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Virtual & in-person

30 May, 2024

Registration link

Quantum Engineering

Workshop

For in-person attendance at Caltech contact:
Dr. Farbod Khoshnoud farbodk@caltech.edu

Supported by CAST, Caltech, Cal Poly Pomona, JAVS, ASME

30 May, 2024, A 1-day free hybrid workshop

Pushing the engineering boundaries beyond classical techniques, supported by the **CAST Caltech, Journal of Autonomous Vehicles and Systems (JAVS), American Society for Mechanical Engineers (ASME), College of Engineering, Cal Poly Pomona, STARS Program, Cal Poly Pomona**

8:30 am - 9:00 am (PST)
Opening welcome and introduction
Organizers: Dr. Marco Quadrelli and Dr. Farbod Khoshnoud

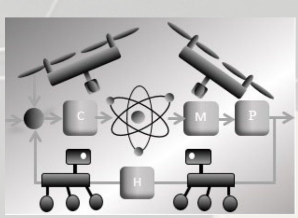
9:00 am - 10:30 am
Nobel Laureate Dr. John F. Clauser
“Experimental proof that non-local quantum entanglement is real**”**

11:00 am - 11:30 am
Dr. Spyridon Michalakis, *Caltech*
“The Quantum Advantage”

11:30 am - 12:00 am
Professor Mark Balas, *Texas A&M University*
“Closed-Form Hilbert Projection for Quantum State Observers”

12:00 pm - 1:30 pm **Break**

1:30 pm - 2:00 pm
Dr. Jens Küchenmeister
Thorlabs‘ Education
“The Quantum Optics Kit”



2:00 pm - 2:30 pm
Professor Friedemann Reinhard, *University of Rostock*
“Positioning and readout for quantum magnetic field sensors”

2:30 pm - 3:00 pm
Professor Paola Cappellaro, *MIT*
“Design and control of quantum devices”

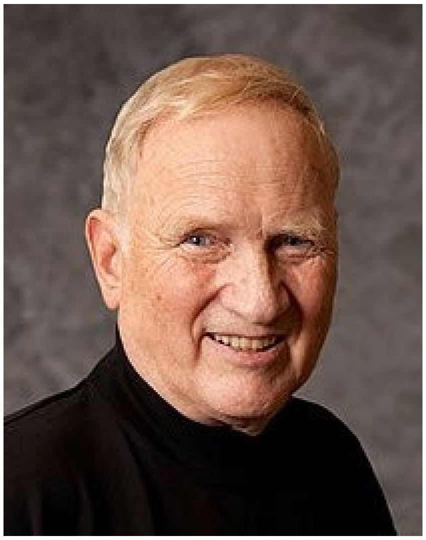
3:00 pm - 3:30 pm;
Dr. Loïc Anderegg, *Harvard University*
“Laser Cooled Molecules for Quantum Science Applications”

3:30 pm - 4:00 pm
Jason J Hyon, *JPL*
“JPL Space Quantum Innovation Center”

4:00 pm - 4:45 pm
Professor Mansour Shayegan, *Princeton University*
“Non-Abelian Fractional Quantum Hall States for Topological Quantum Computing”

5:00 pm – 5:30 pm
Andrew Phillip Conrad, *University of Illinois, Urbana-Champaign*
“Vehicle-to-Vehicle Quantum Key Distribution (V2V-QKD)”

5:30 pm - 5:45 pm
Q&A, and adjourn



Dr. John Clauser

“Experimental proof that non-local quantum entanglement is real”

