Cooperative Autonomy for Contact Investigation

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OCEANS '10 IEEE Conference: Sydney, Australia

Broad Problem

Terrorist threats against ships

- are real (USS Cole, Limburg, Somalian pirates)
- can look like normal boat traffic
- are highly likely to occur in harbors

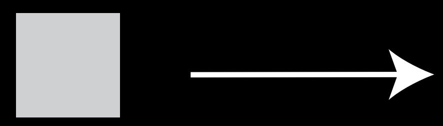
Unmanned Surface Vehicles (USVs) offer a potential solution. Relative to manned systems, USVs are:

- safe (no danger for sailors due to threat or rough seas in small boat)
- low cost
- scalable

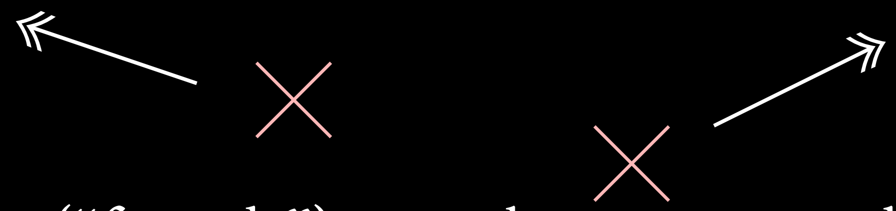
Specific Problem: Scenario

Scenario:

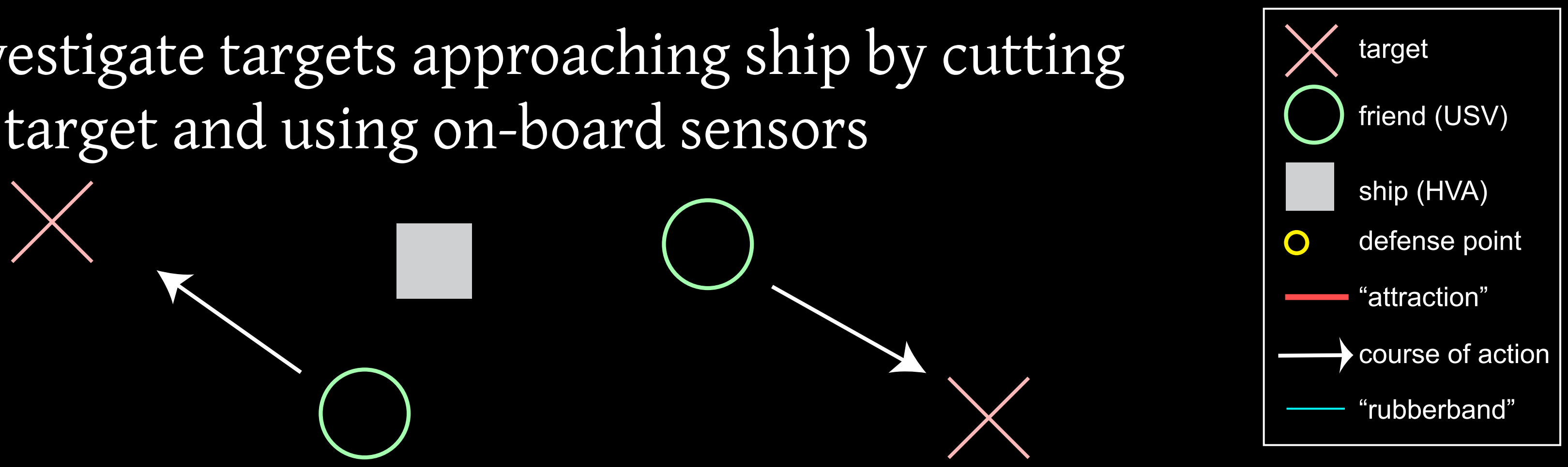
- Ship at anchor or transiting at slow speed through harbor.



