C⁵I Center Overview

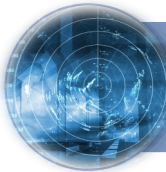**Dr. Paulo Costa – Director**
c5i.gmu.edu

Center Goals

Provide an intellectual base for the Nation's C^5I Community

Integrate theories and multidisciplinary research for Command and Control

Significantly impact C^5I SoS design, analysis, implementation, training and fielding

Bridge cultural gaps among government, industry and academia C^5I community of interest

C⁵I EXPLAINED

Goal:

Decision Guidance to support C2 in a
Multi-Domain Environment

- Air, Land, Sea, Space & Cyber Domains
- AI enabled Analysis at the speed of mission
- Mission Engineering (ME)
- Processing at the user's edge
- Sensor Fusion

Critical Functions

Command & Control

Critical Enablers

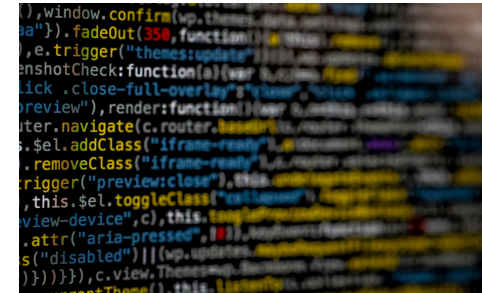**Communications Computing Cyber Intelligence**
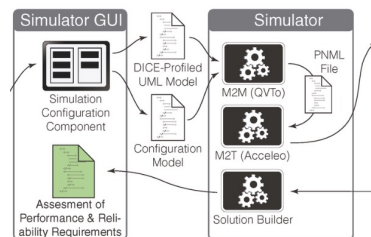
Core Research Capabilities

Sensing & Fusion

Decision Guidance Support

C³ Systems and Platforms (including civilian and dual use)

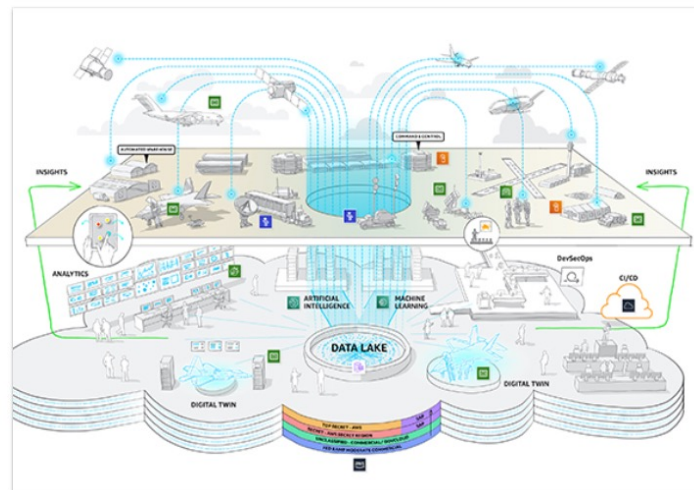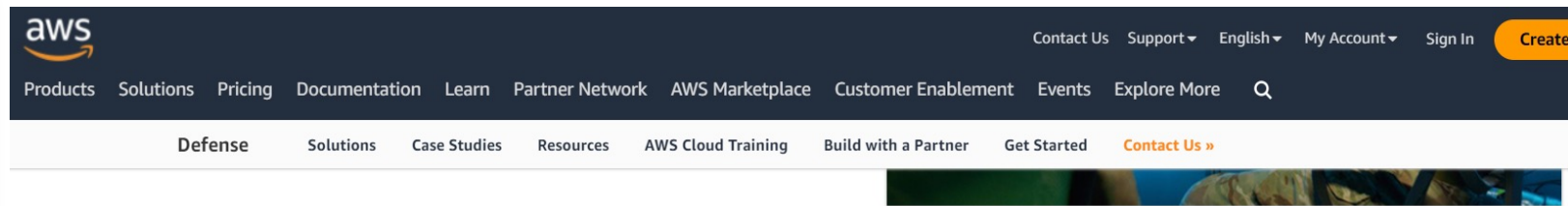**Modeling and Simulation**

Communications and Signals Processing

Systems Architectures

Why Research on C⁵I?

Evolve Command and Control with the cloud

As the U.S. Military moves to embrace Joint All-Domain Command and Control (JADC2), AWS is uniquely positioned to deliver reliable cloud capability.

We're supporting mission success for the DoD across the Mission Partner Environment—the framework enabling command and control across the full range of military operations.

AWS is supporting each service's JADC2 initiative, including recently participating in testing edge computing capabilities for the Air Force's Advanced Battle Management System (ABMS).

How AWS will support the emerging JADC2 vision ›

https://aws.amazon.com/federal/defense/

Our Leadership Team

Dr. Paulo C. G. Costa
Center Director

Dr. Michael Hieb
Deputy Director

Dr. Peggy Brouse
Associate Director, Ed. Initiatives & Work Force Dev.

