Center Overview

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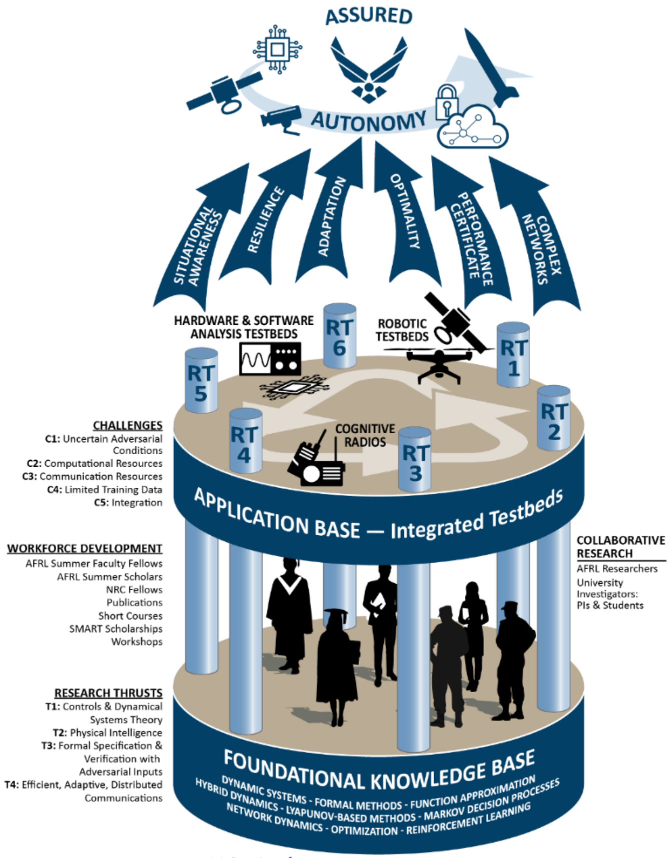
Center Overview



AFOSR Center of Excellence in Assured Autonomy in Contested Environments

- $6M over 6 years (3 x 2 year increments)
- 10 PIs @ 4 Universities:
  - R. Bevilacqua (UF: optimal, switching)
  - K. Butler (UF: cyber resiliency/privacy)
  - W. Dixon (UF: ADP, networks, hybrid)
  - N. Fitz-Coy (UF: optimal, games)
  - M. Hale (UF: networks, privacy)
  - M. Pajic (Duke: cyber resiliency/privacy)
  - R. Sanfelice (UCSC: hybrid, networks)
  - J. Shea (UF: networks, privacy)
  - U. Topcu (UT: formal, hybrid, optimal)
  - M. Zavlanos (Duke: ADP, networks, formal)
- AFOSR provides 50% of funding
- AFRL (RV, RW, RY) provide 50%

Center Motivation

- Innovation & technology dominance and strong economy have allowed exquisite systems to operate for decades in largely uncontested environments
  - Remote piloted vehicles (RPV) and monolithic satellites provide various strategic and tactical advantages
  - Intelligence, surveillance, and reconnaissance (ISR) in close proximity with RPVs or from protected space assets
  - We have the ability to attack from distances and with speeds beyond the capability of countermeasures
- Increased stand-off distance, persistence, and scaled projection of power have resulted in an urgency for development and fielding of human-in-the loop/semiautonomous systems
- These advantages are mitigated as the technology gap closes and as other world economies become near peers and risks to the warfighter and financial costs increase and tactical capabilities become stressed when military operations are in contested or denied environments (i.e., anti-access/area denial (A2AD) environments)

Center Motivation

- As these advantages are taken to the limit, coupled with the resultant need for rapid decision-making capabilities, emerging technology will move along a spectrum towards greater automation with less human intervention.
- In contested environments, autonomous systems are even further motivated by the potential desire to complete mission execution when communication with a human operator is unavailable.
- Autonomous systems must execute high level missions plans with verifiable assurances despite uncertain adversarial environments where the integrity and availability of sensor information and communications are challenged.
- Key innovations include analysis, design and synthesis tools that enable autonomous mission execution despite uncertainty within complex dynamics while accounting for the integrity and privacy of information on computationally constrained resources.

Center Goals & Vision

- Networks of autonomous systems will require information exchanges of many data types, including high-level mission specifications and sensor feedback for navigation and control
- The goal of assuring autonomy is complicated by the interplay between dynamics of autonomous agents and the stochastic and intermittent dynamics of network traffic
- This challenge is further amplified by delays and asynchrony in information flows
- Information perturbations can also emanate from adversarial actors in unique and complex ways, requiring security-aware design and analysis methods
- For example, we will develop techniques to protect mission-critical information and prevent information disruption/corruption
- These challenges must be addressed considering resource limitations and quantitative tradeoffs.

