



Autonomous Systems Interdisciplinary Research Theme
2018 Year End Report

2018 Autonomous Systems IRT Annual Report

IRT Scope and Mission

Autonomous systems interact with human partners for extended periods of time, sometimes at remote distances and promise improved safety, reliability, efficiency, adaptability, resiliency, usability, affordability, and previously unattainable capabilities. Networked cyber-physical systems pervade modern society—from smart vehicles to medical robots, from automated infrastructure to teams of robotic explorers, from mobile devices to connected communities. The Autonomous Systems Interdisciplinary Research Theme (ASIRT) investigates how smart, safe, and secure autonomy can expand and exploit the full capabilities of these networked systems. This theme convenes faculty from across the College of Engineering and Applied Science at the University of Colorado Boulder with expertise in robotics, cyber-security, verification and validation, control theory, artificial intelligence, unmanned systems, machine learning, formal methods, and human-robot interaction.

To realize the promise of autonomous systems, the Autonomous Systems Interdisciplinary Research Theme is focused on the ability to certify their performance, showing that they are **smart** enough to perform across a wide range of conditions; they are **safe** in the face of unexpected inputs; and that they are **secure** in the face of adversarial and malicious interactions.

Most Significant IRT Accomplishments in 2018

- ASIRT faculty awarded over \$20.9M for 28 autonomy-related projects since Jan 1, 2018 (the start of the IRT initiative), with funding from DARPA, DHS, DOE, NSF, DOD, NASA, and industry. Of these projects, 16 include multiple CU investigators. A total of over \$48.3M in autonomy-related projects has been proposed by ASIRT faculty.
- \$4.5M DARPA project "MARBLE: Multi-Agent Autonomy with Radar Based Localization for Exploration" led by Sean Humbert with Chris Heckman, Christopher Williams and Eric Frew, is result of collaboration initiated at an ASIRT workshop.
- ASIRT faculty are part of a team invited to submit the full proposal "The HOME (Habitats Optimized for Missions of Exploration) Space Technology Research Institute for Deep Space Habitat Design" to the NASA Space Technology Research Institute on Smart Deep Space Habitats (\$3.5M to CU, total of \$15M over 5 years for all collaborators).
- Planning workshops were held for the NSF IUCRC Center on Pervasive Personalized Intelligence being created by CU Boulder (Evan Chang and Shiv Mishra) and Oregon State University.
- Five out of the nine 2018 Draper Fellows at CU Boulder are conducting autonomy-related research.

Seed Grant Summary

- Autonomous Distributed Computation in Honeybee Swarms (PI: Orit Peleg)
 - Results on the dynamics of information flow in a social network of mutually shading plant was used to prepare a submission to the Human Frontier Science Program \$400,000.00 Status: Pending (\$1.2M collaboration with other universities).
- Autonomous Virtual Assistant for Crewed Space Missions (PIs: Torin Clark, Nisar Ahmed, Dan Szafir)
 - Based on the seed grant, the proposal “Approaches to Assess Human Performance, Trust, and Situation Awareness for Autonomous Long-Duration Exploration Missions” was submitted to the NASA Human Research Program for \$1,200,000.00. The proposal was declined.
- Collaboration Initiation: Formation Control in Chaotic Systems (PIs: Natasha Bosanac, Xudong Chen)
 - Natasha Bosanac, along with Jay McMahan and Nisar Ahmed, were awarded \$500K from the NASA Early Stage Innovation program for the project “Autonomous Maneuvering within Chaotic Multi-Body Systems”.
- Collaboration Initiation: Secure Ensemble Control (PIs: Xudong Chen, Eric Wustrow, Fabio Somenzi)
 - The seed grant was used in part to prepare material for an NSF CAREER proposal by Xudong Chen titled “CAREER: Design, Control, and Estimation of Continuum Ensemble of Networked Systems.”
- Detection and Localization of Methane Sources Using Teams of Autonomous UAS (PIs: Sean Humbert, John Crimaldi, Michael Hannigan, Chris Heckman, Brian Argrow)
- In Vivo Robot Localization (PIs: Mark Rentschler, Chris Heckman)
 - A \$1M proposal based on the seed grants was submitted to NSF titled “S&AS: INT: COLLAB: An Intelligence-Driven Patient Care Approach to Reduce Medical Errors (I-CARE) by Mark Rentschler and Chris Heckman.
- Natural Language Constraint-Based Learning from Demonstration (PI: Brad Hayes)
- Systematic and Integrated High-Assurance Autonomous Systems (PIs: Sriram Sankaranarayanan, Chris Heckman, Nisar Ahmed, John Hauser, Ashutosh Trivedi)
- Temporal-Logic Based Reinforcement Learning (PIs: Ashutosh Trivedi, Pavol Cerny, Fabio Somenzi)
- Robotic Chemists: Automating the Synthesis of Multifunctional Materials (PIs: Daniel Szafir, Carson Bruns)
- Automated Fabrication Tools for Robots and Electromechanical Systems (PIs: Robert MacCurdy, Chris Keplinger, Greg Whiting)
- Mobile Sensing Using UAVs to Enable Accurate Wind Field Estimation Across Wind Farms: Feasibility Study (PIs: Lucy Pao, Chris Bay, Cory Dixon, Ute Herzfeld)
 - Initial results from the project have already been incorporated into our 1st-year graduate student David Pasley’s application to the National Defense Science and Engineering Graduate (NDSEG) Fellowship Program.
- Super-Resolution Applied to Detection and Identification of Autonomous System (PIs: Lijun Chen, Eugene Liu)

