Multi-Robot Persistent Coverage Under Fuel and Stochastic Failure Constraints

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Abstract

The guiding application of this research project is **multi-robot systems** as they relate to agricultural challenges, especially in the **persistent inspection of cropland.** In this research project, we present both baseline (MILP) and novel algorithms to solve a multi-robot coverage problem under **battery depletion** and **stochastic failures**. We compare the solutions based on metrics about visitation and redundancy. Finally, we present a visualization, a simulation, and a real-world demonstration (using Khepera IV robots) setup to provide additional data to analyze our solutions.

Methods

We developed **three methods** to solve the problem. **MILP** and **Heuristic 1** generate initial paths for the problem, and expect that the robots will loop through them a number of times before experiencing a failure. MILP provides a mathematically optimal solution to the problem, but takes longer to generate solutions than either Heuristic 1 or 2. When they do experience failures, they use a recalculation method (Heuristic 2) while the failed robot(s) are being replaced. **Heuristic 2** can generate both initial and recalculated solutions based on which robot fails.

Failures

We define failures as having a set chance of occurring at each time step, but that the failed robots will not be obstacles..

Charging

Our robots have a charge capacity, after which they must return to the depot, placed in the lower left hand corner of the map, to recharge.

Results

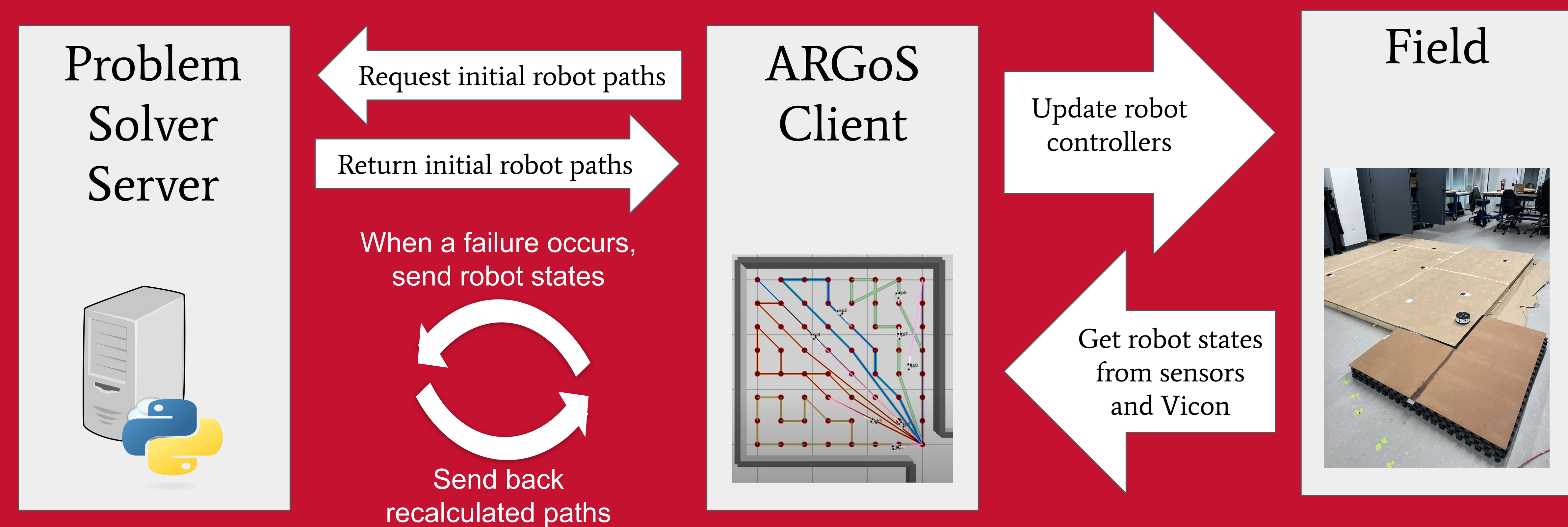
We execute the calculated solutions using three ways: **pseudo-simulate**, **ARGoS Simulation**, and **Vicon-assisted arena** setup with ARGoS. For each of the solution, we visualize the paths assigned to each tobor, the visitation frequency of the map, percent coverage over time, and percent coverage over other parameters.

