Simulation and experimentation of coordinated strategies for pursuit-evasion games

René Vidal

Electronic Research Lab
University of California at Berkeley

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Outline

- **A Probabilistic Approach to Map Building and Pursuit Evasion Games**
  - **Theory**
  - **Extensions**
  - **Simulation Results**
- **Implementation Issues**
  - **System and Agent Architecture**
  - **Map Building Implementation**
  - **Pursuit Evasion Implementation**
- **Conclusions and Current Research**

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A Probabilistic Approach to Map Building and Pursuit Evasion Games

- **Map Building Scenario:**
  - **Shahid Rashid**
- **Pursuit Evasion Scenario:**
  - **Joao Hespanha, Jin Kim**
- **Extensions to multiple evaders in 2.5 D:**
  - **Shahid Rashid**
- **Evaluation of different heuristic policies:**
  - **Jin Kim, Shahid Rashid**
- **Matlab Simulation Environment:**
  - **Jin Kim, Shahid Rashid**

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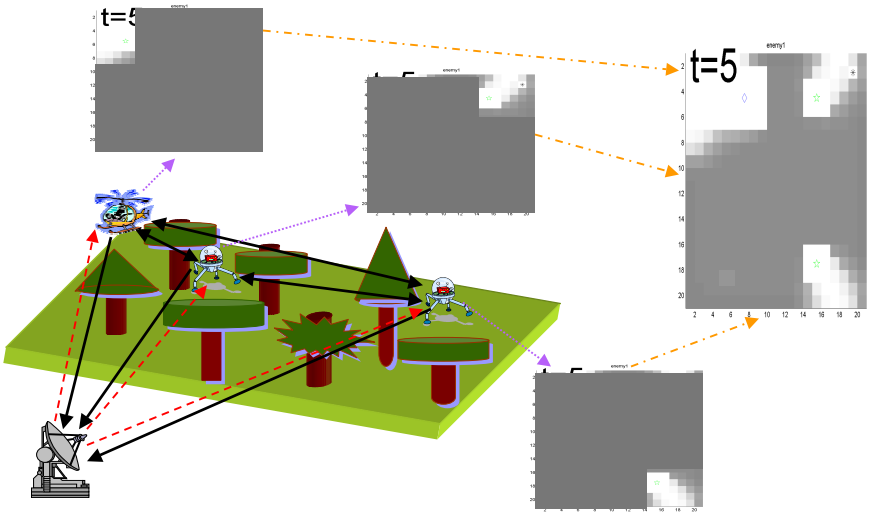
Map Building Scenario



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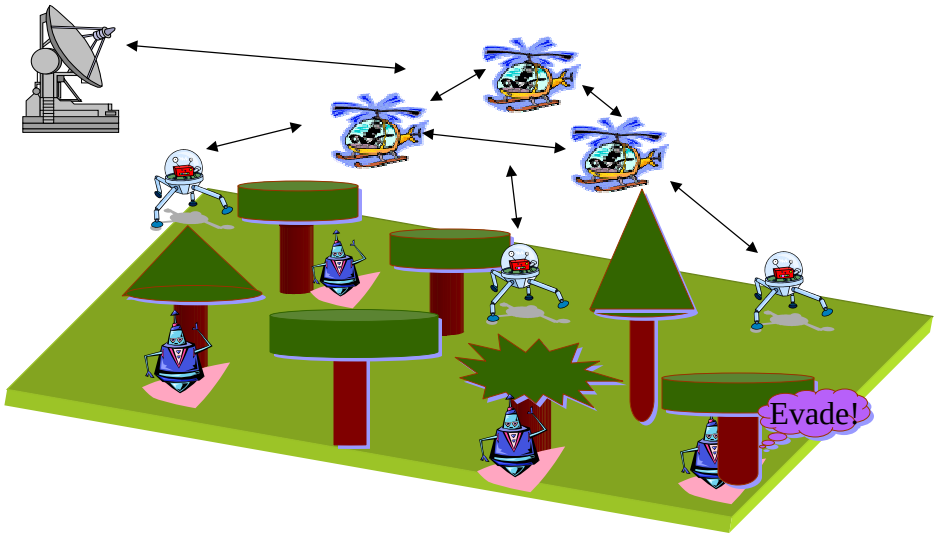
Pursuit Evasion Scenario