John Clauser received his B.S. in physics from the California Institute of Technology in 1964, his M.A. in physics in 1966 and Ph.D. in physics in 1969 from Columbia University. From 1969 to 1996 he worked at Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and the University of California, Berkeley. John was awarded the Wolf Prize in Physics in 2010 and the Nobel Prize in 2022, together with Alain Aspect and Anton Zeilinger for their observations of non-local quantum entanglement and experimental tests of Local Realism. In 1969, with Michael Horne, Abner Shimony, and Richard Holt, inspired by theoretical results by John Bell, he proposed the first test of local hidden variable theories, and provided the first experimentally testable CHSH-Bell's Theorem prediction for these theories -- the Clauser-Horne-Shimony-Holt (CHSH) inequality. In 1972, working with Stuart Freedman, he carried out the first experimental test of the CHSH inequality's prediction. This was the world's first observation of non-local quantum entanglement, and was the first experimental observation of a violation of a Bell inequality. In 1976 he carried out the world's second experimental test of the CHSH inequality prediction. In 1974, working with Michael Horne, he formulated the theory of Local Realism as a generalization of local hidden-variable theories, and first showed that a generalization of Bell's Theorem provides severe constraints for all Local Realistic theories of nature. That work introduced the Clauser–Horne (CH) inequality as the first fully general experimental requirement set by Local Realism. It has only recently (2013) been tested experimentally. He also introduced the "CH no-enhancement assumption", whereupon the CH inequality reduces to the CHSH inequality, and whereupon associated experimental tests also constrain Local Realism. In 1974 he made the first observation of sub-Poissonian statistics for light (via a violation of the Cauchy–Schwarz inequality for classical electromagnetic fields), and thereby first experimentally proved that photons can behave like localized particles and not like brief pulses of electromagnetic radiation. In 1987-1991 he proposed (and patented) atom interferometers as useful ultra-sensitive inertial and gravity sensors. In 1992, with Matthias Reinsch, he first deduced the number-theoretic properties of the fractional Talbot effect, and invented the Talbot-Lau interferometer. In 1990-1997, with Shifang Li, he first used Talbot-Lau interferometry to build an atom interferometer. In 1998 he invented and patented use of the Talbot-Lau interferometry for "Ultrahigh Resolution Interferometric X-ray Imaging". This invention, in turn, allows x-ray phase-contrast medical imaging of soft tissue.

Title of the talk: ***Experimental proof that non-local quantum entanglement is real***

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Journal of Autonomous Vehicles and Systems (JAVS)

ASME SETTING THE STANDARD

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Student Success and Transfer Articulation through Research and Support Services STARS

Quantum Engineering Workshop

Kenote: Dr. John Clauser


Professor Mansour Shayegan


Professor Paola Cappellaro


Dr. Spyridon Michalakis


Professor Mark Balas


Dr. Jens Küchenmeister


Professor Friedemann Reinhard


Mr. Jason Hyon


Dr. Loïc Anderegg


Mr. Andrew Conrad

Organizers: Dr. Marco Quadrelli and Dr. Farbod Khoshnoud
Contact: farbodk@caltech.edu

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30 May, 2024, A 1-day flexible free hybrid workshop

Pushing the engineering boundaries beyond classical techniques, Supported by the American Society for Mechanical Engineers (ASME), Center for Autonomous Systems and Technologies (CAST), Caltech, College of Engineering, California State Polytechnic University, Pomona, STARS Program, Cal Poly Pomona

In-Person Locations

- 8:30 am to 12 pm Beckman Auditorium
- 1:30 pm to 5:30 pm F-384 Firestone Flight Sciences Laboratory

CalPolyPomona College of Engineering

Journal of Autonomous Vehicles and Systems (JAVS)

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Student Success and Transfer Articulation through Research and Support Services STARS

Organizers:

Dr. Marco Quadrelli, Jet Propulsion Laboratory, California Institute of Technology
Contact: marco.b.quadrelli@jpl.nasa.gov

Dr. Quadrelli is a principal research technologist and the supervisor of the Robotics Modeling and Simulation Group in the Robotics Section at JPL. He is an expert in modeling for dynamics and control of complex space systems. He has a degree in Mechanical Engineering from Padova (Italy), a Master's Degree in Aeronautics and Astronautics from MIT, and a PhD in Aerospace Engineering from Georgia Tech. He was a visiting scientist at the Harvard-Smithsonian Center for Astrophysics, at the Institute for Paper Science and Technology, and a lecturer at the Caltech Graduate Aeronautical Laboratories. After joining NASA JPL in 1997 he has contributed to a number of flight projects including the Cassini-Huygens Probe, Deep Space One, the Mars Aerobot Test Program, the Mars Exploration Rovers, the Space Interferometry Mission, the Autonomous Rendezvous Experiment, and the Mars Science Laboratory, among others. He has been the Attitude Control lead of the Jupiter Icy Moons Orbiter Project, and the Integrated Modeling Task Manager for the Laser Interferometer Space Antenna. He has led or participated in several independent research and development projects in the areas of computational micromechanics, dynamics and control of tethered space systems, formation flying, inflatable apertures, hypersonic entry, precision landing, flexible multibody dynamics, guidance, navigation and control of spacecraft swarms, terra-mechanics, precision pointing for optical systems. His current research interests are in the areas of multi-domain, multi-physics, multi-body, multi-scale physics-based, and quantum technologies modeling, dynamics and control. He is an Associate Fellow of the American Institute of Aeronautics and Astronautics, a NASA Institute of Advanced Concepts Fellow, and a Caltech/Keck Institute for Space Studies Fellow.