Parameters	Robots	Node to Robot Ratio	Redundancy: Failure Rate Ratio	Charge Capacity (L_min ratio)
ARGoS Heuristic 1&2	8, 64, 1024	8:1, 16:1, 256:1	1:10	1.5, 3
ARGoS MILP	8, 16	8:1, 16:1	1:10	1.5, 3
Real World Heuristic 1&2	8	8:1	1:10	1.5, 3
Real World MILP	8	8:1	1:10	1.5, 3

Acknowledgments

We would like to thank Dr. Carlo Pinciroli, Dr. Benjamin Cooper, and Dr. Daniel Zwillinger for guiding this project and showing tremendous support throughout its completion.

WPI BAE SYSTEMS




```
Heuristic 1
initialize map of nodes based on cellular decomposition
sort nodes into groups, based on angle and distance
divide map to group nodes that satisfy fuel constraints
(OPTIONAL) run TSP optimization on selected nodes
make RP (Redundancy Parameter) # of copies of "novel" subtours
assign generated subtours to robots
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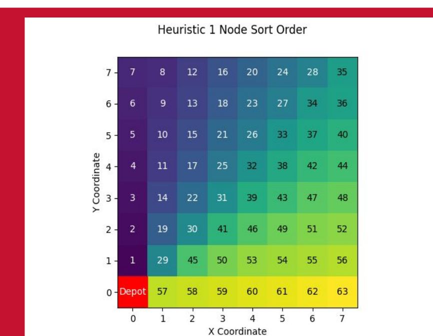

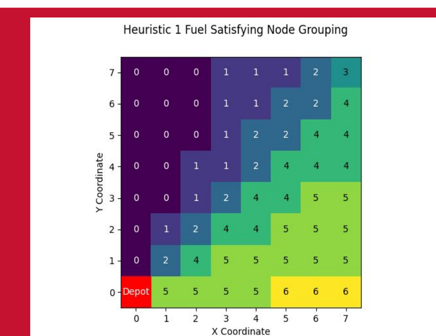


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Heuristic 2
while more nodes to be covered do
  for ki in num_of_robots do
    while goal in nodes already covered AND fuel for return journey do
      max_dist ← 0
      goal ← (0,0)