- One proposal is currently being developed: “Super-Resolution for MIMO Systems (PIs; Chen and Liu)”.
- Algorithmic Challenges in Multi-Agent Reinforcement Learning for Autonomous Systems (PIs: Ligun Chen, Chris Heckman)
 - One proposal, titled “CPS: Medium: Algorithmic Challenges and Collaborative Computing for Distributed Autonomy (PIs: Chen, Frew, Grunwald, Heckman and Mishra)” was prepared but was declined. We plan to revise and resubmit during the next submission window.
- Simultaneous Learning of Objects and Grasp Models for Shared Autonomy Through Novel Tactile Sensing Technology (PIs: Brad Hayes, Chris Heckman)
- Guiding Autonomous Systems by Real-Time Characterization of Spatial Field Structures (PIs: Ute Herzfeld, Brian Argrow, Cory Dixon, Lucy Pao)
 - The team has been able to identify which specific objectives are most critical for advancing research in the interdisciplinary area of automated systems, computational systems and applications in the cryospheric sciences and thus laid the foundation for preparation of a larger proposal to a federal funding agency, likely NSF

IRT Performance Metrics

Industry Collaboration

New external collaborations

- ASIRT faculty Frew, Lahijanian, and Roncone visited Ball Aerospace and AFRL in Dayton, OH to discuss contributing to \$150M+ program being proposed by Ball to be funded by AFRL.
 - Frew pursuing a sabbatical with Ball Aerospace as part of the project
- Five out of the nine 2018 Draper Fellows at CU Boulder are conducting autonomy-related research.
- Planning workshop held on Oct 11-12 for the NSF IUCRC Center on Pervasive Personalized Intelligence being created by CU Boulder and Oregon State University.
- New collaboration with SSCI as part of DARPA Subterranean Challenge team (PI Humbert).
- Brad Hayes and Nisar Ahmed visited United Technology Research Center, December 2018.
- ASIRT faculty member Christopher Williams met with Kairos to discuss funding startup in radar work (part of DARPA Sub-T project)

Technology transfer, IP generation, and start-ups

- None yet.

Reputation

Faculty in national leadership positions

- Provide a list of faculty appointments at agencies, requests as peer reviewers, etc.
- Sean Humbert and Brian Argrow served on National Research Council committees investigating counter unmanned aircraft systems and assessing the risk of unmanned aircraft systems, respectively. Both committees recently released reports describing their findings.

- Natasha Bosanac, Eric Frew, and Jay McMahon participated in the 2018 Workshop on Autonomy for Future NASA Science Missions.
- Chris Heckman was invited to be a member of the NAE Frontiers of Engineering organizing committee.
- Sean Humbert served on the Board on Army Science and Technology for the National Academies (BAST)
- Eric Frew invited to contribute to 2019 JPL workshop for cloud computing in support of deep space science and exploration missions.

National press for IRTs

- Orit Peleg's work was highlighted in various media outlets including: New Scientist, Science News, Nature Asia, Phys.org, Technology.org, Forbes, Environmental News Network
- Ch7 and Ch31 Denver visited campus and did stories on the CU DARPA Subterranean Challenge team.

Recognition by peer institutions

- Nisar Ahmed selected for 2018 Dave Ward Memorial Lecture Award from the Aerospace Control and Guidance Systems Committee
- Chris Heckman selected as Research & Innovation Office (RIO) Faculty Fellows
- Jay McMahon selected for NASA Early Career award for project "Robust Entry and Landing Guidance Under Dynamic Uncertainty".