Map Building vs PE Scenario

- **Map building is a subset of pursuit**
- **State of unknown environment is static in map building**
- **Timing of exchange of information is not critical**
- **Map building/Pursuit** by a network of agents:
  - "How to combine local maps acquired by the individual agents into a global map?"
  - How to allocate resources?
  - How to pool resources?

Probabilistic Approach for Pursuit & Map-building

- Why probabilistic approach?
  - Non-determinism from sensor information and imperfect knowledge on environment and movements of enemies
- Probabilistic PE game with 1 evader
  - **Theorem :** There exist an integer T and an admissible pursuit policy *g* that is persistent on the average with period *T., i.e.,*

$$P_g(\mathbf{T}^* \in \{t, t+1, \ldots, t+T-1\} \mid \mathbf{T}^* \geq t\} \geq \varepsilon > 0$$

$$E_g[\mathbf{T}^*] \leq T\varepsilon^{-1}$$

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Recursive Algorithm

At each t,

$$p_e(x, Y_{t-1}) = prob(\mathbf{x}_e(t) = x \mid \mathbf{Y}_{t-1} = Y_{t-1})$$

1. Measurement step ↓ + $y(t) = \{v(t), e(t), o(t)\}$ model for sensor

$$prob(\mathbf{x}_e(t) = x \mid \mathbf{Y}_t = Y_t)$$

2. Prediction step ↓ model for evader's motion

$$p_e(x, Y_t) = prob(\mathbf{x}_e(t+1) = x \mid \mathbf{Y}_t = Y_t)$$

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Rules of the PE game

- Game
  - ends when all evaders are captured by the pursuers
  - capture=a pursuer occupies the same cell as the evader
- Evaders
  - random motion
  - smartness will also be considered
- Pursuers
  - start the game without the map for evaders and obstacles
  - each agent sees some visibility region around themselves and updates map as they move around
  - eye-in-the-sky has larger region of visibility but can not see the evaders hiding under the obstacles and cannot capture them.

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Extension to Multiple Evaders in 2.5D

- How to utilize the information from an eye-in-the-sky?
- Problem of agent assignment
  - team-theory
    - cooperation/redundancy of agents
    - effective division of resources

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Heuristic Strategies

- Greedy Policy
  - try to maximize the probability of finding the evader at the next instance
  - well-scaled
  - may not utilize the information from eyes-in-the-sky
- Global-max Policy
  - try to move towards the place with ‘maximal probability’ of being an evader at the next instance
  - may not utilize the multiple pursuers (may move towards the same place)

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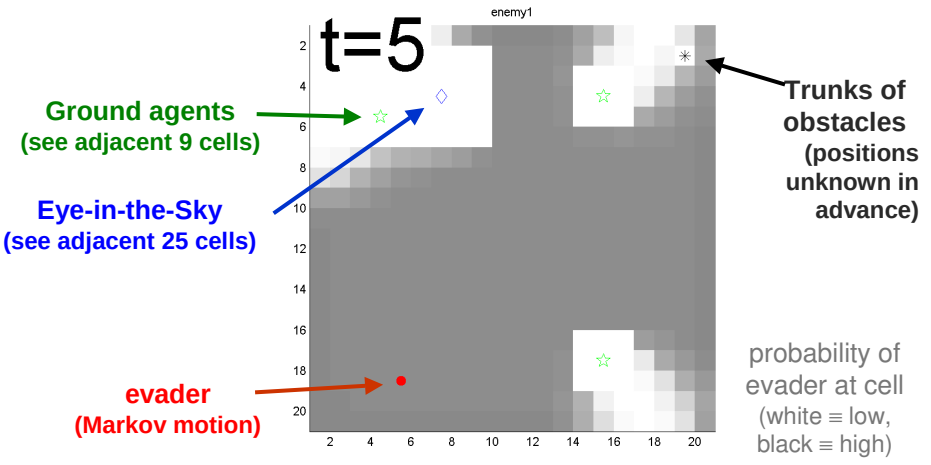
Matlab Simulation Environment