      for n in uncovered nodes do
        if distance((0,0), n) > max_dist then
          max_dist ← distance((0,0), n)
          goal ← n
    path, distance_travelled ← Modified_A*(last_node(ki), goal)
    robot_paths(ki) ← robot_paths(ki) + path
     UpdateNodesCovered()
    robot_fuel(ki) ← robot_fuel(ki) − distance_travelled
    last_node(ki) ← robot_paths(ki)(−1)
    if (0,0) == last_node(ki) then
      robot_fuel(ki) ← FUEL_CAPACITY
end
```
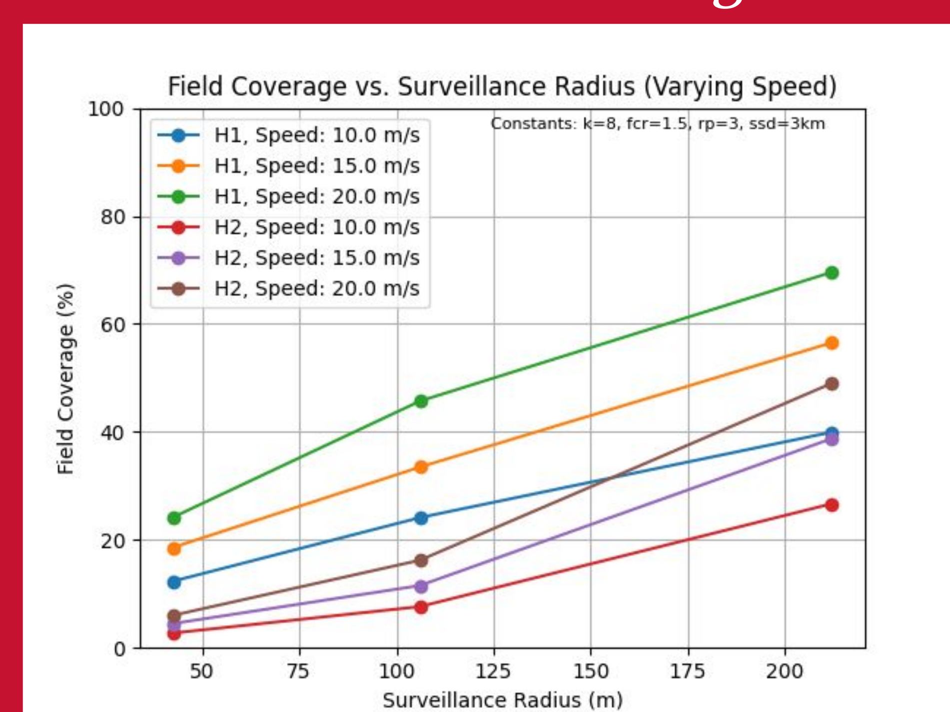
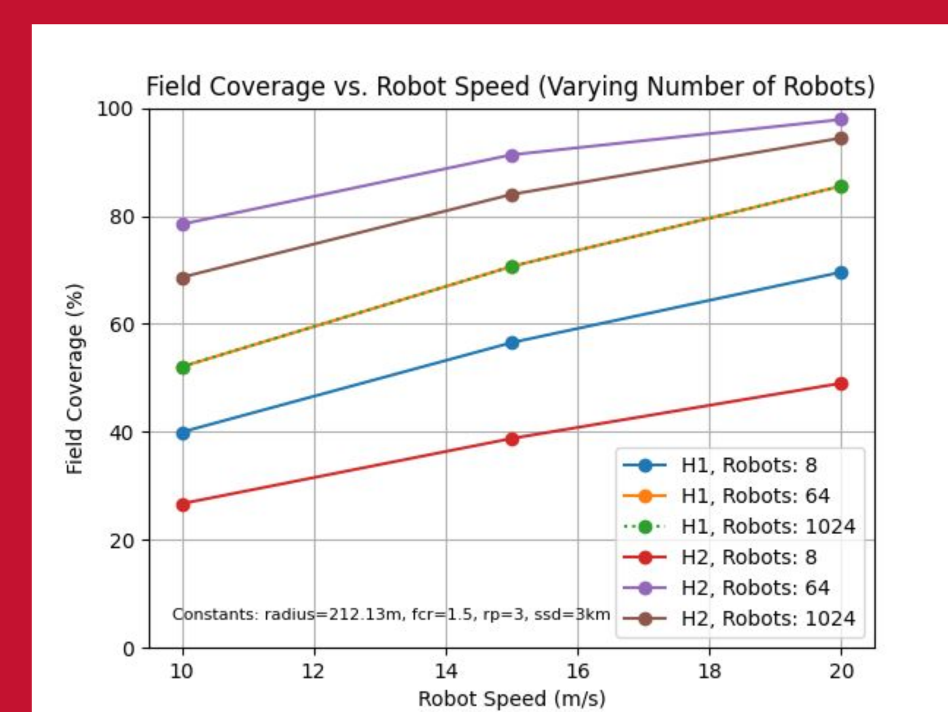
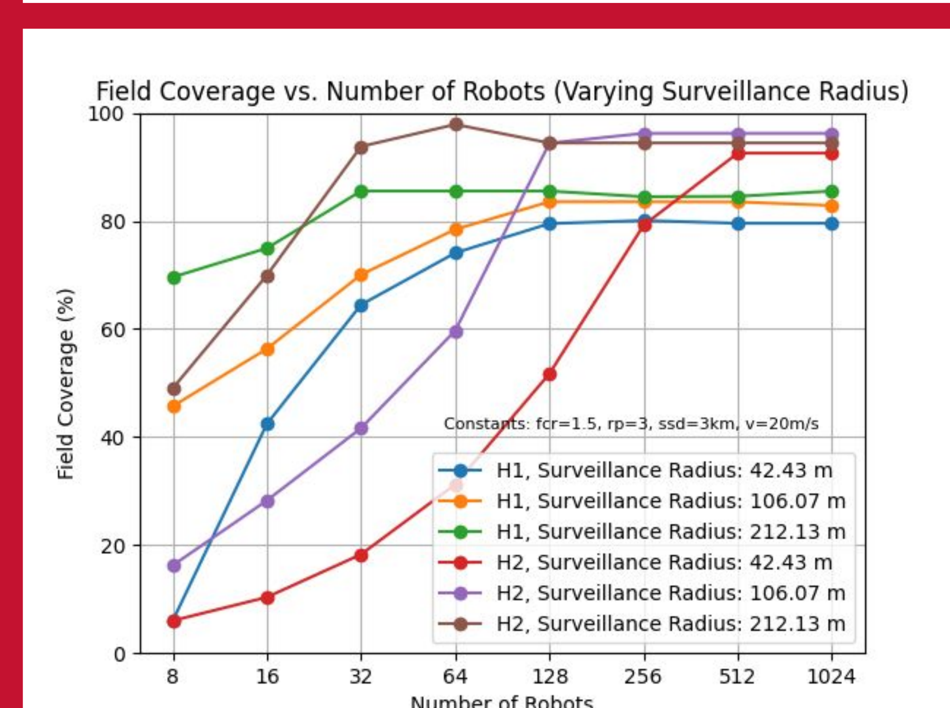
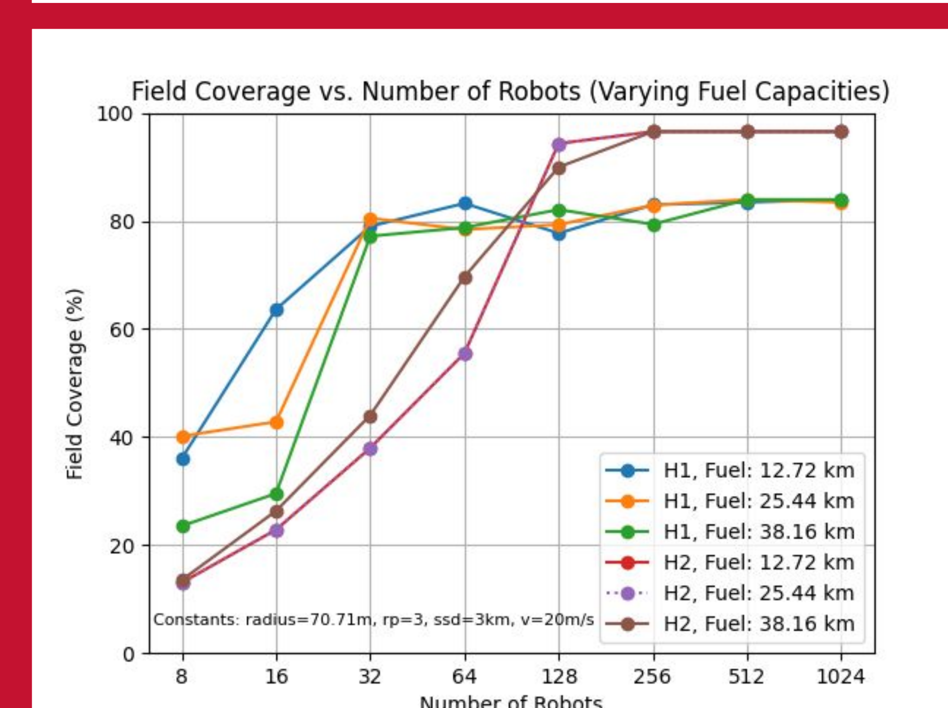