Dr. Nick Clark
Associate Director, Systems Security / Cyber Resilience

Dr. Sherry Crissman
Associate Director, Center Operations

Dr. Ali Raz
Associate Director, Intelligent Systems Integration

Our Advisory Group

Dr. Linton Wells II
Executive Advisor
Advisory Group Chair

Dr. J. Mark Pullen
Director Emeriti

Dr. Daniel T. Maxwell
KaDSci, US Army (ret)

Maj. Gen. Eric W Vollmecke
GMU RPRC, US Army (ret)

Lt. Gen. Robert Elder
USAF (ret), Mason

RADM (ret) Willie Metts
National Security All. Exec.

Maj. Gen. Robert Wheeler
Strategic Consulting, LLC
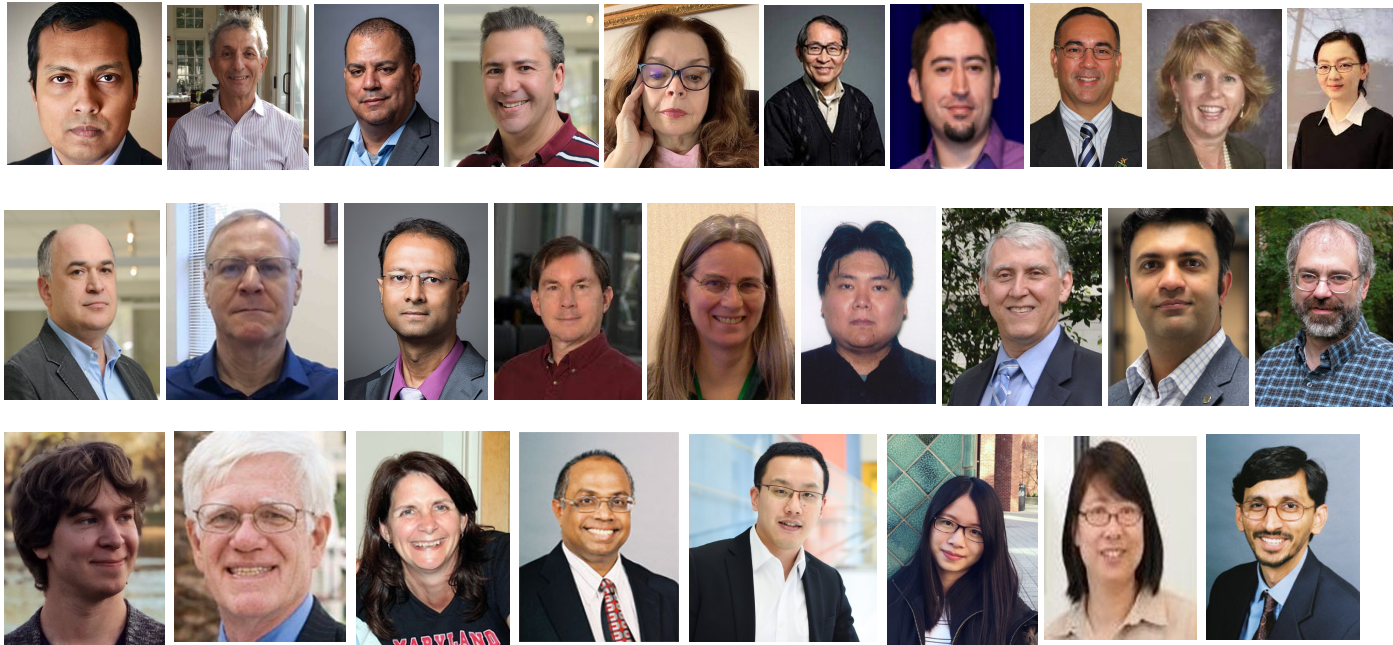
Dr. Gil Duvall
USN (ret), NDU, CSCIS

Capt. Leslie (Jake) Schaffner
USN (ret)

Dean Worley
MITRE, USAF (ret)

Research Faculty

- Dr. Tanvir Arafin
- Dr. James Baldo
- Dr. Alex Barreto
- Dr. Alex Brodsky
- Dr. Peggy Brouse
- Dr. Kuo-Chu Chang
- Dr. Nick Clark
- Dr. Paulo Costa
- Dr. Sherry Crissman
- Dr. Pei Dong
- Dr. Zoran Duric
- Dr. Jair Ferrari
- Dr. Rajesh Ganesan
- Dr. Michael Hieb
- Dr. Kathryn Laskey
- Dr. Shou Matsumoto

- Dr. Arthur Pyster
- Dr. Ali Raz
- Dr. Robert Simon
- Dr. Gregory Stein
- Dr. Linton Wells, II
- Dr. Liz White
- Dr. Duminda Wijesekera
- Dr. Xuesu Xiao
- Dr. Ziyu Yao
- Dr. Bo Yu
- Dr. Abbas Zaidi

New & Upcoming:
- **Dr. Joe Bricio**
- **Dr. Michael Bunting**
- **Joesph Kobsar**
- **Dr. Bryan Nyac**