- Specified number of potential targets (“targets”) (normal small boat traffic) with arbitrary destinations within the harbor



- Specified number of USVs (“friends”) actively protecting ship
- USVs investigate targets approaching ship by cutting range to target and using on-board sensors



Specific Problem: Assumptions

Simulation Initial Assumptions:

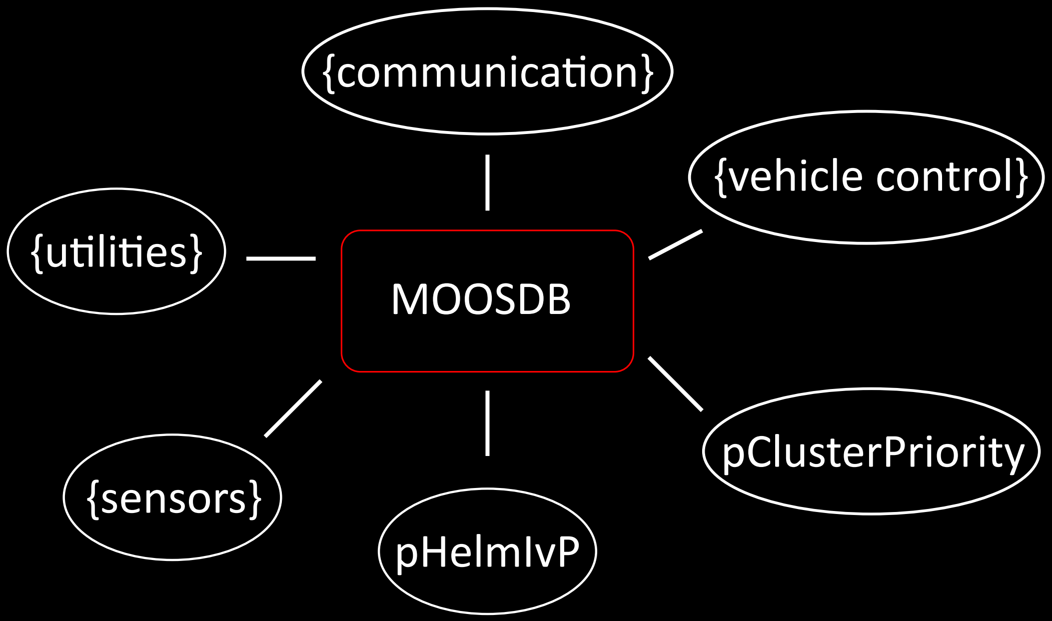
- Ship radar is capable of accurately picking up targets
- Ship to USV communications are robust (though not necessarily high throughput)
- USVs have short range sensors for determining target’s potential threat (video / still camera, lidar, etc.)
- USVs may have hailing system to warn away (accidental) intruders from ship

SCOUT USV

Software Architecture (MOOS)

Publish / subscribe infrastructure

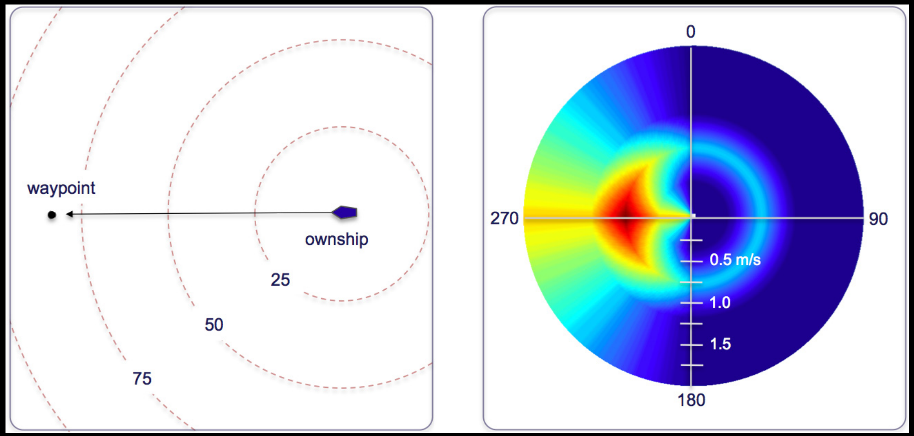
- comprised of individual processes ("MOOS modules")
- modules communicate through central database (`MOOSDB`)
- modularity allows contributions from many authors and incremental design