Research Topics

- Nonsmooth Systems
- Adaptation, Optimality, and Synthesis
- Network Systems
- Asynchronous Information
- Attack-Resilient Design
- Protecting Information

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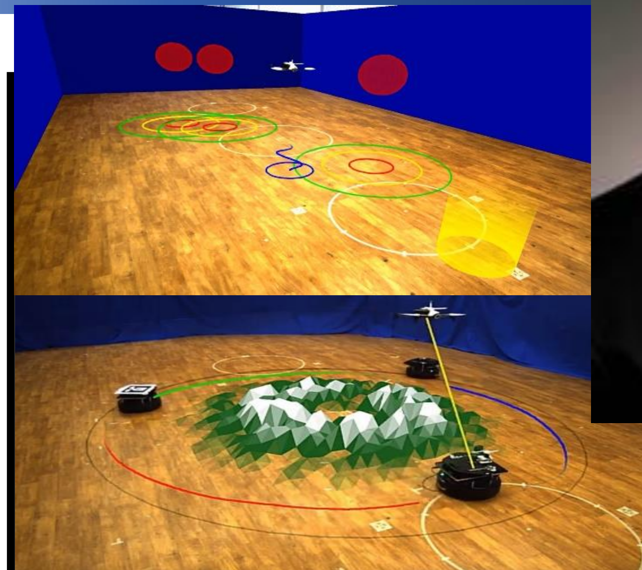
Center Goals & Vision

- Pioneer the development of fundamental theories and methods to enable assured autonomous mission execution in complex, uncertain, and adversarial conditions

- Our vision is that assured autonomous operations by a network of agents in contested environments require an integrated focus on the complex union of both physical and information dynamics within the analysis, design, and synthesis of logical decision making and control design

- Efforts will focus on the availability, integrity, and effective use of information by leveraging our team's diverse toolsets in dynamics, mathematics, control theory, information theory, communications, and computer science

Warren Dixon



Research Objectives and Key Challenges:

- How to ensure stability for switched systems for adaptive control systems with arbitrarily slow convergence rates
- How to achieve exploration and exploitation concurrently
- How to ensure network function in opportunistic networks with adversarial agents with data intermittency

Significance of Work:

- Enabling capabilities for optimal performance for complex systems with uncertainty, under computational and real-time constraints
- Enabling capabilities for more general classes of control methods for systems that have mixed continuous and discrete dynamics

High-Level Technical Approach:

- Lyapunov-based stability methods
- Switched systems analysis methods
- Actor-critic reinforcement learning and data-based learning methods

Potential AFRL Collaboration Areas:

- Attitude control systems
- Navigation estimation with intermittent and corrupted data
- On-line learning of changing dynamics & fault/change detection

Center Research Areas:

- Nonsmooth Systems
- Adaptation, Optimality, and Synthesis
- Network Systems

Recent Accomplishments:

- ✓ Developed new reinforcement learning –based approximate dynamic programming methods for approximate optimal solutions for real-time control of uncertain nonlinear systems
- ✓ Developed new strategies to compensate for input delayed systems
- ✓ Developed new strategies for adaptive switched systems

Current Funding:

- AFOSR, AFRL, NavSea, Naval Surface Warfare Center: Panama City Division, NSF, ONR, CDMRP, and industry partners

Short-Term Research Vision:

- Further development of control methods for uncertain nonlinear systems with feedback intermittency
- Further development of switched systems methods

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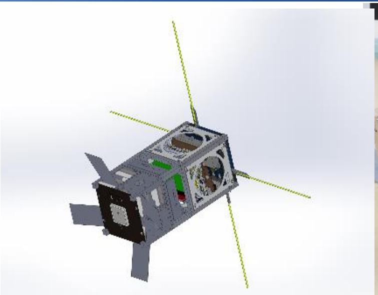
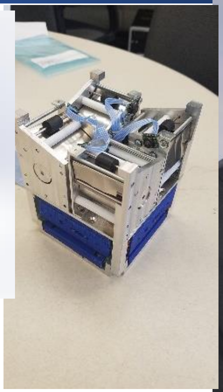
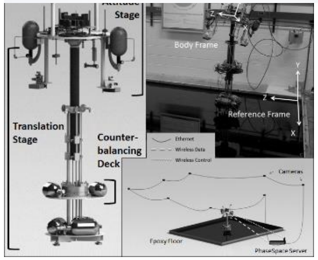
Riccardo Bevilacqua