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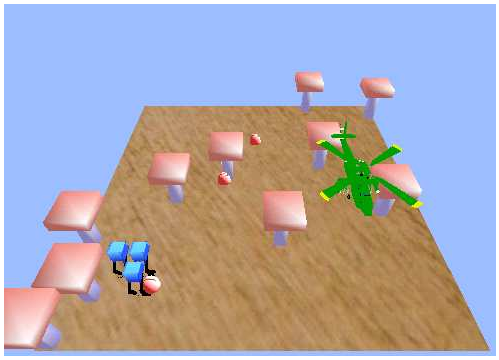
2.5 D Simulation



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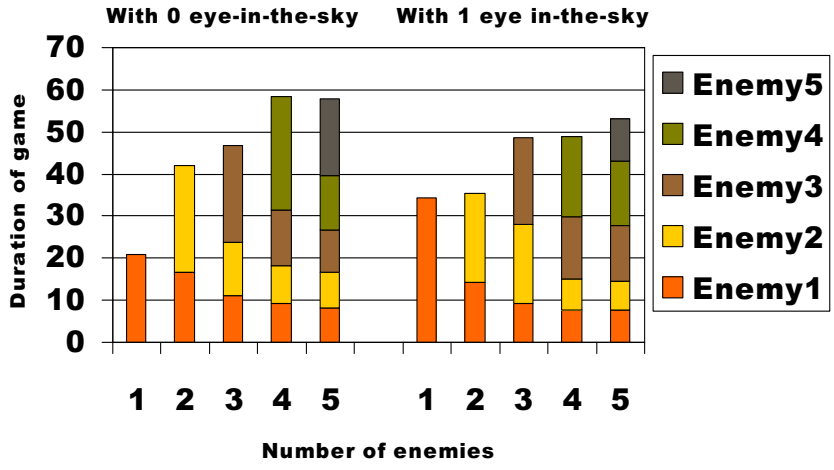
Greedy Policy

with 3 ground agents



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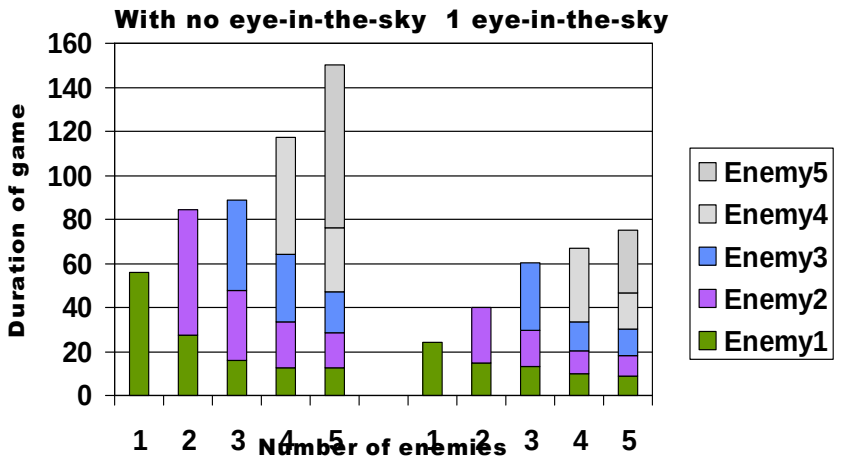
Global-max Policy

