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Observability Options Against an Adversarial Swarm - a Quantitative Analysis

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Observability Options Against an Adversarial Swarm – a Quantitative Analysis

Isaac Kaminer

joint work with

Hyeongjun Park, Claire Walton, Wei Kang

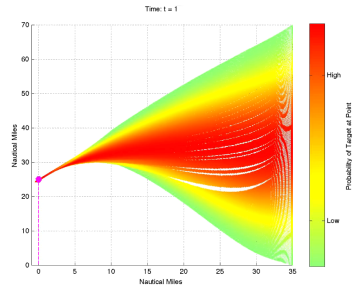
NPS

Qi Gong

UCSC

CRUSER TECHCON 2018

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

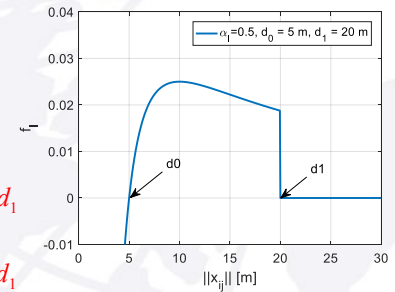
$$u_i = -\sum_{j \neq i}^{50} \frac{f_l(x_{ij})}{\|x_{ij}\|} x_{ij} - \sum_{k=1}^1 \frac{f_h(h_{ik})}{\|h_{ik}\|} h_{ik} - K\dot{x}_i$$

➤ Unknown parameters α_l, d_0, d_1 in interaction force magnitude

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

where

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



➤ Swarm model

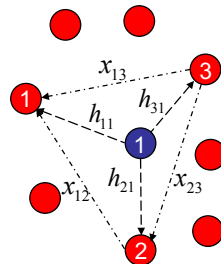
- Distributed autonomous control framework
- Using virtual leaders and artificial potential functions

➤ Example scenario

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

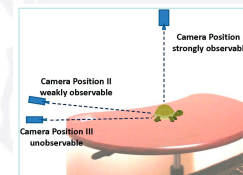
$$\ddot{x}_i = u_i, \quad i = 1 \dots 50$$

Leonard et al 2001, 2004

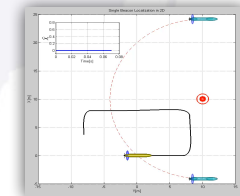


Nonlinear Observability

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

Empirical Observability Gramian

➤ Let the inner product of

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

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

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

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

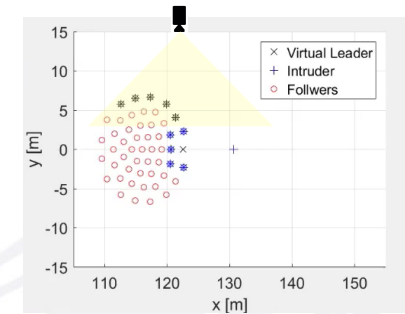
Then for small perturbations ρ , **unobservability index**

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

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

Scenario 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

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!!

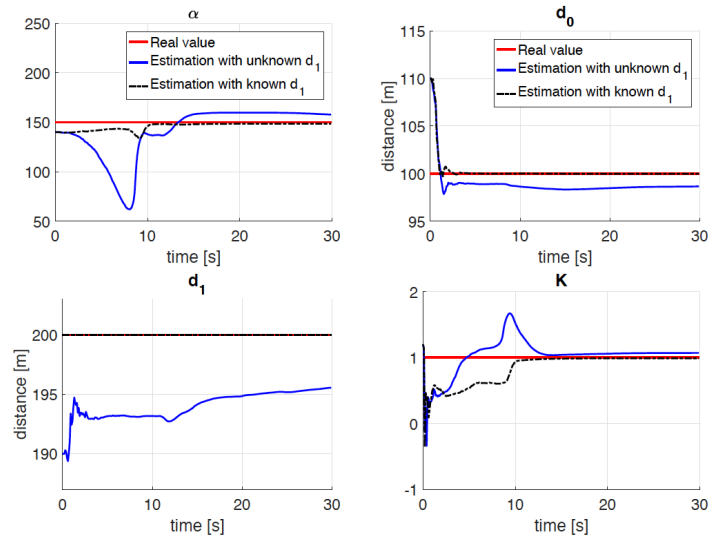
Scenario 2: disrupt using an intruder and measure all positions, 60 sec observation window

- Observability using measurements of all positions

	With an intruder
Unobservability index ρ/ε	0.73

Observable!!

Estimation of Parameters using UKF



➤ Summary

- Unobservability 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