Dr. Farbod Khoshnoud, Cal State Poly Pomona, California Institute of Technology, UC Riverside

Contact: farbodk@caltech.edu

Farbod Khoshnoud, PhD, PGCE, CEng, M.IMechE, M.ASME, HEA Fellow, is an associate professor of electromechanical engineering technology at California State Polytechnic University, Pomona, a visiting associate in the Center for Autonomous Systems and Technologies in the Department of Aerospace Engineering at California Institute of Technology, and an adjunct lecturer in the department of mechanical engineering at the University of California. His current research areas include Self-powered Dynamic Systems, Nature/Biologically Inspired Dynamic Systems, and the applications of Quantum Technologies in Robotics and Autonomous Systems.

He was a research affiliate in the Mobility and Robotic Systems section at NASA Jet Propulsion Laboratory, Caltech in 2019; an Associate Professor of Mechanical Engineering at California State University, USA; a visiting Associate Professor in the Department of Mechanical Engineering at the University of British Columbia (UBC), Vancouver, Canada, in 2017; a Lecturer in the Department of Mechanical Engineering at Brunel University London, UK, 2014-16; a senior lecturer at the University of Hertfordshire, 2011-2014; a visiting scientist and postdoctoral researcher in the Industrial Automation Laboratory, Department of Mechanical Engineering, at UBC, Vancouver, 2007-2012; a visiting researcher in applied mathematics at California Institute of Technology, USA, 2009-2011; and a Postdoctoral Research Fellow in the Department of Civil Engineering at UBC, 2005-2007. He received his Ph.D. in Mechanical Engineering from Brunel University in 2005. He has worked in industry as a mechanical engineer for over six years. He is an associate editor of the Journal of Mechatronic Systems and Control (formerly Control and Intelligent Systems); an editor of the Quantum Engineering special issue of the Journal of Mechatronic Systems and Control, an associate editor of the ASME Journal of Autonomous Vehicles and Systems (JAVS), and an editor of the ASME JAVS Special Issue on Quantum Engineering for Autonomous Vehicles.

Speakers:

Dr. Spyridon Michalakis, California Institute of Technology
"The Quantum Advantage"

Abstract: Quantum computers are poised to radically accelerate scientific discovery and technological advances by the end of this decade. Achieving quantum advantage, that historic moment when a quantum computer solves a problem of practical importance that the world's most powerful supercomputers can't handle, is now just a matter of clever engineering. At least, that's what the headlines tell us. In this talk, I will delve into the promise and puff of the coming quantum age, using quantum machine learning as an illustrative example. We will explore the source behind the power of quantum computers, illuminating the exciting next steps on the way to quantum advantage.

Bio: Spyridon Michalakis is a mathematical physicist and the manager of outreach at Caltech's Institute for Quantum Information and Matter. His work on the quantum Hall Effect, with Microsoft's Matthew Hastings, helped elucidate the mechanism underlying the emergence of macroscopic quantum phenomena, resolving one of thirteen significant problems in mathematical physics. As a science consultant on "Ant-Man" and "Ant-Man and the Wasp", Dr. Michalakis introduced the concept of the Quantum Realm into the Marvel Cinematic Universe, sparking a global fascination with the concepts of quantum superposition and quantum entanglement. His current research focuses on quantum many-body physics and the study of wormholes and time machines within the context of quantum gravity.

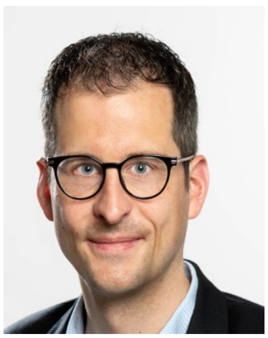
Professor Mark Balas, ***Texas A&M University***
"Closed-Form Hilbert Projection for Quantum State Observers"

Abstract: The Purpose of this presentation is to bring together the areas of Quantum Dynamical Systems and Control Theory State Estimation Observers. Designing an observer of an unknown quantum density operator is difficult because the operator must be Hermitian positive semidefinite with unit trace. In this presentation, we derive a closed-form solution for projecting an arbitrary matrix onto the convex set of valid quantum density operators. This allows us to design linear quantum state observers and retract the observer's state back to this set while retaining the exponential convergence rate of the linear observer. The derived closed-form projection can be used alongside any quantum state estimation technique to produce a valid state estimate without increasing the state estimation error. In addition, we will show that quantum information in the form of Von Neumann Entropy and Quantum Relative Entropy can also be estimated with exponential rates.