Collaborating Centers and Laboratories

- ❑ Center for Air Transportation Systems Research
- ❑ Center for Assurance Research and Engineering (CARE)
- ❑ Center for Resilient and Sustainable Communities (C-RASC)
- ❑ Center for Excellence in Government Cybersecurity Risk Management and Resilience
- ❑ Criminal Investigations and Network Analysis (CINA)
- ❑ Greg and Camille Baroni Center for Government Contracting
- ❑ Institute for Digital InnovAtion (IDIA)
- ❑ Learning Agents Center
- ❑ Mason Autonomy and Robotics Center (MARC)
- ❑ Mason University Department of Police and Public Safety
- ❑ Rapid Prototyping Research Center (RPRC)
- ❑ Cyber Living / 5G Innovation Lab – Arlington
- ❑ Wireless Cyber Center / Wireless Innovation and Cybersecurity Lab (WICL)

C5I Center Overview (2023-2024)

Student Engagement
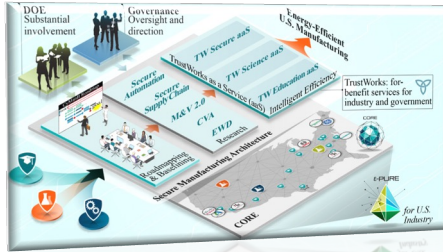
Selected Projects



Cybersecurity Manufacturing Innovation Institute (CyManII)

DOE will provide CyManII with $70M in 5 years to create economically viable, pervasive, and inconspicuous cybersecurity in American manufacturing to secure the digital supply chain and energy automation. The Institute is composed of 23 leading universities, 3 National Labs, and 50+ industry partners including CISCO, Schneider Electric, GE, and others. The projected budget is $120M for the 5 years. Mason is a Managing Partner (highest tier) and responsible for the East Cost Satellite Facility of the Institute.

DARPA SAFE-SIM Program – Applying Analytical Process with Multiple Methods

The project is developing an integrated analytical process that ties multiple technical methods for analysis and evaluation of complex system and systems of systems. The team is investigating how to build a consistent logical notation for complex systems and tie to technical methods (e.g., graph theory, deep learning etc.) to help with closing feasible and infeasible paths and help answer analyst questions.
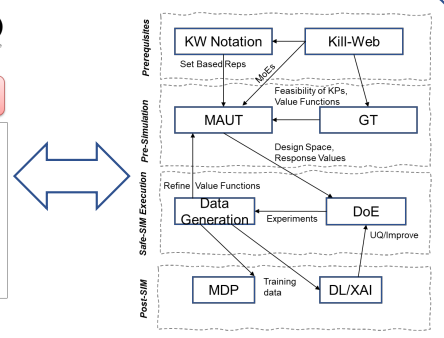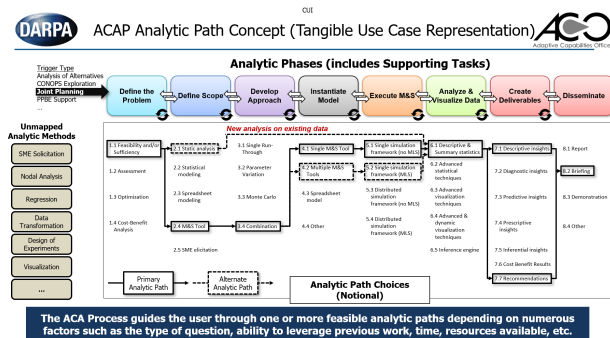
Selected Projects

UAVs at 20 m (60 ft)
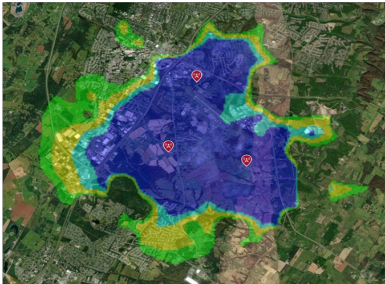
Orlan-10 (2 m)

Full-Spectrum Intelligence, Surveillance, and Reconnaissance (ISR) Innovation and Integration (Air Force Central Command)
Provide a UAV Sensor Testbed that has a rigorous analytical capability to predict Sensor Performance to improve Base protection from UAV threats.. C5I / SEOR is customizing the MUSCAT testbed infrastructure to provide a solution for established AFCENT requirements. The testbed will be used to create & run scenarios to evaluate and optimize sensor placement based on detection probabilities. In addition, future tasking will include incorporating Multi Sensor Fusion and platform analytics to assess swarm vs. single platforms as well as predict platform intent.

NCMS Integrated Photonics For Sustained Military Operations (National Center for Manufacturing Sciences)

The project is investigating the efficacy and advancing the technology readiness level (TRL) of low size, weight, and power, and low cost (SWaP-C) free-space optics (FSO) battlefield communications using chip-scale integrated photonics technologies. This will include assessing potential in the context of performance requirements flowing from system engineering of potential use-cases associated with Army battlefield applications in communications and PNT.