with 3 ground agents



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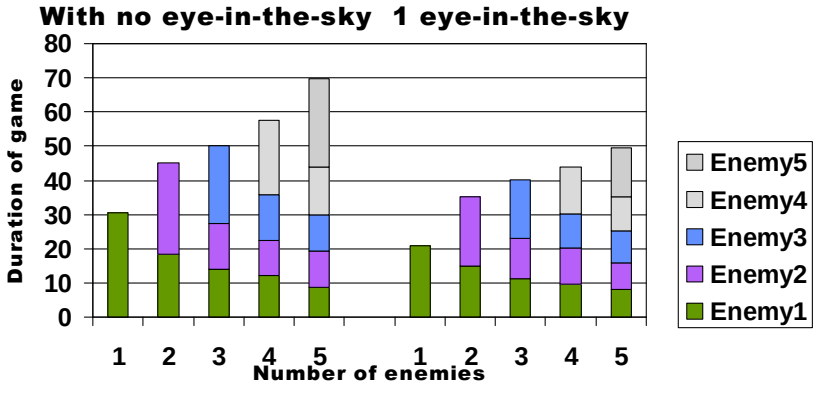
Combined Policy

with 3 ground agents



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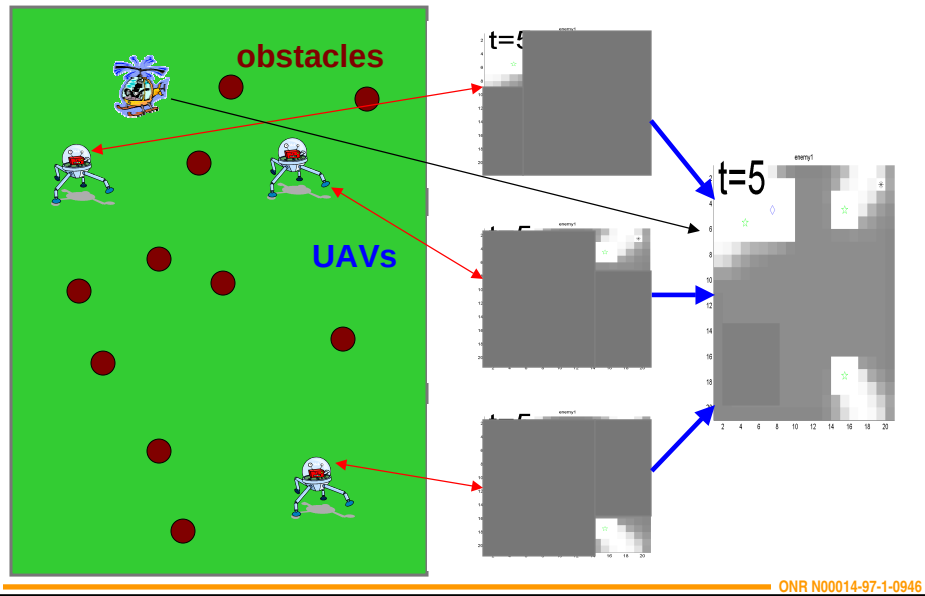
Distributed Map Building



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Complete Map Building Scenario

Consists of a subset of tasks needed
To complete the pursuit-evasion scenario:

- **Identification of vehicle dynamics and control**
- **Sensor integration**
- **Vision system**
- **Probabilistic map building**
- **Path planning**
- **Coordinated multi-agent operation**
- **Networking and intelligent data sharing**

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Coordinated Distributed Map Building

- An effective scheme must incorporate both movement strategies and informational protocols
- In the P-E context, simple simulations have shown lack of communication between agents to more than double capture time of evaders
- Movement strategies are being tuned according to the amount of information available and the communication delay

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Implementation Issues

- System and Agent Architecture
- Helicopter:
  - David Shim
- Ground Robots: sensor integration, software
  - Rene Vidal
- Map Building Implementation:
  - Shahid Rashid, Rene Vidal
- Pursuit Evasion Implementation:
  - Rene Vidal, Cory Sharp

