Observability Options Against an Adversarial Swarm - a Quantitative Analysis

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Observability Options Against an Adversarial Swarm – a Quantitative Analysis

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joint work with

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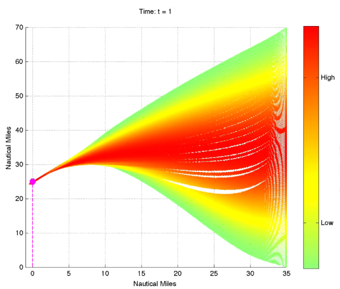
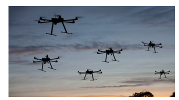
CRUSER TECHCON 2018

INTRODUCTION

Protection of an HVU from a swarm attack



- A swarm of UAVs is headed towards a protected asset
  - High numbers of agents
  - Unknown capabilities



Research Objective: Estimate swarm's internal cooperation strategy in a limited window of time

- **Control law**

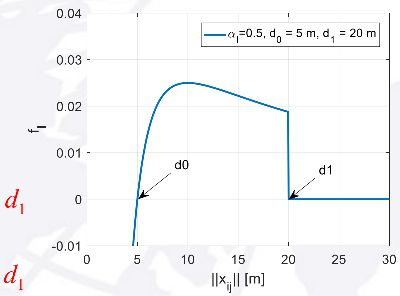
$$u_i = -\sum_{j\neq i}^{50} \frac{f_I(x_{ij})}{\|x_{ij}\|} x_{ij} - \sum_{k=1}^{1} \frac{f_h(h_{ik})}{\|h_{ik}\|} h_{ik} - K\dot{x}_i$$

- **Unknown parameters α_I, d_0, d_1 in interaction force magnitude f_I**

$$f_I = \begin{cases} \nabla_{\|x_{ij}\|} V_I, & 0 < \|x_{ij}\| < d_1 \\ 0, & \|x_{ij}\| \geq d_1 \end{cases}$$

where

$$V_I = \begin{cases} \alpha_I \left(\ln\left(\|x_{ij}\|\right) + \frac{d_0}{\|x_{ij}\|} \right), & 0 < \|x_{ij}\| < d_1 \\ 0, & \|x_{ij}\| \geq d_1 \end{cases}$$

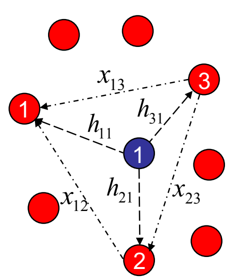


- **Swarm model**
  - **Distributed autonomous control framework**
  - **Using virtual leaders and artificial potential functions**

- **Example scenario**
  - **One virtual leader and 50 followers**
  - **Point mass in plane with fully actuated dynamics**

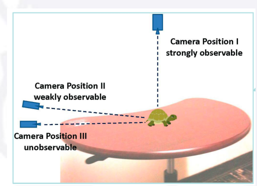
$$\ddot{x}_i = u_i, \quad i = 1 \cdots 50$$

Leonard et al 2001, 2004

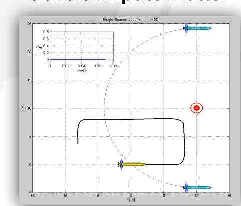


Nonlinear Observability

Sensor locations matter



Control inputs matter



- **Challenges**
  - **Non-cooperative swarm**
    - unknown control inputs
  - **Optimal sensor/observer placement**
  - **Big Data - partial observability**
  - **Small observation window**

Krener 1977, Kang 2012, Pascoal 2014

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RESULTS

Empirical Observability Gramian

- **Let the inner product of**

$$\langle y, y \rangle = y^T y$$

Let $\{w_1, w_2, \cdots, w_{n_z}\}$ **be a basis of** W **and** $v_0 = (x_0, \mu_0)$. **Define**

$$\Delta_i = \frac{1}{2\rho} \int_{t_0}^{t_1} \left(y(t, v_0 + \rho w_i) - y(t, v_0 - \rho w_i) \right) dt$$

$$G_Y = \left(\langle \Delta_i, \Delta_j \rangle \right)_{i,j=1}^{n_z}$$

Then for small perturbations ρ **,** **unobservability index**

$$\rho / \varepsilon \approx \sqrt{\frac{1}{\lambda_{\min}(G_Y)}}$$

Moore 1981, Marsden 2002, Singh 2005,2006, Krener 2009, Kang 2009-2014, Serpas 2012, Morgensen 2015

Scenario 1: Measure all positions

- Initial positions and trajectories, 60 sec window
- Observability measurement with full measurement of all positions

	Straight line
Unobservability index ρ/ε	∞

Unobservable!!

Scenario 2: disrupt using an intruder and measure all positions, 60 sec observation window

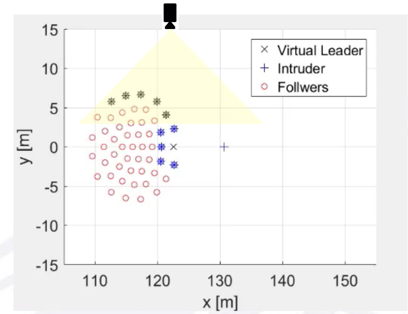
- Observability using measurements of all positions

	With an intruder
Unobservability index ρ/ε	**0.73**

Observable!!

Scenario 3: Partial information with intruder

60 s time window

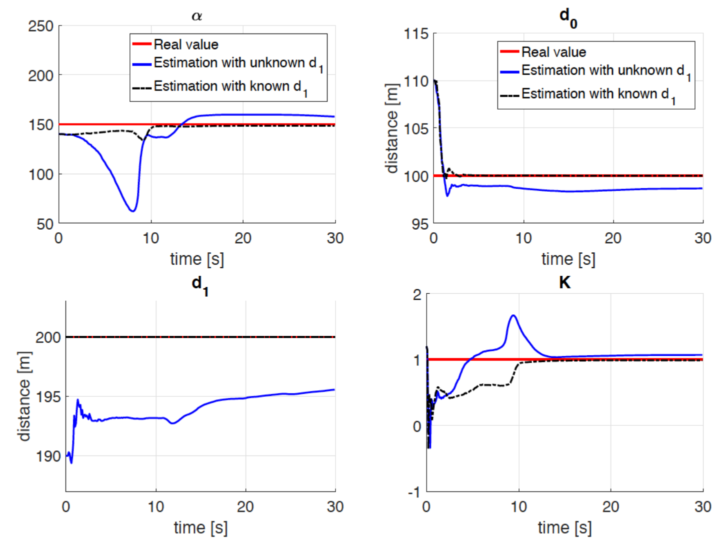


- Observability measurement with positions of 5 followers

	From observer	**From intruder**
Unobservability index ρ/ε	**2.55**	**1.65**

Use intruder as mobile sensor

Estimation of Parameters using UKF



Summary and Future Work

- Summary
  - Unobservabilty index: a very useful metric
  - Trajectory of the intruder matters
  - Time window matters
  - Optimization is a must

- Future work
  - Optimization
    - observability
    - estimation
    - intruder trajectories
  - Partial observability
    - unknown number of attackers
    - big data problem
  - Centralized and Distributed Solutions
  - More sophisticated swarm models
  - Controllability