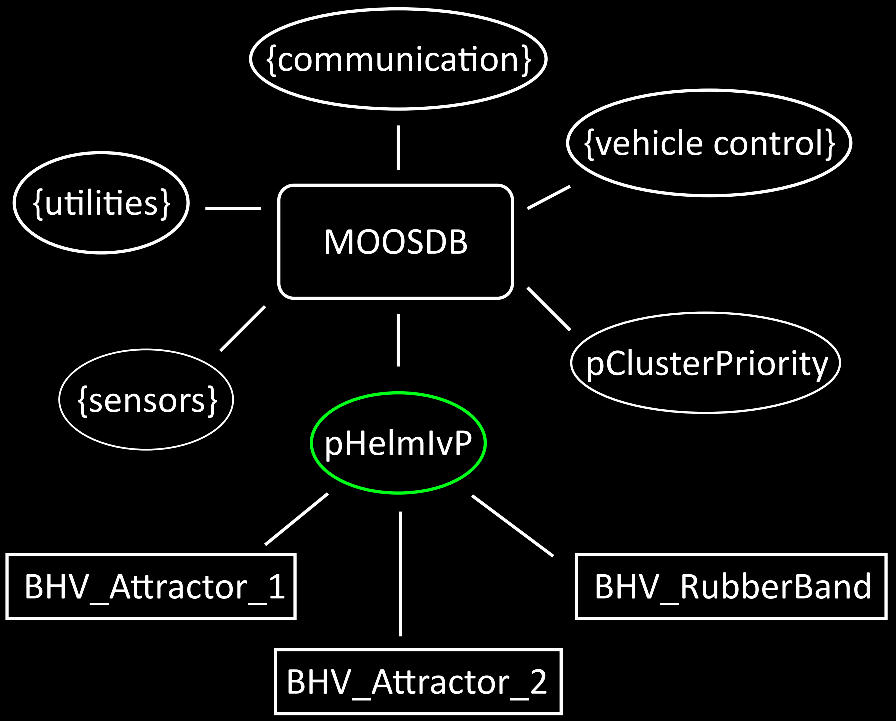
Autonomy Infrastructure (MOOS-IvP)

Behavior based autonomy

- Set of behaviors govern action space (heading and speed for USV)
- Each behavior generates an objective function -- function of utility over the entire heading-speed plane
- IvP Helm (`pHelmIvP`) optimizes over all running behaviors to choose mutually beneficial action.



