Controlling groups of autonomous systems

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Planning operations for teams of aircraft

**Local objectives:**
- Safety and efficiency with respect to vehicle’s dynamics and actuation

**Global objectives:**
- Region coverage, collision avoidance

**Constraints:**
- Communication – private information
- Computation performed on each vehicle
Collision Avoidance
Collision Avoidance

Normal
OwnShipSpd=30.7 m/s, OwnShipSpd=31.0 m/s
OwnShipHdg=-73.2 deg, OthShipHdg=-39.0 deg
time=265.0 s
Region Surveillance

Problems:
Information gathering, fast decomposition of team commands into actions for each vehicle

(Source: Prof. Robin Murphy, Univ. South Florida, Katrina Search and Rescue)
Mobile Sensor Network

Control Objectives:
• Automatic information gathering
• Safe interaction

Constraints:
• Power budget
• Communication bandwidth
• Computational resources
• Secure interaction
Quadrotor testbed: control and software architecture

- Autonomous UAVs
  - Onboard computation & sensors
  - State and environment estimation
  - Attitude, altitude, position and trajectory control
  - 4 flightworthy vehicles
  - More are being made

- Testbed goals
  - Quadrotor UAV design
  - Cooperative multi-agent control
  - Mobile sensor networks
Quadrotor System

- Self Sufficient UAVs
  - Onboard computation
  - Onboard sensing
- Real Time Execution
  - Estimation
  - Control

[Diagram with labels: Wifi, Ground GPS, Ground Station Computer]
Vehicle Design

**High Level Control**
Gumstix PXA270, or ADL PC104

**Low Level Control**
Robostix Atmega128

**Electronics Interface**

**Sensorless Brushless DC Motors**
Axi 2208/26

**Elect. Speed Cont.**
Castle Creations Phoenix-25

**Battery**
Lithium Polymer

**Landing Gear**

**Inertial Meas. Unit**
Microstrain 3DM-GX1

**Ultrasonic Ranger**
Senscomp Mini-AE

**GPS**
Novatel Superstar II

**Carbon Fiber Tubing**

**Fiberglass Honeycomb**

**Tube Straps**

**Electro Speed Cont.**

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Lithium Polymer
System Cost Metric

- **Efficient solution**
  - Standard of comparison
    - Marginal cost
      \[ J_e = \sum_{j \in \mathcal{J}} J_j \]

- **Nash Bargaining solution (NBS)**
  \[ J_{NBS} = - \prod_{j \in \mathcal{J}} (d_j - J_j) \]
  - Standard of comparison
    - Percentage change in marginal cost
Decentralized Optimization Program

Vehicle 1

- Penalty Weight Update
- Receive Solutions
- Local Optimization #1
- Local Optimization #n

Broadcast to Neighborhood

Select Preferred Solution

[Waslander, Inalhan, Tomlin, 2003]
Proposition [Convergence to Nash Bargaining solution]:

The penalty method formulation of the decentralized optimization problem converges to a solution that satisfies the necessary conditions for optimality of the Nash Bargaining solution to the centralized optimization problem.

[Waslander, Inalhan, Tomlin, 2003]
Decentralized Optimization Program

\[
\begin{aligned}
\text{minimize} \quad & -I^{(i)}(x^{(i)}_t, u^{(i)}_t, \theta^{(i)}_t | x^{(-i)}_t, u^{(-i)}_t) \\
\text{subject to} \quad & x^{(i)}_{t+1} = f^{(i)}_t(x^{(i)}_t, u^{(i)}_t) \\
& z^{(i)}_{t+1} = h^{(i)}_t(x^{(i)}_{t+1}, \theta^{(i)}_t, \eta^{(i)}_t)
\end{aligned}
\]

Ihalhan, Stipanovic, Tomlin, CDC, 2002
Four Vehicle Scenario
Four Vehicle Scenario
In flight
Embedded Humans

Combine Bayesian models of human interaction with automation, and hybrid system models of automated system.

- Continuously evolving dynamics: spatial, temporal properties
- Mode switches: coupled, independent, search, cue, track…
- New methods to learn such models from data (games, training)
Cooperative Collision Avoidance

- System Requirements
  - Scalability
  - Safety
- Method for Acceleration Constrained Vehicles
  - Each agent broadcasts its state
  - Agents compute pairwise “keep-out” regions
  - Collision avoidance control inputs mandated when violations occur
Cooperative Collision Avoidance

- **System Requirements**
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STARMAC history
STARMAC history

STARMAC
Stanford Testbed of Autonomous Rotorcraft for Multi-Agent Control

System Development
Pursuit Evasion Games with 4 UGVs and 1 UAV
ARO: Integrated Approach to Intelligent Systems
(Spring’ 01)
Pursuit Evasion Games with 4UGVs and 1 UAV
ARO: Integrated Approach to Intelligent Systems
(Spring’ 01)
Pursuit-Evasion Game Experiment Details

PEG with four UGVs
- Global-Max pursuit policy
- Simulated camera view (radius 7.5m with 50degree conic view)
- Pursuer=0.3m/s Evader=0.5m/s MAX
Pursuit-Evasion Game Experiment Details

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- Pursuer=0.3m/s Evader=0.5m/s MAX
• Max 20 min. games:
  – Evader goal: get to final waypoint or avoid evader
  – Pursuer goal: ‘target’ evader

• Pursuer and evader restricted to same performance limits – *reliant on F-15 pilot’s cooperation*

• Planes on the same logical plane, but separated by 6000ft altitude at all times
  – After first PEG, F-15 pilot request this be reduced to a 2000ft altitude separation

• Two scenarios:
  – UAV as evader
  – UAV can become pursuer
UCB PEG Test Plan: UAV as Evader and Pursuer

• UAV attempts to cross Scenario Area (SA) from East to West without being targeted by the F15, however, UAV will attempt to target F15 if suitable conditions arise

• UAV “wins” by:
  – Reaching the END ZONE
  – Not being targeted for 20 minutes
  – Targeting the F15

• F15 “wins” by targeting the UAV

Note: F15 performance is restricted
Flight Test: Results
Flight Test: Results
NEST Demo Movie
Closing the Loop in Sensor Networks: Multi-Target Tracking and Pursuit Evasion Games

NEST Final Experiment
August 30, 2005

EECS, UC Berkeley
Hunt Research Plans

• What is missing to date
  – Multi-person, multi-objective games
  – Biological inspiration drawn from hunting patterns
  – Group/Team behavior modeling

• Research Strategy on HUNT
  – Solution Concepts for Partially Observable Games with Partial Information
  – Existence of Solutions: heuristics drawn from predator prey interactions in the wild: team behaviors

• New S&T to be developed on HUNT
  – Traditional solutions to games are “causal”: that is to say plans depend on observations: this excludes the kind of predictive team behavior that characterizes hunting. New “predictive” solution concepts are needed.
  – Learning of Utility Functions of Predator-Prey from engagement to engagement. Traditional learning has focused on updates of strategy rather than learning of utility functions of the adversary