Proposals and Projects

Multi-department proposals/projects (> \$1M)

- AIDA: Representing Abstract Meaning for Images and Speech (RAMFIS); DARPA; Martha Palmer (PI), Chris Heckman and Jim Martin; \$2,760,000.00; **Awarded**.
- AMUSE (Aircraft Mapping Updraft Structure Experiment); NASA Earth Ventures – Suborbital; Cory Dixon (CU PI) and Eric Frew; \$2,187,662.00 ; Declined. [\$15M collaboration with several other universities].
- Analysis to evaluate and improve model performance in the Central Arctic: Unique perspectives from autonomous platforms during MOSAiC; NSF OPP; Gijs de Boer (PI), Dale Lawrence, and Brian Argrow; \$1,673,672.00; **Awarded**.
- Approaches to Assess Human Performance, Trust, and Situation Awareness for Autonomous Long-Duration Exploration Missions; NASA Human Research Program; Torin Clark (PI), Nisar Ahmed, Dan Szafir, and Jack Burns; \$1,200,000.00 ; Declined. [Based on seed grant]
- DNS4CES: Data- and Network-driven Science for Complex Energy Systems; DOE MMICC; Emiliano Dall'Anese (PI) and Lucy Pao; \$1,200,000.00; Declined. [Part of \$10M proposal with Cornell, Univ. Minnesota, UT Austin, Univ. Virginia, and Vtech].
- MARBLE: Multi-Agent Autonomy with Radar Based Localization for Exploration; DARPA Sub-T; Sean Humbert (PI), Chris Heckman, Chris Williams, and Eric Frew; \$4,500,000.00; **Awarded**. [Collaborators include CU Denver and SSC].
- NSA Site Science: Use of ARM Observations from Northern Alaska to Evaluate and Improve Prediction Capabilities; DOE BER; Gijs de Boer (PI), Matthew Shupe, Amy Solomon, Christopher Williams, Sergey Matrosov, Christopher Cox, and Joseph Sedlar; \$1,499,815.00 ; Pending.

- NSF AISL: Broad Implementation: Robotic Outreach Activities for Informal Science Education (RAISE) NSF; Sean Humbert (PI), Robert MacCurdy, Violet Mwaffo, and Shalom Ruben; \$2,996,342.00 ; Pending.
- NSF CHS: Medium: Data-Mediated Communication with Proximal Robots for Emergency Response; NSF CHS; Daniel Szafir (PI), Danielle Szafir, and Chris Heckman; \$1,194,056.00; **Awarded.**
- NSF CHS: Medium: Scaling Qualitative Inductive Analysis through Computational Methods; NSF CHS; Danielle Szafir (PI), Jed Brubaker, Casey Fiesler, and Michael Paul; \$1,070,508.00; **Awarded.**
- S&AS: INT: COLLAB: An Intelligence-Driven Patient Care Approach to Reduce Medical Errors (I-CARE) ; NSF; Mark Rentschler (PI) and Chris Heckman; \$1,000,000.00 ; Pending. [Based on seed grant].
- SCC: Engaging Smart and Connected Communities to Address Drone Safety and Privacy; NSF SCC; Rick Han(PI), Tam Vu, and Eric Frew; \$1,873,150.00; Declined.
- SCC: Interdisciplinary Approach Towards Smart and Connected Affordable Housing Communities; NSF SCC; Wangda Zuo (PI), Stefan Leyk and Brian Mueller; \$2,218,933.00; Declined.
- Targeted observation and seeding using autonomous unmanned aircraft systems; United Arab Emirate Rain Enhancement Program; Eric Frew; \$1,500,000.00; **Awarded.** [External collaborators Droplet Measurement Technologies and North-West University, South Africa]

Center-scale proposals/projects (> \$10M)

- Pending proposal: “The HOME (Habitats Optimized for Missions of Exploration) Space Technology Research Institute for Deep Space Habitat Design” submitted to the NASA Space Technology Research Institute on Smart Deep Space Habitats. CU PIs are Torin Clark, Dave Klaus, Allie Anderson, and Jim Nabity (\$3.5M to CU, total of \$15M over 5 years for all collaborators, led by UC Davis).
- Eric Frew, Lucy Pao, and Zoya Popovic all involved in NSF ERC pre-proposals being led by other universities.
- Eric Frew, Dale Lawrence, and Brian Argrow are preparing a Planning Grant proposal for the NSF Navigating the New Arctic program. The size of the anticipated center funded out of the NNA program has not been announced yet.

APPENDIX

IRT Members

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