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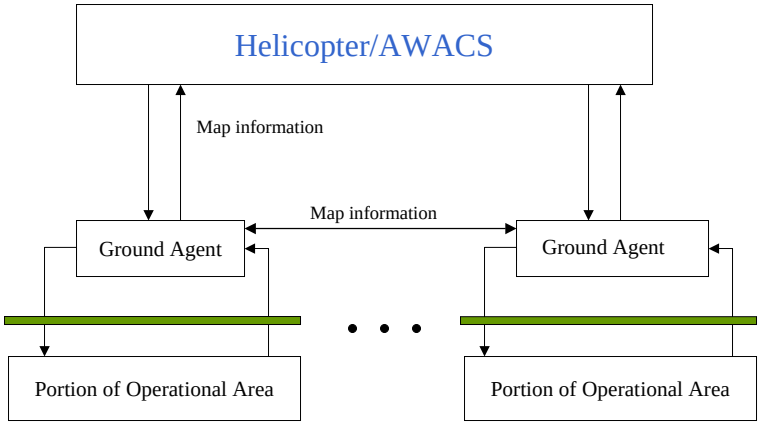
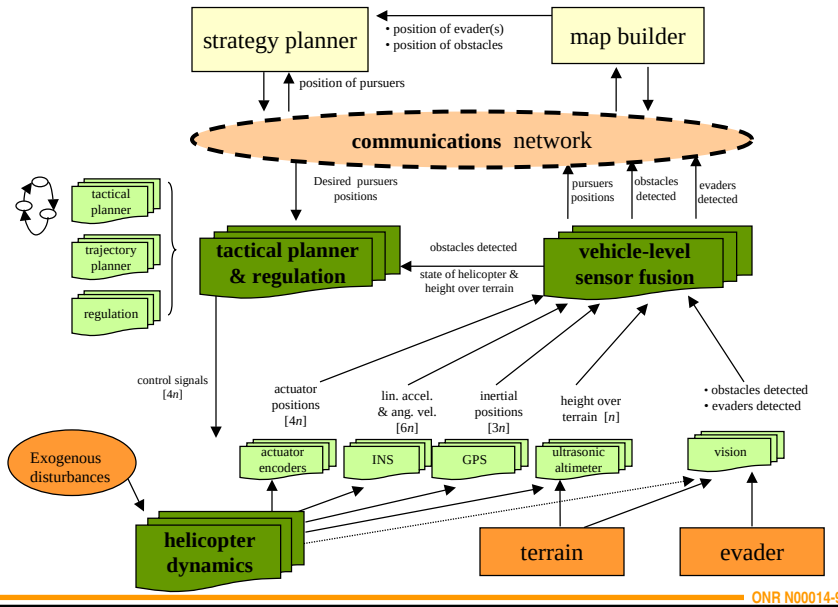
System Architecture



Agent Architecture



Pioneer Ground Robots

- **Pioneer ground robots**
  - Hardware
  - Sensors
  - Communication
- **Software & Programming Languages**
  - Saphira
  - Colbert-C
  - Ayllu
- **Vision System**
  - PTZ: Pant Tilt Zoom Camera
  - ACTS: Color Based Tracking

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Pioneer Ground Robots

- **Hardware**
  - Micro controller: motion control, camera control
  - Onboard computer: communication, video processing
- **Sensors**
  - Sonars: obstacle avoidance, map building
  - GPS & compass: positioning
  - Video camera: map building, navigation, tracking
- **Communication**
  - Serial
  - Wave-LAN: communication between robots and base station
  - Radio modem: GPS communication

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Software & Programming Languages

- **Saphira**
  - Direct motion control
  - Programming activities
  - Multi processes
- **Colbert**
  - Behavior based control
- **C, C++**
- **Ayllu**
  - Multi agent based programming

Behavior Based Programming

- **Sample behaviors**
  - Follow Corridor, Avoid obstacles, Constant Speed
- **Behavior**
  - Parameters: input parameters of the behavoir
  - Rules: set of fuzzy rules that control the motion
  - Update: update variables each 100 ms
- **Blending behavoirs**
  - Sequencing, priorities, status depending