System Engineering Approach – Overview

System Considerations with Multi-Level Integration
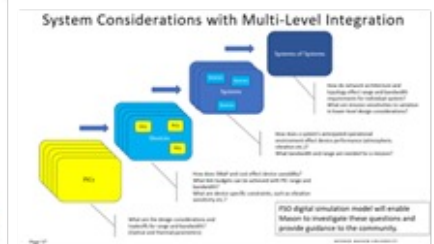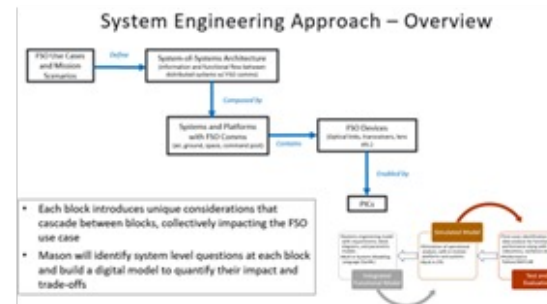
Selected Projects

ODNI/ARLIS: Recombinant AI: Exploiting Heterogeneous Data Fusion with Ontological Frameworks and NLP

This project is focused on developing analytical frameworks (e.g., ontological framework) to enable heterogenous data exploitation and fusion in support of Recombinant AI objectives. It builds on the outcomes of Natural Language Processing (NLP) applied to various documents in a given domain (e.g., data extraction, indexing, and translation etc.), an ontology framework, for example, will identify key entities of interest in that domain and how these entities are interlinked towards inferring root causes or potential future courses of action. It set foundations for exploiting and fusing heterogeneous data to overcome limitations of missing data and/or extract new information from disparate and siloed data sets.
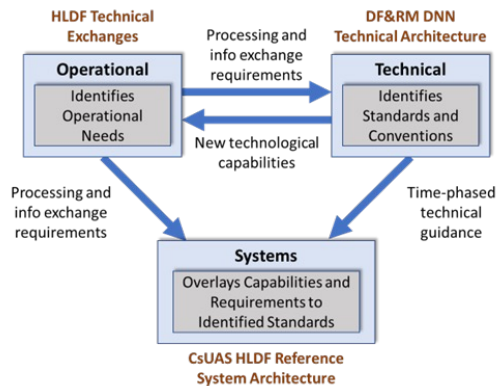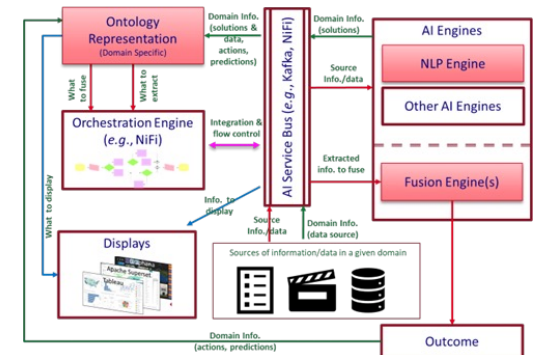
CUAS: Standardized High Level Data Fusion (HLDF) System Architecture for Counter Unmanned Aerial Systems (CUAS)

This project delivers innovative engineering and cost-effective technical implementation capabilities to address DoD's critical High Level Data Fusion (HLDF) system architecture needs in the Counter Unmanned Aerial Systems (CUAS) mission area. Our objective in this project is to create a flexible HLDF system architecture that provides system-of-systems interoperability between existing sensors and Command & Control (C2) systems, maximizes reusability of key technical resources including software modules, and supports future innovation and evolution of HLDF, C2 and sensing systems

Statewide and National UAS Research

C5I Center has a growing expertise in UAS Analysis

- Counter UAS Expertise applied to Navy Projects
- VA CCI Project developed UAS Sensor Testbed in MATLAB
- Partnership with GMU Police Department

400 ft
300 ft
200 ft
100 ft

400 ft

detection starts

Distance

Flight area
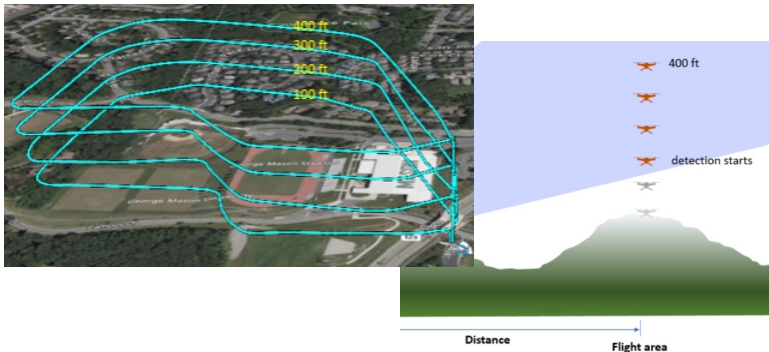
Mason's UAV Systems Cyber Analysis Testbed (MUSCAT)

The Mason team is currently developing a UAV Operational Analysis Testbed

- Focus on predicting sensor coverage areas (Radar, RF, Optical, Acoustic)
- Utilize detailed 2D and 3D terrain models
- Model UAV Sensor detection as a function of altitude and range
- Results intended to support optimal placement of multiple types of sensors to maximize detection

Drones as First Responders (DFR)

Goal: Implement a regional DFR program in Northern Virginia. This project maximizes use of low-cost UAVs to accelerate situational awareness, decrease time to incident response, and increase First Responder safety for law enforcement, fire, and other dispatched services.