example objective function

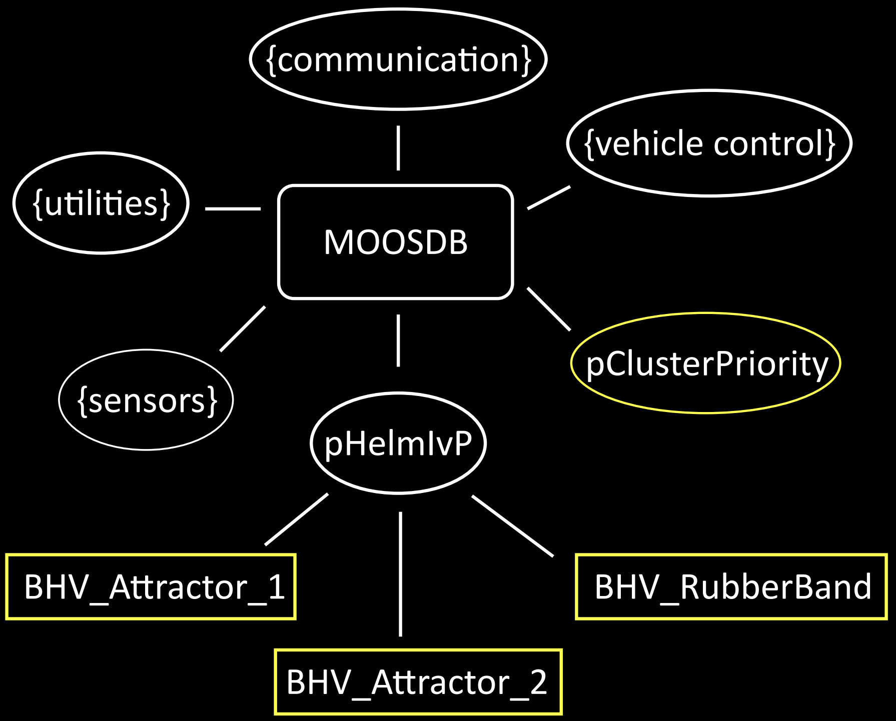


Cluster Defense Overview

Two behaviors and one MOOS module govern USV actions in this work:

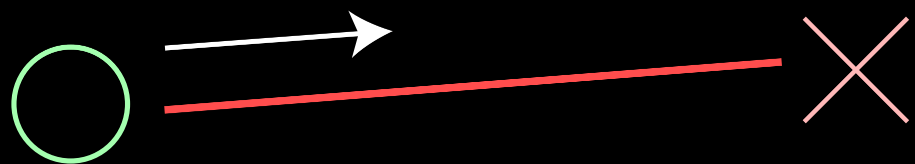
- BHV_Attractor: seeks to draw vehicles towards targets.
- BHV_RubberBand: seeks to bring vehicles back to defense positions around ship.

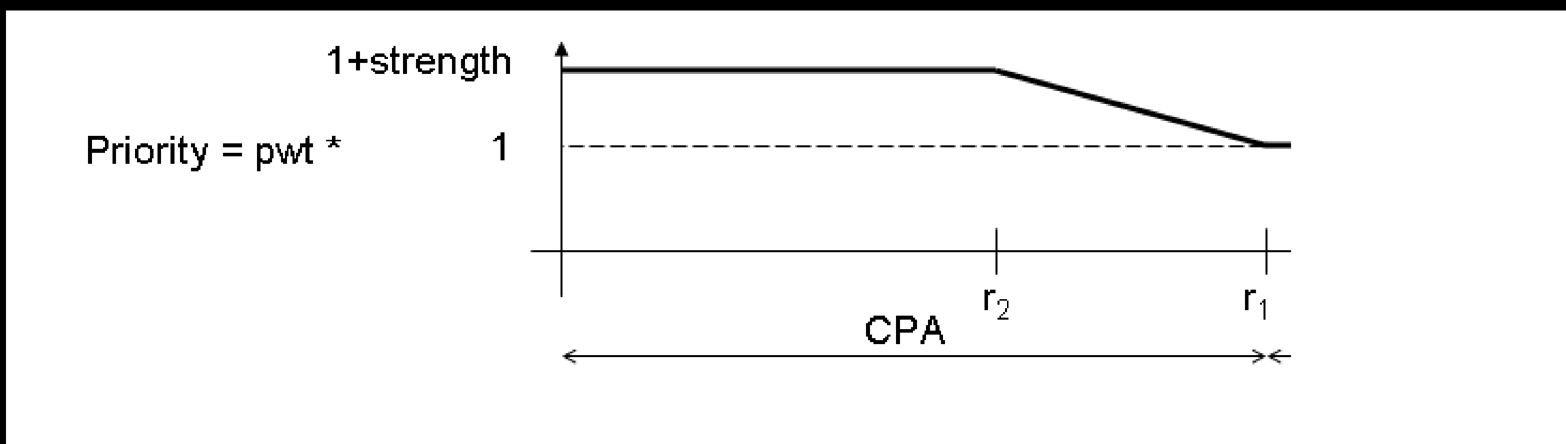
- pClusterPriority: balances priorities for both behaviors in the context of multiple USVs / multiple contacts.