Vision System: PTZ & ACTS

- PTZ System
  - Pan tilt and zoom can be controlled from Saphira
- ACTS System
  - Captures and processes video
    - 32 color channels
    - 10 blobs per channel
  - Extract color information and sends it to a TCP socket
    - Number of blobs,
    - Size and position of each blob
- Color information can be used by Saphira for navigation

Map Building Implementation

- Synthetic sensors provided by groundstation by correlating agents position (GPS) with a pre-defined environmental map
- Simple wireless network allows agents to communicate measurements and position to each other and also used by groundstation to send simulated sensor readings
- Obstacle avoidance provided by Saphira using sonars

Map Building Algorithm

For a map, M, If sensor makes positive reading:

$$M(x,y,t) = (1-q)*M(x,y,t-1)/((1-q)*M(x,y,t-1)+p*(1-M(x,y,t))$$

If sensor make negative reading:

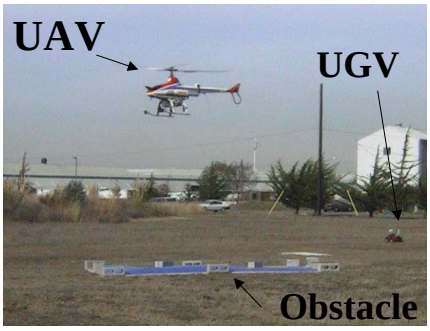
$$M(x,y,t) = q*M(x,y,t-1)/(q*M(x,y,t-1)+(1-p)*(1-M(x,y,t))$$

sensor model:

p = prob of false positive

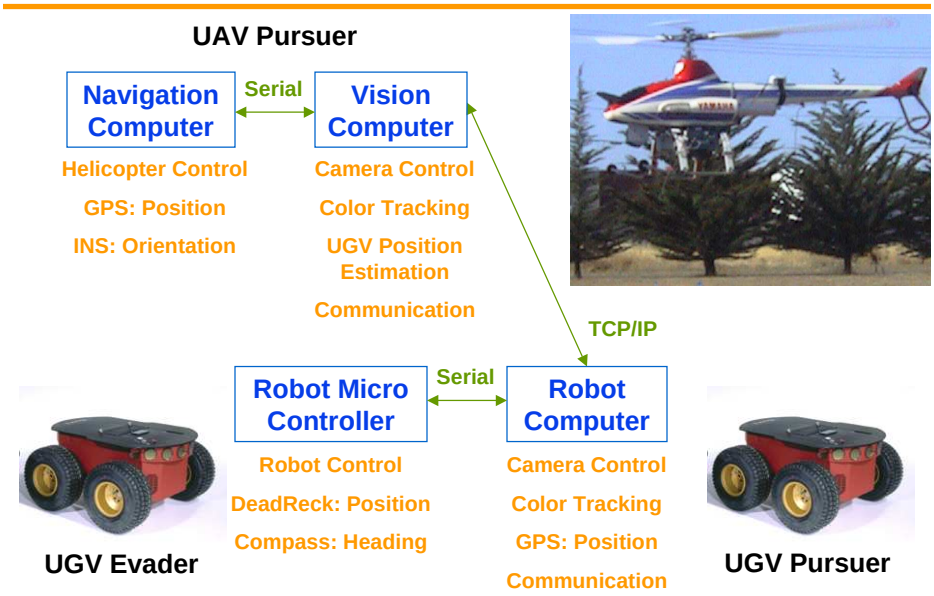
q = prob of false negative

Coordinated Multi-platform Map Building



Integrate helicopter to have combined UAV/UGV map building

System Organization

- Groundstation gives general course of action to UAVs and UGVs (in the form of mission objectives)
- UAVs supply UGVs with rough map of area
- UGVs explore region and update maps with local information

Pursuit Evasion Implementation