Center Overview

http://ncr.mae.ufl.edu/aacoe.php

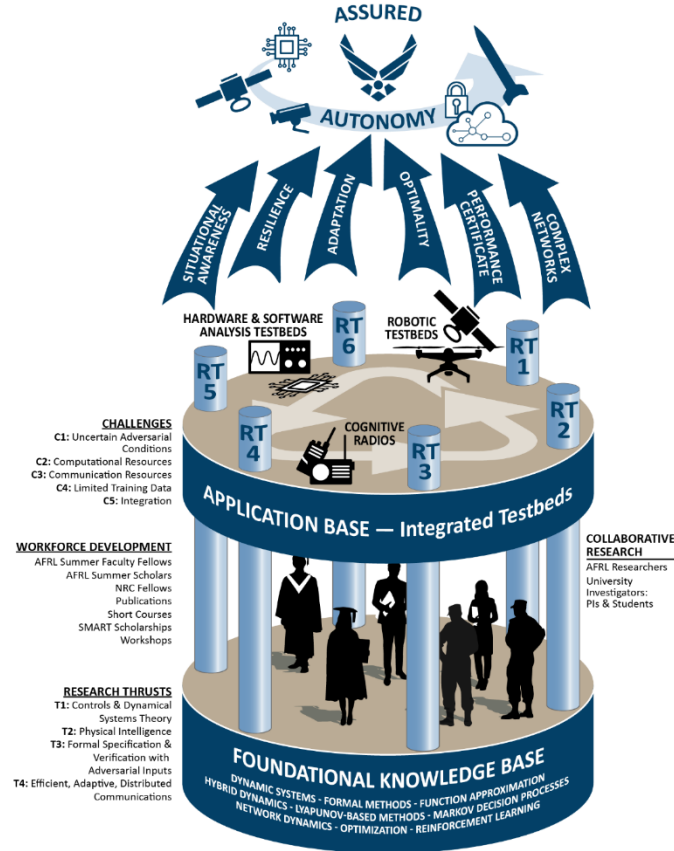**AFOSR Center of Excellence in Assured Autonomy in Contested Environments**

- >$7M over 6 years (3 x 2 year increments)
- 9 PIs @ 4 Universities:
  - 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)
  - C. Petersen (UF: Space GNC)
  - A. Petersen (Space weather/physics)
- AFOSR provides 50% of funding
- AFRL (RV, RW, RY) provide 50%

- Innovation & technology dominance and strong economy have allowed for exquisite systems that for decades have operated 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, while simultaneously striking from distances and with speeds beyond the capability of countermeasures
- 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)
- 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

- 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

Workforce Dev. AFRL Collaborations Publications

Collaborative Interactions

- Project currently partially supports
  - 4 postdocs/research scientists, ~50PhD
- >40 Alumni
  - ~10 postdocs – NRC (RW), NVIDIA, Univ. of Sherbrooke, Univ. of Arizona, Apple, Univ. Grenoble Alpes, UC Berkeley, University of Florida (x2), Torch Technologies
  - ~25 PhD – RW (x2), Ford, Qualcomm, Intel, Univ. of the Bio, Opener, Purdue University, Dematic, DJI, Amazon, Satellogic, University of Florida, Zoox, University of Dayton Research Institute, Aurora Flight Sciences (x2), (RY/ACT3), JPL, Supernal, EpiSci, MIT Lincoln Labs, Mathworks, Samsung Electronics
  - ~10 MS – Lockheed Martin (x2), Walmart Labs, UCSC, Zoox, Intel, AgroAI, Rain, Tesla, Aerospace Corp.
- **SMART Fellows** for RV: S. Edwards (Dixon), RW: C. Makumi (Dixon), C. Nino (Dixon), NSWC: Patrick Amy (Dixon)
- **NRC Postdoc** for RW: A. Isaly (Dixon)
- **NSF Fellow:** Becca Hart (Dixon)
- 10 Summer 2023 **AFRL/Space Scholar/interns**
  - RV: A. Allen (Fitz-Coy), C. Fedele (Butler)
  - RW: W. Warke (Hale), A. Benvenuti (Hale), G. Behrendt (Hale), C. Makumi (Dixon), C. Nino (Dixon), J. Philor (Dixon), Z. Lamb (Sanfelice)
  - RY/Act3: C. Hawkins (Hale)
- **AFRL Summer Faculty Fellows** program
  - Chrispy Petersen (2024 RY) - proposed
  - Riccardo Bevilacqua (2019 & 2020 RW, 2021 RV)
  - Matthew Hale (2020 RW)

- Publications
  - ~375 total, ~75 published or accepted to appear in 2023
  - Joint publications –
    >40 w/ PIs,
    ~50 w/ AFRL

- International collaborations (Pontifical Catholic University of Rio de Janeiro (PUC-RIO) in Rio de Janeiro, Brazil)

- Testbed Development
  - Starlink Connection established
  - Transitioned all assets to ROS2
  - Upgraded sensing
  - Focus on 5G/LTE
  - Collaboration with AFRL/RW for remote (Starlink) connection to Aviary