- Reduces response time by pushing situational awareness to first responders while enroute
- Increases safety through increased situations awareness
- Able to remotely access the situation and efficiently direct appropriate response teams
- Reduces cost by more effectively utilizing police & fire resources though identifying "false" alarms and calls that have incorrect locations

NATO Collaborations
Country-specific Partnerships
Current Funding Opportunities

C5I Center
International Collaborations
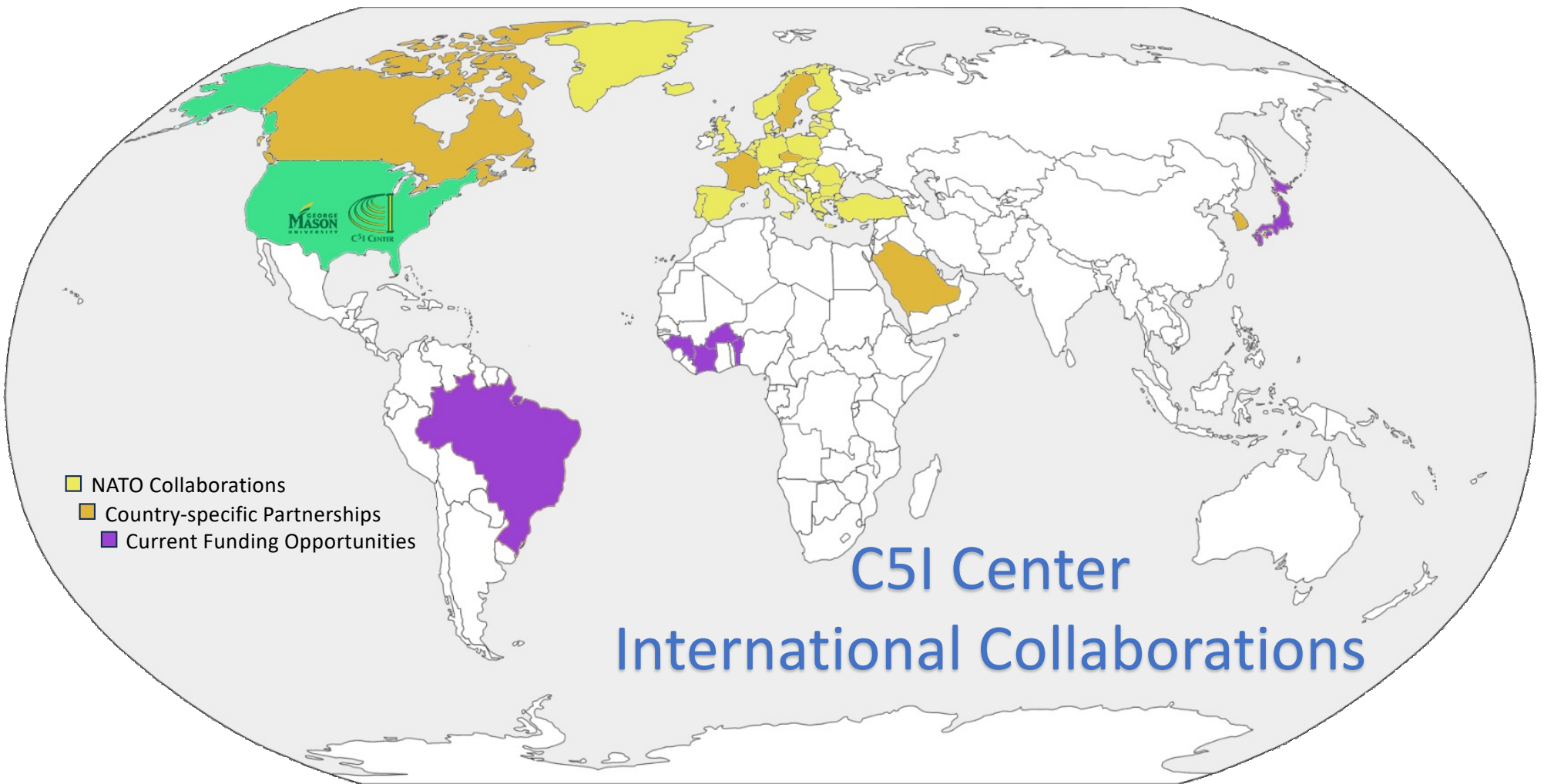
Conclusion, Discussion…

How to Work with the C^{5}I Center

C^{5}I CENTER

Points of Contact:

Director, Dr. Paulo Costa

pcosta@gmu.edu

Associate Director of Operations, Dr. Sherry Crissman

scrissma@gmu.edu

Visit our Website: c5i.gmu.edu

A MODERN LOOK AT COMMAND AND CONTROL
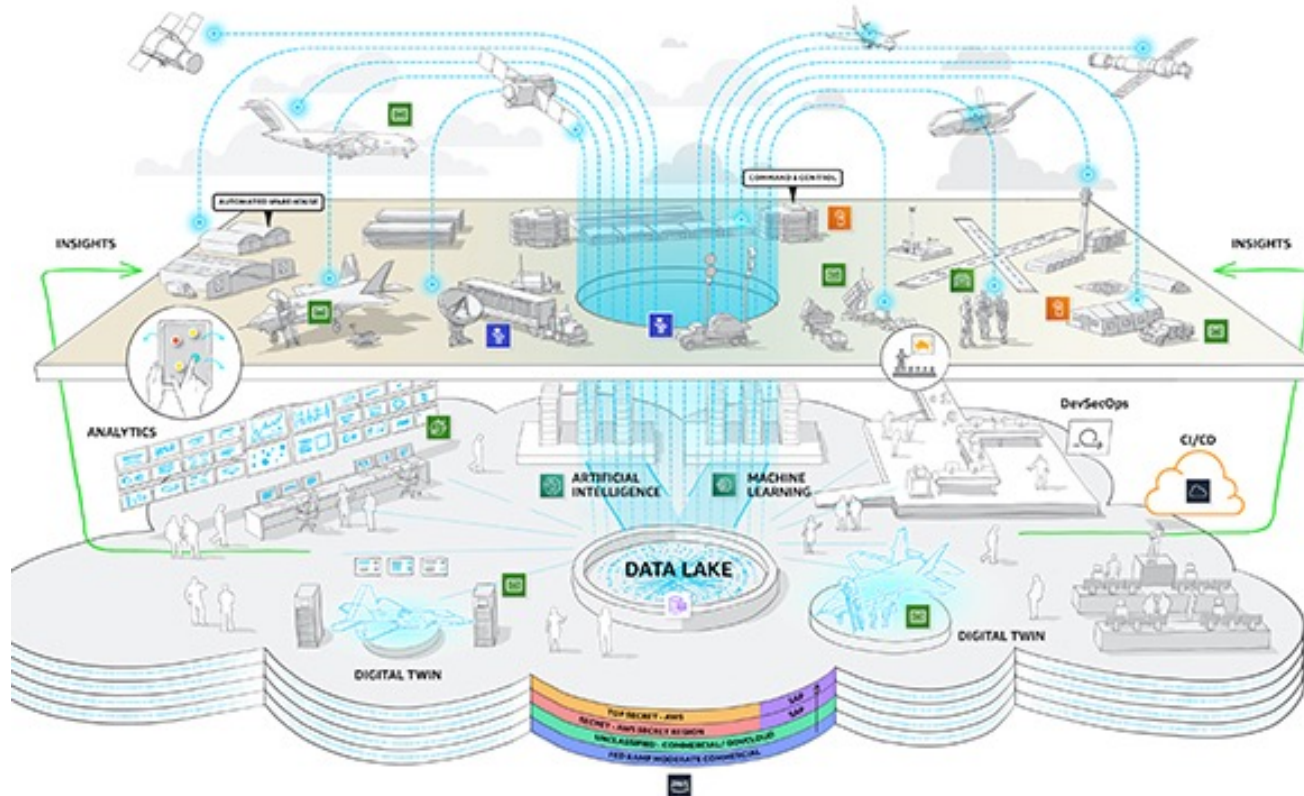
Publications, Honors & Recognition

Publications

1. Matsumoto, Shou, Jair Feldens Ferrari, Han Jun Yoon, Ashrith Reddy Thukkaraju, Jin-Hee Cho, Paulo Costa, Donghwan Lee, and Myung Kil Ahn. 2023. "Software-Friendly Subjective Bayesian Networks: Reasoning within a Software-Centric Mission Impact Assessment Framework." In *26th International Conference on Information Fusion*. Charleston, South Carolina, USA. https://doi.org/10.23919/FUSION52260.2023.10224119.
2. Srivastava, Saurabh, Gaurav Singh, Shou Matsumoto, Ali Raz, Paulo Costa, Joshua Poore, and Ziyu Yao. 2023. "MailEx: Email Event and Argument Extraction." In *Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing*, 12964–87. Singapore: Association for Computational Linguistics. https://doi.org/10.18653/v1/2023.emnlp-main.801.
3. Thukkaraju, Ashrith Reddy, Han Jun Yoon, Shou Matsumoto, Jair Feldens Ferrari, Donghwan Lee, Myung Kil Ahn, Paulo Costa, and Jin-Hee Cho. 2023. "Interdependent Mission Impact Assessment of an IoT System with Hypergame- Theoretic Attack-Defense Behavior Modeling." In *2023 31st International Symposium on Modeling, Analysis, and Simulation of Computer and Telecommunication Systems (MASCOTS)*, 1–8. Stony Brook, NY, USA: IEEE. https://doi.org/10.1109/MASCOTS59514.2023.10387597.
4. [Preprint] Yoon, Han Jun, Ashrith Reddy Thukkaraju, Shou Matsumoto, Jair Feldens Ferrari, Dongwhan Lee, Myung Kil Ahn, Paulo Costa, and Jin-Hee Cho. 2023. "Subjective Bayesian Network-Based Interdependent Mission Impact Assessment with Game-Theoretic Attack-Defense Interactions." https://doi.org/10.36227/techrxiv.24566917.v2.