Research Objectives and Key Challenges:

- How to utilize Lyapunov theory to enable propellant-less 3-axis attitude control of satellites exploiting aerodynamic and gravity gradient torques
- How to utilize switched systems theory to combine spacecraft attitude control and formation control using only natural forces
- How to utilize dynamical systems theory to enable Resident Space Object (RSO) characterization under uncertainty and intermittent ambiguous measurements

Significance of Work:

- Space situational awareness
- Tactical maneuvering around hostile space vehicles
- Possibility to extend to high orbits through solar sailing and/or under-actuated low-thrust spacecraft

High-Level Technical Approach:

- Lyapunov-based stability methods
- Switched systems analysis methods

Potential AFRL Collaboration Areas:

- Attitude control systems
- Formation control systems
- Spacecraft relative navigation with intermittent and ambiguous data

Center Research Areas:

- Lyapunov theory

Recent Accomplishments:

- ✓ Developed new controller enabling 3-axis control utilizing natural torques in LEO
- ✓ Developed new controller enabling any number of satellites to be in formation using differential drag
- ✓ Designed CubeSat selected by NASA's CSLI to test some of the above techniques.

Current Funding:

- AFOSR, NASA KSC (AI solutions), AFRL SFFP (Eglin AFB), NASA Graduate Student Fellowship.

Short-Term Research Vision:

- Further development of control methods to combined attitude and position controller of spacecraft formations
- Further development of relative navigation techniques for RSO characterization

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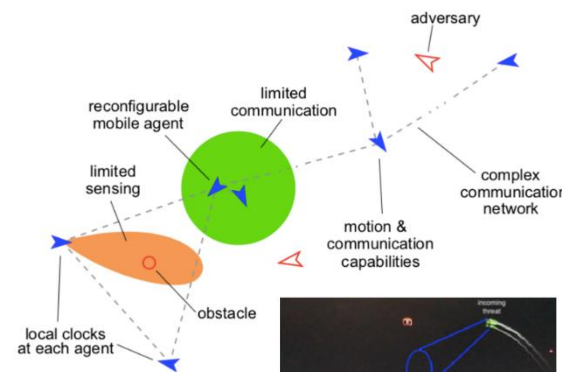
Ricardo Sanfelice

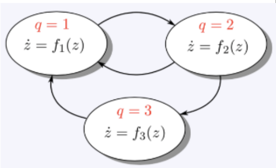
Research Objectives and Key Challenges:

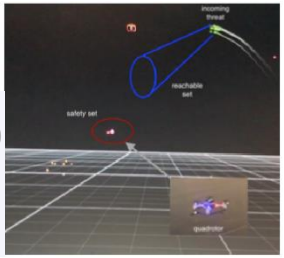
- How to systematically design systems featuring switching and intermittency of information with provable robustness to uncertainty arising in real-world environments
- How to design distributed hybrid control algorithms guaranteeing high performance in contested environments

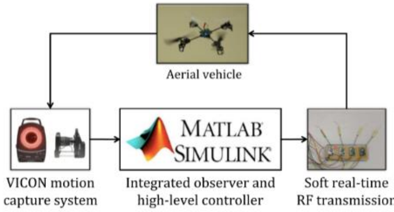


Significance of Work:

- Enabling systematic analysis and design of dynamical systems with combining continuous and discrete dynamics
- Enabling the design and distributed operation of algorithms for nonsmooth, hybrid, and cyber-physical systems under uncertainty and adversarial actions







High-Level Technical Approach:

- Hybrid dynamical system modeling
- Robust stability analysis via Lyapunov methods
- Systematic hybrid control design methods

Potential AFRL Collaboration Areas:

- Hybrid control systems for decision making
- Model predictive control under uncertainty
- Control design for high-level mission specifications

Center Research Areas:

- Nonsmooth, Hybrid, and Cyber-Physical Systems
- Adaptation, Optimality, and Synthesis
- Design and Analysis with Asynchronous Information

Recent Accomplishments:

- ✓ Developed new hybrid control algorithms for global robust stabilization of underactuated vehicles
- ✓ Developed new tools for certifying the satisfaction of linear temporal formulae for hybrid dynamical systems
- ✓ Developed sufficient and necessary conditions for safety using barrier functions for hybrid dynamical systems

Current Funding:

- AFOSR, AFRL, NSF, NASA, CITRIS and the Banatao Institute at the University of California, and industry partners

Short-Term Research Vision:

- Further development of control methods guaranteeing safety under intermittent information
- Development of hybrid control algorithms for threat detection

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