth Charge Delay – 3 variables
- Number Held – 3 variables
- Time to re-stock – 2 variables

Number of Experiments:

$2^2 \cdot 3^6 = 2{,}916$

Real Water Testing in the Charles River

- Put programs on Kingfisher USV's and to try to actual water runs
- Finish Collision Avoidance Behavior
- Use a simulated UUV if necessary

Bonus Work

- Get an actual UUV
- Use acoustic modems for range sensing rather than just
  - uFldContactRangeSensor now on sensor

Suggestions

- Papers
  - Chitre (range-only sensor work in Singapore)
  - Alex Bahr - thesis from MIT
  - Chou Ke – active sensing a robot position optimization
    - Putting sensor distance constraint into control problem ma be a novel approach
- Journal of Underwater Acoustics
- Should put in a literature review
- Animations in particle filter description
- Gaussian Distribution – better explanation
- New Order of Presentation
  - Background
  - Previous work comparison
    - How my work diverges
  - Particle Filter Description
  - Problem formulation
  - My specific contributions
  - Future Work

More Suggestions

- Slide 3,4, and 5 are too small
- Background Slide – should be summary of everything
  - Tone down amount of information
- Picture or video to make the problem better understood upfront
- Have a few ideas for measure of success and how to measure.
- Literature comparison slide – restructure with bigger graph
- P-3 communities use range-only sonar buoys
- After Slide 8 indicate verbally that this is where my work begins