Speaking engagements (presentations)

1. Ali K. Raz, Shou Matsumoto, and Paulo C. G. Costa. 2023. "Exploring Explainable Artificial Intelligence to Aid Systems Engineers in Design and Evaluation of Complex Systems." Paperless presentation presented at the EMEA WORKSHOP & CONFERENCE 2023, Sevilla - Spain, April 24. https://www.incose.org/emeawsec2023.

Honors, kudos, and other milestones.

1. [Software release] Andy HJ Yoon, Shou Matsumoto, Ashrith Reddy Thukkaraju, Jair Feldens Ferrari, Jin-Hee Cho, and Paulo Costa. *IMIA: Interdependent Mission Impact Assessment Framework* (version 1). Python, Java. GitHub. VATech, GMU, 2023. https://github.com/hjyoon93/iMIA.
2. [Award] UAI 2023, best UAI reviewers 2023. https://www.auai.org/uai2023/top_reviewers#:~:text=Shou%20Matsumoto%20(George%20Mason%20University)

On January 1st, 2024, the IEEE announced Dr. Alexandre Barreto's elevation to the grade of IEEE Senior Member. This milestone is essential since only 10% of the IEEE's more than 450,000 members hold this grade, which requires extensive experience and reflects professional maturity and documented significant achievements.

Publications, Honors & Recognition

Publications

1. <u>X. Huang</u>, Y. Li, E. Witherspoon, <u>R. He</u>, G. Petruncio, M. Paige, M. Li, T. Liu, K. Amine, Z. Wang, Q. Li*, <u>P. Dong*</u>, Species-selective detection of volatile organic compounds by ionic liquid-based electrolyte using electrochemical methods, ACS Sensor, 8, 9, 3389, 2023 (Impact Factor: 9.6)
2. <u>R. He</u>, L. Kong, Y. Yu, X. Liu*, <u>P. Dong*</u>, Capacitive Deionization System with Ultra-high Salt Adsorption Performance: From Lab Design to Agricultural Applications, Chem Comm, 59, 83, 12376, 2023 (Impact Factor: 4.9)
3. <u>X. Huang</u>, Matthew Li, <u>Pei Dong*</u>, Catalytic strategies for four-electron conversion for molten-salt lithium-oxygen batteries, Chem Catalysis (Cell Press), 3, 3, 2023
4. <u>X. Huang</u>, E. Witherspoon, <u>R. He</u>, Y. Li, J. Yu, J. Huang, C. Luo, M. Li, T. Liu, K. Amine, Q. Li, Z. Wang, <u>P. Dong*</u>; Superior Photodynamic Effect of Single-walled Carbon Nanotubes in Aprotic Media: A Kinetic Study, Materials Today Energy, 101242, 2023 (Impact Factor: 9.3)
5. M. Neupane†, Q. Yan†, <u>R. He</u>, R. Masmoudi, Y. Liu, Z. Benedict, J. Wang, C. Tripp, <u>P. Dong</u>, Z. Cai*, Y. Yang*, Sodium-Dictated Free-Standing Lignin-Carbon Electrode towards Ultrahigh Capacitance, Batteries & Supercapacitors, (Cover Feature), 6, 9, 2023 (Impact Factor: 6)
6. F. Bhatti, D. Xiao, T. Jebagu, <u>X. Huang</u>, E. Witherspoon, <u>P. Dong</u>, S. Lei, J. Shen, Z. Wang, Semiconductive biocomposites enabled portable and interchangeable sensor for early osteoarthritis joint inflammation detection, Advanced Composites and Hybrid Materials, 6, 1, 1-9, 2023 (Impact Factor: 9.9)

Speaking engagements (presentations)

1. Biomass Converted Carbon Electrodes for Energy-efficient Water Desalination Technology, Society of Engineering Science, 2023
2. Advanced Materials for Sustainability, Virginia Clean Energy and Catalysis Club, 2023
3. Nanosensor Enabled Sustainable Disinfection Through Photodynamic Effects, Defense Threat Reduction Agency (DTRA), 2023

Honors, kudos, and other milestones.

1. Materials Today Energy Promising Early Career Scientist Award 2023
2. Rising Star of Science Award, 2023
3. Led development of ME concentration in Microfabrication now in catalog
4. Led development of certificate program for graduate students in Microfabrication (Approved by the state of Virginia, CIP code: 15.1601

Publications, Honors & Recognition

Publications

- "Limitations of Existing Policy and Regulations in Enabling Coordinated, Cross-Sector Planning and Operations of Critical Cyber-Physical Systems," Linton Wells II, Kathryn Blackmond Laskey, Submitted to DoD Strategic Environmental R&D Program (SERDP), Aug 2023
- "Recommendations with corresponding justifications to policy and regulatory decision-makers/institutions for cross-sector regulatory standards," Submitted to SERDP, Aug 2023
- "A Resilience Assessment Framework for Coupled Power and Communication Infrastructure," Mohamed Lotfi, Mathaios Panteli, Linton Wells II, Kathryn Blackmond Laskey, John van de Lindt, Yair Amir, Amy Babay, Imes Chiu, Presented at IEEE PES GM July 2023