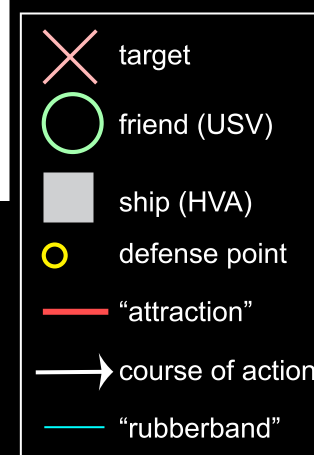
Autonomy: BHV_Attractor

- seeks to cut range to a target. An instance is run for every target
- objective function governs over heading



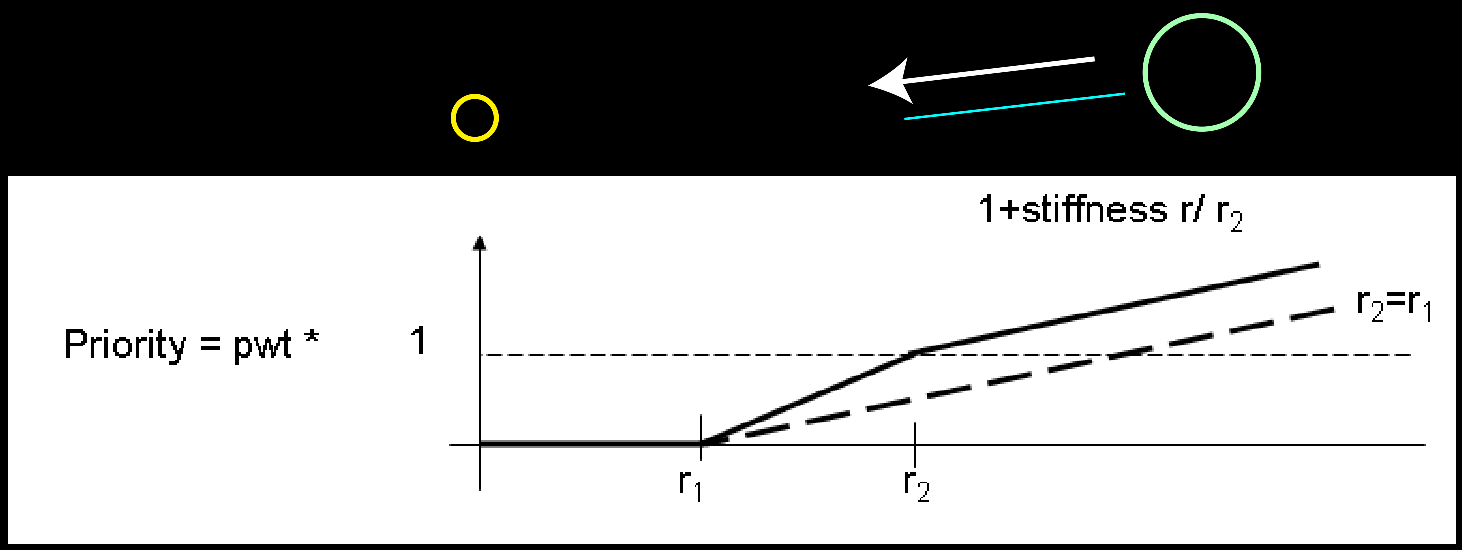


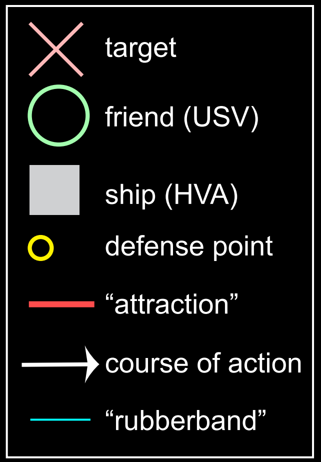
CPA: closest point of approach (USV <-> target)
pwt: priority weight set by pClusterPriority
results presented: r1 = 0 m, r2 = 100 m, strength = 0.5



Autonomy: BHV_RubberBand

- seeks to station keep near a fixed point (assigned by `pClusterPriority`). one instance is run.
- objective function governs over heading and speed