Bio: Mark Balas is a control systems expert in the theory and practice of adaptive control systems. He has made theoretical contributions in linear and nonlinear systems, especially in the control of distributed and large-scale systems. His results in low-order control of infinite- dimensional systems are the key to practical controller design and operation for many new engineering systems application, e.g., large aerospace structures and flexible mechanical systems, high precision optics, high performance aircraft, and possibly quantum information systems. His adaptive control research has led to the first mathematically rigorous proof of stable control of an infinite-dimensional system by a finite-dimensional controller. His current work in the theory of control of systems in Hilbert space is setting the stage for the first use of adaptive control on quantum gates in quantum information systems and quantum computing.

Dr. Jens Küchenmeister, ***Thorlabs‘ Education***
“The Quantum Optics Kit”

Abstract: Thorlabs' new Quantum Optics Kit provides an opportunity for students to demonstrate and perform experiments with a true non-classical light source. I will walk through the setup and explain the different experiments that students can perform with the kit and how the kit experimentally addresses some of the typical misconceptions students face when being introduced to quantum optics. Furthermore, I will talk about extensions, such as a 2-bit optical quantum computer, the single photon double slit and polarization-entanglement.
Bio: Dr. Jens Küchenmeister is the leader of Thorlabs‘ Educational Products business unit. After studying physics and maths, he received his Ph.D. from the Karlsruhe Institute of Technology, Germany where his doctoral thesis focused on the numerical solution of Maxwell’s equations in nanostructured systems. His high motivation for teaching physics, demonstrated by numerous voluntary teaching assignments, led him to Thorlabs, where he has been growing the educational business unit since 2013.



Professor Friedemann Reinhard, ***University of Rostock***
“Positioning and readout for quantum magnetic field sensors”

Abstract: Quantum sensors are widely recognized as the most promising short-term route to the quantum market, and NV color centers in diamond are a front-runner platform for quantum magnetic field sensors. These can either be extremely small, when consisting of a single atom in diamond, or extremely sensitive, when consisting of a millimeter-sized ensemble of color centers. Single centers have enabled imaging of magnetic fields at the nanoscale. Millimeter-scale ensemble sensors could rival the sensitivity of superconducting sensors in a room-temperature device and could pave the way to large-scale application of magnetoencephalography, to microfluidic NMR spectrometers, or to navigation in GPS-denied environments. Both directions (nano- and millimeter-scale sensors) are well established by laboratory prototypes, but the existing engineering routes towards mass-fabrication and large-scale application face major challenges. Scanning-probe imaging of magnetic fields requires sophisticated nanofabricated diamond scanning probe tips, ensemble sensors require efficient readout of the spin state, which optical fluorescence readout fails to provide. I will survey the state of the art in both techniques, and will present unconventional solutions to these challenges that my laboratory has recently put forward. For scanning probe imaging, we have developed a scheme that can approach an extended planar diamond into nanometer-scale proximity to a sample, and hence enables scanning probe microscopy in a simplified setup with a commercial diamond substrate rather than a custom nanofabricated tip. For ensemble sensors, we have put forward a novel scheme to read out the spin state of NV center ensembles by integration into a microwave resonator, which promises to solve several subtle problems of optical readout.
Bio: Friedemann Reinhard is heading the quantum technology research group at the Institute of Physics and the Interdisciplinary Faculty of the University of Rostock [1]. His laboratory is working on nanoscale magnetic resonance spectroscopy using NV centers in diamond, biosensing, and scanning-probe imaging. Prior to this position, he has been running an independent Emmy Noether research group at the Technical University of Munich, following an extended postdoctoral stay at the University of Stuttgart. He obtained a PhD from Université Pierre et Marie Curie Paris in 2009, and a diploma in physics from the Georg-August-Universität Göttingen in 2005.
[1] https://www.qt.physik.uni-rostock.de/en/