Speaking Engagements / Presentations

- delivered President's Lecture, Shepherd University, Shepherdstown, WV, "Public Service, Shepherd International, Disruptive Technology—A Challenging and Fascinating Future Awaits" Sep 12
- made presentation on "Global Treaties, Cyber, and The Sea," to workshop on " "Cyber Warfare, Navies, and New Technologies," U.S. Naval War College, Oct 25

Other
- Sponsored 4 Data Engineering (DAEN) 690 Capstone Courses
- Made 4 visits to Puerto Rico building collaborative networks for further research (Feb, May, Aug, Dec)
- Coordinated STAR-TIDES 16th Annual Capabilities demonstration, April 17-21
- participated in Multi-Domain Awareness (MDA): Keys to Understanding the Impacts of Climate Change on Safety & Security in Indo-Pacific Region, in Hawaii, June 5-7
- Addressed student applicants and selected team members involved in the international Country-to-Country (C2C) capture the flag (CTF) competition, Mar and July
- Staff at DEF CON Policy Team (hacker convention), Aug 10-13, 2023
- Helped coordinate Govt of Puerto Rico delegation visit to US Army Corps of Engineers (USACE) Geospatial Research Laboratory

Links to Publications

Paulo Costa - https://scholar.google.com/citations?user=2vE_NmMAAAAJ&hl=en&oi=ao

Michael Hieb – https://scholar.google.com/citations?user=dWAqWsMAAAAJ&hl=en

Ali Raz - https://scholar.google.com/citations?user=dVMdGAQAAAAJ&hl=en&oi=ao

John Shortle - https://scholar.google.com/citations?user=Ilu__agAAAAJ&hl=en&oi=ao

Duminda Wijesekera - https://scholar.google.com/citations?user=mL6lVzIAAAAJ&hl=en&oi=ao

Lance Sherry - https://scholar.google.com/citations?user=vYuc5OYAAAAJ&hl=en&oi=ao

Tanvir Arafin - https://scholar.google.com/citations?user=8NqlrnUAAAAJ&hl=en

Jair Ferrari - https://scholar.google.com/scholar?hl=en&as_sdt=0%2C47&q=jair+ferrari&btnG=

Shou Matsumoto - https://scholar.google.com/citations?user=2ukan3AAAAAJ&hl=en&oi=sra

Alexandre Barreto - https://scholar.google.com/citations?user=b0YPqdIAAAAJ&hl=en&oi=ao

Command & Control
Still the Essence of C5I

- **authority** given a military commander to lawfully exercises over subordinates to assign missions

- **direction** to forces through communications that convey decisions and intent

Command Intent - a concise statement of the purpose of an operation.
The single unifying focus for all subordinate elements of an organization.

C⁵I Mission and Vision

Mission

Advanced research in defense, intelligence, and security-related applications in C⁵I , bridging cultural gaps and aligning requirements between government, industry, and academia.

Vision

Serve as a multi-disciplinary hub connecting faculty and researchers working in areas related to the Center's mission and be widely recognized as a premier source of knowledge and innovation to military and civilian authorities.

C5I Research in 2023

Publications

- Over 40 publications across C5I Center Faculty Pis and Co-Pis in 2023

Selected Speaking Engagements

- "Exploring Explainable Artificial Intelligence to Aid Systems Engineers in Design and Evaluation of Complex Systems." Paperless presentation presented at the EMEA WORKSHOP & CONFERENCE 2023, Sevilla - Spain, April 24. https://www.incose.org/emeawsec2023. Raz, Matsumoto, Costa; 2023
- "MUSCAT (Mason's UAV Systems and Cyber Analysis Testbed)." IEEE / AIAA Digital Avionics Systems Conference (DASC); 2023; Best of Session Award.
- "AI Characteristics for Regulatory Consideration" Workshop; U.S Nuclear Regulatory Commission; Raz ; 2023
- Biomass Converted Carbon Electrodes for Energy-efficient Water Desalination Technology, Society of Engineering Science, Dong; 2023
- Advanced Materials for Sustainability, Virginia Clean Energy and Catalysis Club, Dong; 2023
- Nanosensor Enabled Sustainable Disinfection Through Photodynamic Effects, Defense Threat Reduction Agency (DTRA), Dong; 2023
- "Return on Investment (RoI) in Cybersecurity" Keynote speech at Federal University of Rio de Janeiro's 2023 PESC Week Seminar, Costa; 2023

Selected Honors, kudos, and other milestones.

- Air Force Office of Scientific Research (AFOSR) Summer Faculty Fellowship; Raz ; 2023
- Jean Pierre le Cadre Award for best paper of the Fusion 2023 Conference – 2nd Place "Uncertain about ChatGPT: Enabling the Uncertainty Evaluation of Large Language Models; Costa, Laskey, and co-authors. Charleston, SC, 2023
- *IMIA: Interdependent Mission Impact Assessment Framework* (version 1) Software Release. VATech, GMU, 2023. https://github.com/hjyoon93/iMIA.
- UAI 2023, best UAI reviewers 2023. https://www.auai.org/uai2023/top_reviewers#:~:text=Shou%20Matsumoto%20(George%20Mason%20University)

C5I Center Overview (2023-2024)