CPA: closest point of approach (USV <-> target)
results presented: r1 = 15 m, r2 = 30 m, stiffness = 2, pwt = 50

Autonomy: `pClusterPriority`

- prioritizes contacts based on closest point of approach
- rebalances individual `BHV_Attractor` priorities within the cluster of USVs

Overall Priority

Prioritizes most threatening targets

Encourages closest USV

$$
\begin{aligned}
A_{ij}(d_{ij}, \overline{d_j}, cpa) &= A_0 \cdot C_j(cpa) \cdot D_{ij}(d_{ij}, \overline{d_j}) \\
C_j &= \begin{cases} cpa_j \cdot \frac{C_{min} - C_{max}}{cpa_{cutoff}} + C_{max} & \text{if } cpa_j \leq cpa_{cutoff} \\ C_{min} & \text{if } cpa_j > cpa_{cutoff} \end{cases} \\
D_{ij} &= e^{-\alpha(d_{ij} - \overline{d_j})/\overline{d_j}}
\end{aligned}
$$

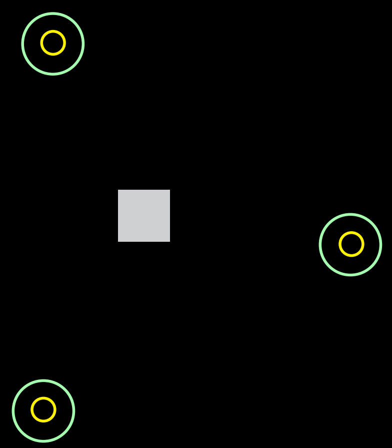
closest point of approach of target *j* to ship

distance from friend *i* to target *j*

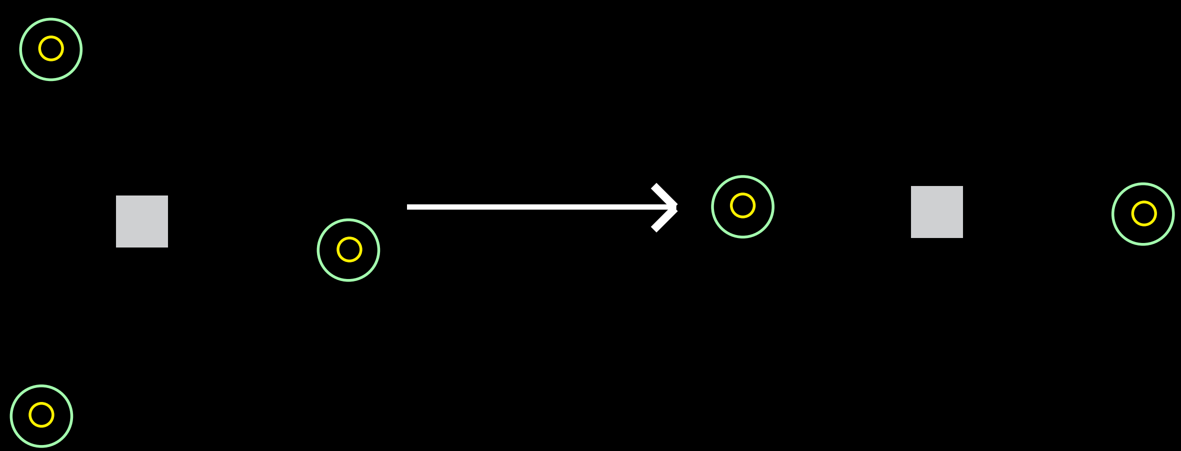
mean distance of all friends to target *j*

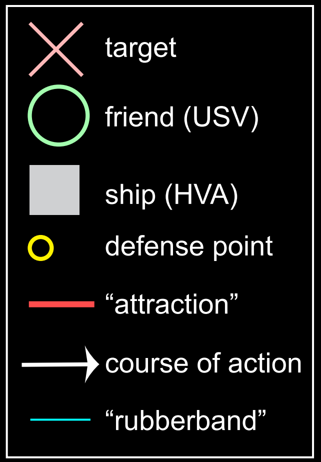
Autonomy: `pClusterPriority`

- sets initial defense locations on evenly spaced points of circle around ship:



- rebalances USVs in case of loss (or addition) of one:

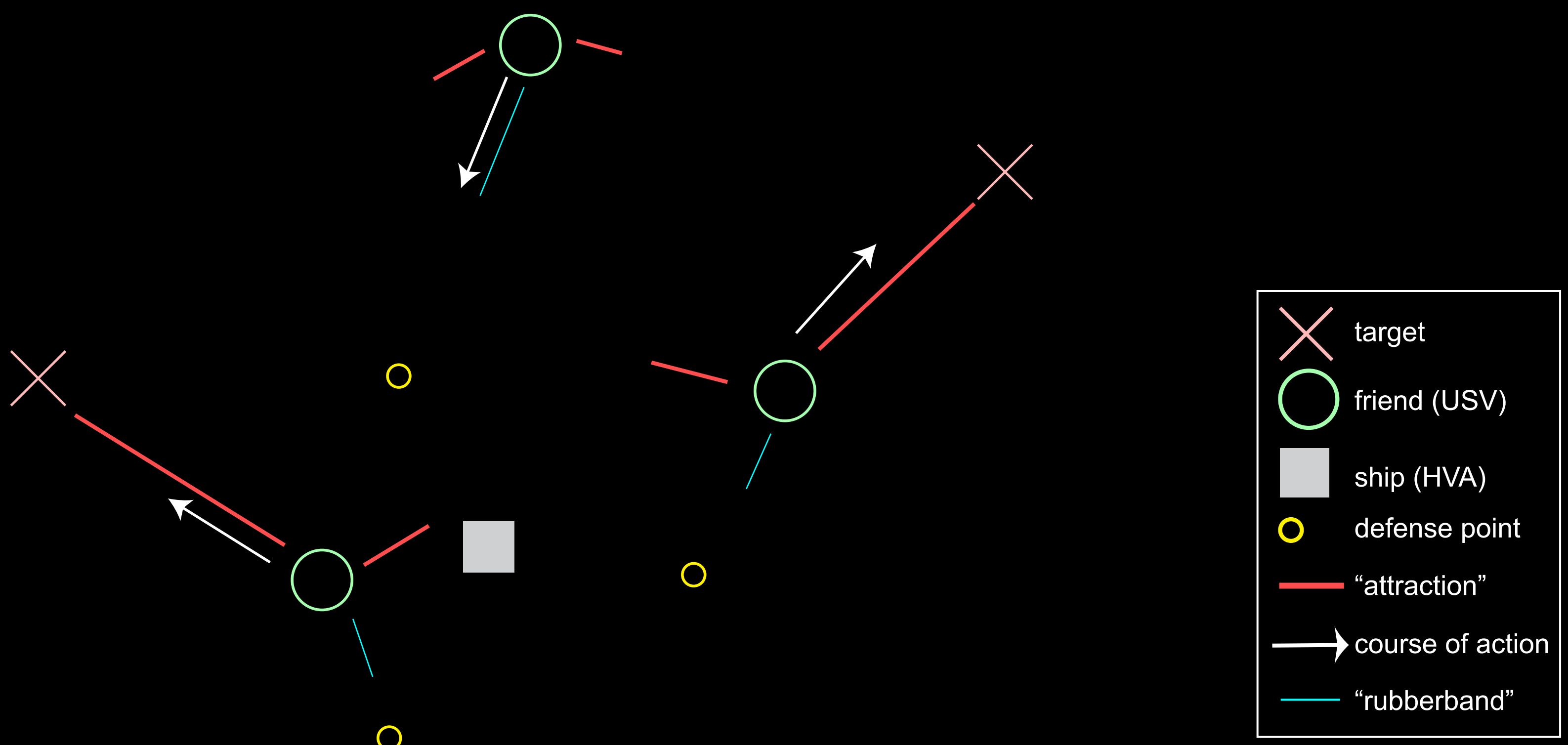




Autonomy: Combined Actions

Together these three pieces perform a task analogous to zone defense in basketball:

- Each USV investigates target(s) nearest to them and other USVs back off when another USV is near.
- When targets are not near or potentially threatening, USVs return to defense points and station-keep



Performance Evaluation: Qualitative

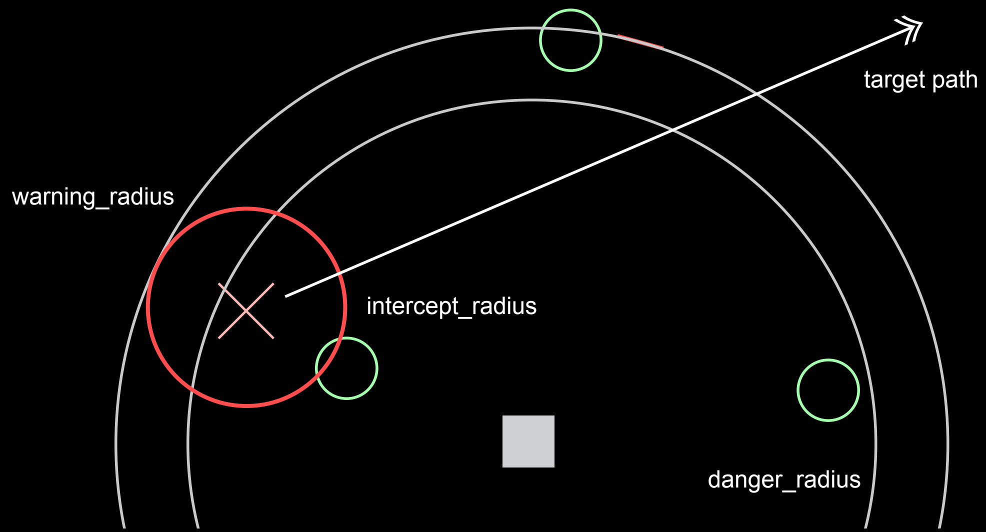
Successes:

- USVs investigate most targets of highest interest (heading close or directly toward ship).
- USVs usually do not overlap investigation at the expense of another target.
- System requires only knowledge of targets' and ship's <speed, heading, position> and friends <position>. No other data must be shared for autonomy to function.

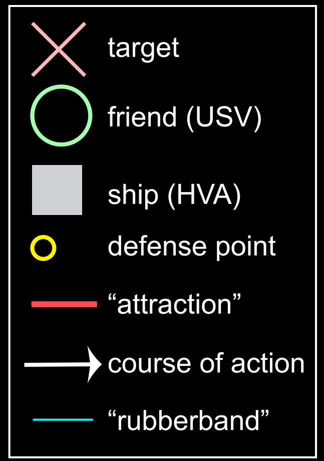
Performance Evaluation: Quantitative

Targets outside "warning radius" are ignored. Targets within "danger radius" are scored:

- Score is an exponential based on *range to ship* at which target is first intercepted (farther is better).
- Perfect Score is interception at "danger radius"
- Interception requires a USV entering "intercept radius"



here: warning_radius = 1200 m
danger_radius = 1000 m
intercept_radius = 20 m



pScorer Results

description	vehicles station keep (baseline)	full system, 1 USV	full system, 3 USVs
defense radius (m)	300	300	300
number of USVs	3	1	3
max number of simultaneous contacts	10	10	10
time (hrs)	5	5	5
overall score (%)	19.3	23.5	26.8

Summary

The system presented here provides:

- Safe inspection of harbor traffic by autonomous vehicles.
- Behavior-based autonomy using "zone defense" analogy.
- Automatic prioritization of contacts.

Acknowledgments

- A. Vermeij, and many others who helped at the NATO Undersea Research Centre (NURC)
- P. Newman for MOOS
- LAMSS: A. Balasuriya, K. Cockrell, S. Petillo