Professor Paola Cappellaro, ***MIT***
"Design and control of quantum devices"

Bio: Prof. Cappellaro is the Ford Professor of Engineering at the Massachusetts Institute of Technology. She is a professor of Nuclear Science and Engineering, a Professor of Physics, and a member of the Research Lab for Electronics, where she leads the Quantum Engineering Group.
Prof. Cappellaro received her Ph.D from MIT and then joined Harvard University as a postdoctoral associate in the Institute for Theoretical Atomic, Molecular and Optical Physics, before going back to MIT as a faculty.
The goals of Cappellaro's research are to design and control quantum devices for quantum simulations, computation, and quantum sensing. She combines theoretical insight into the dynamics of spin qubit systems and expertise in their experimental control to tackle outstanding challenges in developing robust and scalable quantum devices. With collaborators, she pioneered quantum magnetic sensing using electronic spin defects in diamond (the Nitrogen-Vacancy center). Prof. Cappellaro's work has been published in more than 100 peer-reviewed journal articles and has been recognized by several awards, including the Young Investigator Award from the Air Force Office of Scientific Research, the Merkator Fellowship from the German Science Foundation and the APS fellowship.

Dr. Loïc Anderegg, ***Harvard University***
"Laser Cooled Molecules for Quantum Science Applications"

Abstract: Ultracold molecules offer a diverse array of potential applications ranging from fundamental physics to quantum simulation and computation. Motivated by potential discoveries in these areas, significant advances in controlling molecules at the single-quantum-state level have occurred over the past decade. Recently, molecules have been loaded into optical tweezer arrays allowing both high-fidelity readout and quantum control of individual molecules. In this talk, we will discuss creating and employing optical tweezer arrays of diatomic (CaF) and polyatomic (CaOH) molecules to unlock new quantum science applications. We demonstrate second scale coherence times for molecular qubits in optical tweezer traps, parametrizing the potential performance of polar-molecule-based quantum simulators or computers. Additionally, we show progress towards realizing the goal of high-fidelity molecular qubits by demonstrating dipolar interactions and entanglement between molecules. Finally, we extend quantum control techniques to polyatomic molecules. The complexity added by these molecules leads to powerful new scientific avenues, promising significant improvements to searches for physics beyond the Standard Model and new opportunities in quantum simulation.
Bio: Loïc Anderegg received his BA from UC Berkeley in 2014 and his PhD from Harvard University in 2019 where he worked on new methods of laser cooling and trapping of molecules. He continued working with laser cooled molecules as a Harvard Quantum Initiative postdoctoral fellow and is currently a research associate in the group of John Doyle.

Mr. Jason J Hyon, ***Jet propulsion Laboratory, California Institute of Technology***
"JPL Space Quantum Innovation Center"

Abstract: As JPL is the only center to implement quantum sensors in space at NASA and wants to promote collaborations with various NASA centers, universities, and industry for enabling science, JPL has formed the center to address future needs for NASA. It focuses on two aspects: a coordination of technology maturation, and education and training of workforce with universities. I will discuss the charter and approach to manage the center, and how others can partner with JPL.
Bio: Jason J. Hyon has been Chief Technologist for Earth Science and Technology Directorate at Jet Propulsion Laboratory in Pasadena, California since 2003. He is also a director of JPL Quantum Center; he leads JPL's quantum initiative. In this position, he developed a strategic plan for technology development, managed investment in capturing opportunities, conducted numerous NASA technical workshops, and managed advancing technologies for NASA Earth science. During the past 39 years at JPL, he has managed ground data system developments for NASA Earth science missions and developed technologies for remote sensing. His interests include microwave sensing; lidar and quantum devices; real time system development; data distribution and archival mass storage system design; AI/ML based knowledge and information generation. He has published many papers and received NASA Outstanding Leadership

Medal, NASA Exceptional Achievement Medal, and 4 JPL Magellan awards. He has received ABA in Physics and Mathematics from Occidental College, and Minor in EE from Caltech, and MS in Electrical Engineering from USC in 1986.