Average Coverage vs. Problem Parameters





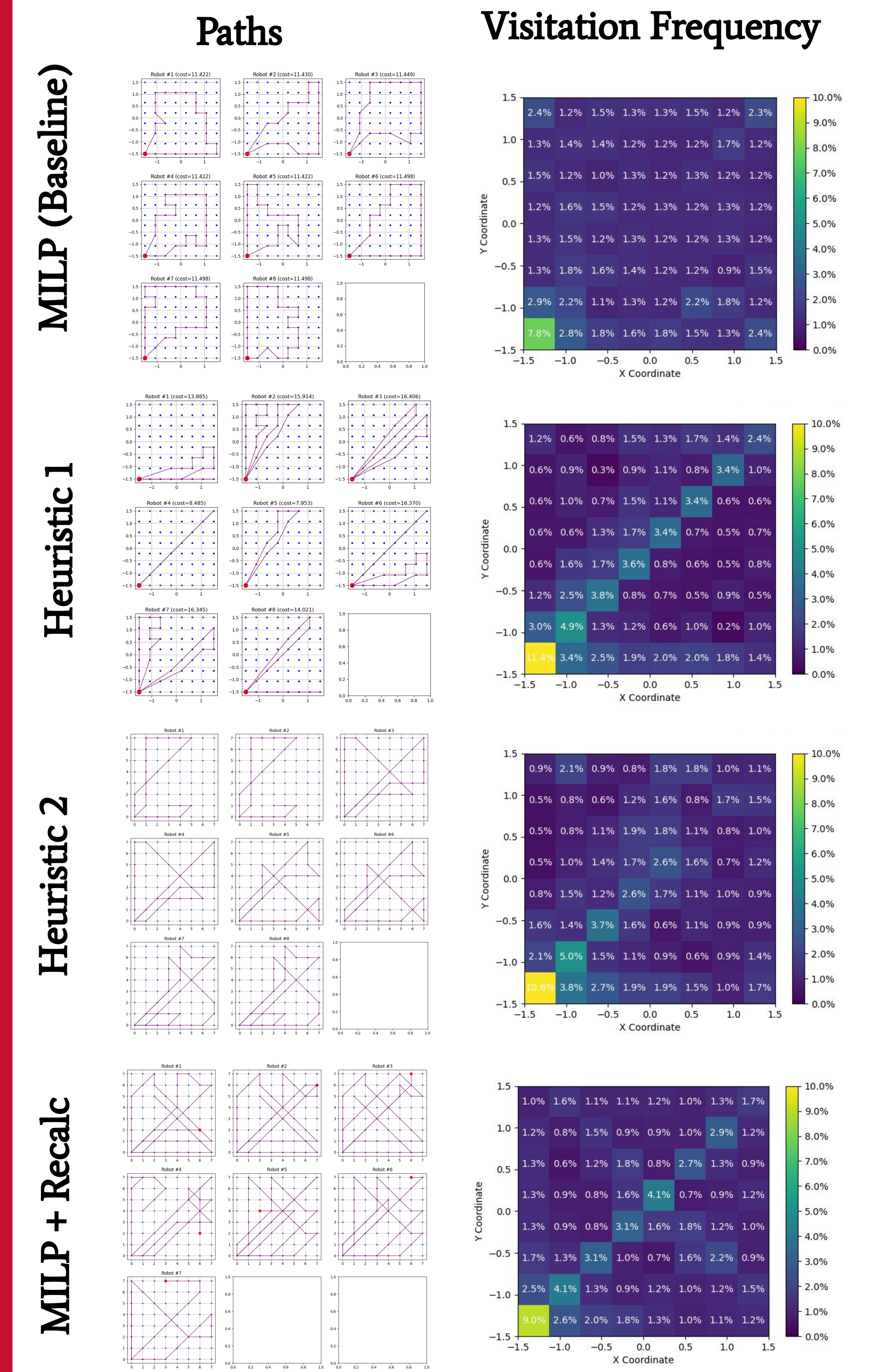




Note: When running MILP on similar parameters we received a coverage of 88%

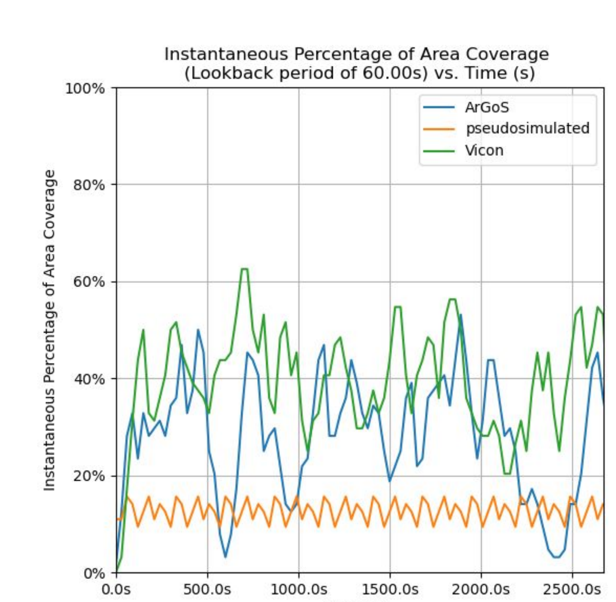
Results when problem parameters are:

- 8 Robots (at 0.2 m/s speed)
- 64 Nodes
- 3 Meter Arena Side Length
- 2 Redundant Robots
- 1.5 Fuel Capacity Ratio



Comparison of

Environments



Solvers