- (C. Petersen with S. Phillips) Two Invited Sessions 2023 American Control Conference:
  - 1) Safe Spacecraft Control
  - 2) Autonomous Control of Satellite Systems
- (C. Petersen) lead author on American Control Conference **Tutorial Session**
  - "Safe and Constrained Rendezvous and Proximity Operations"
- (W. Dixon) Invited Workshop 2023 Conference on Decision and Control
  - Modern Adaptive Control
- (W. Dixon) Two Invited Sessions 2023 American Control Conference
  - Online Learning, Optimization, and Games (I, II)
- (W. Dixon) Invited Assured Autonomy Seminars
  - AIAA Tech Committee on Space Robotics, Embry Riddle, Auburn, Alabama, …
- (K. Butler) Invited **keynote address** at IEEE Workshop on Offensive Technology, May 2023
- (Pajic) Presented the project's results to industry and DoD labs, such as Galois, Intel, SRC, as well as a number of government officials including General Quinton Brown Jr., the Air Force Chief of Staff
- (Pajic) Collaboration with NATO partners from the **NATO Centre for Maritime Research and Experimentation (CMRE)** on transitioning this technology into real-world systems, mostly focusing on security-aware analysis of autonomous unmanned underwater systems

- (Pajic+Topcu) Joined the new NATO IST-122-ET RTG on Designing resilient autonomous vehicles, part of the **NATO Science and Technology Organization**
- (Sanfelice) A co-located workshop of the 2023 CPS-IoT week, May 9-12, 2023: Computation-Aware Algorithmic Design for Cyber-Physical Systems
- (Sanfelice) A co-located workshop of the 2022 IEEE CDC Conference at the 2022 IEEE CDC: Cyber-security in Control of CPS: Recent Developments and Open Challenges
- (Sanfelice) Plenary Speaker, Colloquium on Discrete Event and Hybrid Systems, 2023 (August 25, 2023, organized by Cinestav and Tecnologico de Monterrey)

Recent Breakthroughs

Recent Breakthroughs

- Protecting satellite proximity operations via secure multi-party computation
- Multiphase autonomous docking via model-based and hierarchical reinforcement learning
- Resilient solutions for underactuated autonomous rendezvous and docking operations
- Autonomous satellite operational mode-switching for anomalies and space-weather effects mitigation
- Autonomous satellite rendezvous and proximity operations with time-constrained suboptimal model predictive control

- New theoretical results on forward-invariant sets under hybrid systems (HS)
- Coordinated hybrid source-seeking with obstacle avoidance in multi-vehicle systems
- HySST: an asymptotically near-optimal motion planning algorithm for hybrid systems
- Regularity of optimal solutions and the optimal cost for HS via reachability analysis
- Flow- and jump-based observers for HS with nonlinear maps and known jump times
- L2 state estimation with guaranteed convergence speed under sporadic measurements
- Discretization of the hybrid gradient algorithm for linear regression with sampled hybrid signals

Recent Breakthroughs

- Control of misinformation with safety and engagement guarantees
- Switching algorithm for safety under sensor-DoS attacks via conditional invariance
- Safe controllers for uncertain nonlinear systems using multiple control barrier functions
- Certifying the Always and Eventually signal temporal logic operators for HS via invariance
- Fast verification of control-barrier functions via linear programming
- Weighted prioritization of constraints in optimization-based control

- DOMINO(++): Domain-aware loss functions and regularizations for deep learning calibration and generalizability
- Lyapunov-based (Lb) implicit and DNN-based control of uncertain nonlinear systems:
    - Lb-LSTM neural network-based control
    - Lb-DNN approximate optimal indirect regulation of an unknown agent
    - Lb-DNN-based approximate optimal tracking of unknown linear systems
    - Lb-PINN: deep physics-informed neural networks
    - Adaptive indirect herding of multiple targets with unknown interaction dynamics
- Distributed state estimation with DNNs for uncertain non-linear systems under event-triggered communication

- Second-order heterogeneous multi-agent target tracking without relative velocities
- Controller synthesis for multi-agent systems with intermittent communication and metric temporal logic specifications
- Reactive synthesis for relay-explorer consensus with intermittent communication
- Collaborative spectrum sharing

- Distributed online convex optimization with improved dynamic regret
- Discounted cost minimization in MDPs subject to reachability constraints
- Entropy maximization for MDPs under temporal logic constraints
- Active inverse learning in Stackelberg trajectory games
- Affine Markov games: solutions and inverse learning via soft Bellman equilibria
- Anomaly search over many sequences with switching costs
- Totally asynchronous algorithm for time-varying convex optimization problems
- Totally asynchronous block-based heavy ball algorithm for convex optimization

- Mechanisms, scaling laws for node/edge differential privacy of graph Laplacian spectra
- Bounded Gaussian mechanism for differential privacy
- Differential privacy in cooperative multiagent planning

- Security analysis of distributed IoT-based industrial automation
- Attacks on distributed sequential control in manufacturing automation
- Online attack recovery in cyber-physical systems
- Provable adversarial safety in cyber-physical systems
- AVstack: an open-source reconfigurable platform for autonomous vehicle development