Professor Mansour Shayegan, ***Princeton University***
"Non-Abelian Fractional Quantum Hall States for Topological Quantum Computing"

Abstract: Two-dimensional (2D) carrier systems confined to modulation-doped semiconductor hetero-structures provide a nearly ideal testing ground for exploring new phases of matter and their physical properties. In this presentation, I will discuss some of these phases, with an emphasis on new *even-denominator* fractional quantum Hall states, which are likely to be non-Abelian and be of potential use in topological quantum computing. These states are observed only in the "cleanest" 2D systems, with the least imperfections. At Princeton we have had very recent breakthroughs in the fabrication of GaAs quantum wells via molecular beam epitaxy, which allows layer-by-layer growth of pristine GaAs/AlGaAs with extremely few residual impurities (less than one residual impurity for every 10 billion Ga/Al/As atoms). I will present our latest achievements in the fabrication of samples with world-record high quality as well as their exciting physics.
Bio: Mansour Shayegan received his B.S., M.S., and Ph.D. degrees in Electrical Engineering and Computer Science from the Massachusetts Institute of Technology. Since 1985 he has been a faculty member in the Department of Electrical Engineering at Princeton University where he teaches physics and electrical engineering courses. Shayegan's research is in solid state physics with an emphasis on the fabrication of low-dimensional semiconductor structures and measurements of their electronic properties and collective phenomena. Shayegan has won numerous awards, including an Alfred P. Sloan Fellowship, an NSF Presidential Young Investigator Award, an IBM Faculty Development Award, an Alexander von Humboldt Prize, a Fulbright Fellowship, and a Princeton University Graduate Student Mentoring Award. He is an elected Fellow of the American Physical Society.

Mr. Andrew Phillip Conrad, ***University of Illinois, Urbana-Champaign***
"Vehicle-to-Vehicle Quantum Key Distribution (V2V-QKD)"

Abstract: Secure communication is required for future smart infrastructure networks including Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) links. Quantum approaches, such as Quantum Key Distribution (QKD), can offer performance advantages over classical techniques; however, significant engineering challenges exist for deploying quantum systems on moving vehicles. For instance, quantum links require establishing a free-space optical link between moving cars necessitating active Pointing, Acquisition, and Tracking (PAT) stabilization. Additionally, the quantum transmitter and receiver systems must operate using limited Size, Weight, and Power (SWaP), and perform over a potentially large temperature and vibration environments. Moreover, if QKD links for moving cars could be created, they are expected to be transient in nature – being established for limited time – which would make overcoming QKD finite key effects challenging. In this talk, I will discuss our demonstration of the first-known V2V-QKD link between two moving cars. Our system operates between two vehicles both at low-speeds (5 mph) and at high-speeds (70 mph) on a public U.S. Interstate Highway, achieving secure key rates in the finite-key regime at both speeds.
Bio: Mr. Andrew Conrad is an Electrical Engineering PhD student at the University of Illinois Urbana-Champaign, under the supervision of Prof. Paul Kwiat. Mr. Conrad is a National Defense Science and Engineering Graduate (NDSEG) Fellow. His research interests include drone and vehicle-based Quantum Communications including Quantum Key Distribution (QKD), Entanglement Distribution, Quantum Position Verification (QPV), and remote Quantum Sensing. For his PhD research, he has earned the Paul D. Colemen Outstanding Research Award and the Scott Anderson Award in Physics. Mr. Conrad has B.S. and M.S. Degrees in Electrical Engineering, both from the Missouri University of Science and Technology (Missouri S&T), where he was a member of the Missouri S&T Electromagnetic Compatibility (EMC) Lab. Mr. Conrad has experience working as a student intern at the National Geospatial-Intelligence Agency (NGA), U.S. Naval Air Warfare Center Aircraft Division (NAWCAD), and as a Design Engineer in the U.S. defense industry. He is a licensed Professional Engineer (PE) in the State of Florida, is a member of Tau Beta Pi, Eta Kappa Nu, and IEEE Senior Member.

Journal of Autonomous Vehicles and Systems

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• Cryptography
• Teleportation
• Network and distributed sensing, etc. which can potentially be used as enablers of novel guidance, dynamics, control, estimation, and system identification of enhanced autonomous systems

<u>Publication Target Dates TBA</u>

Editors: Dr. Marco B. Quadrelli, JPL, Caltech; Dr. Farbod Khoshnoud, California State Polytechnic University, Pomona and CAST, Caltech; Dr. David Gorsich, U.S. Army; Prof. Vladimir Vantsevich, Worcester Polytechnic Institute. Contact: Dr. Farbod Khoshnoud farbodk@caltech.edu

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