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Virtual & in-person

25 May, 2023

Registeration link

Quantum Engineering

Workshop

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

Supported by JAVS, ASME, and CAST, Caltech

25 May, 2023, A 1-day free hybrid workshop

Pushing the engineering boundaries beyond existing techniques, supported by the Journal of Autonomous Vehicles and Systems (JAVS), American Society for Mechanical Engineers (ASME)

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Passcode: 939426; **Webinar ID**: 882 5070 7370

8:25 am - 8:30 am (PST) - Opening welcome

Distinguished speakers:

8:30 am - 9:15 am

Prof. Paolo Villoresi, *University of Padova*

"The Space frontier for the quantum communications**"**

9:30 am - 10:30 am

Professor Ivan Deutsch, *University of New Mexico*

"Quantum Computing with Neutral Atoms"

10:30 am - 11:00 am Break

11:00 am - 11:30 am

Professor Mohammad Hafezi, *University of Maryland*

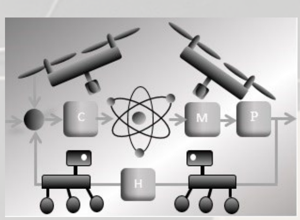
"Many-body quantum optoelectronics"

11:30 am - 12:00 am

Dr. Scott Cushing, *Caltech*

"Exploration of How Entangled Photons Could Change Spectroscopy**"**

12:00 pm - 1:00 pm Break



1:00 pm - 1:30 pm

Dr. Hilary M. Hurst, *San José State University*

"Quantum State Engineering through Weak Measurement"

1:30 pm - 2:00 pm

Dr. Tongcang Li, *Purdue University*

"Quantum Sensing and Photonics"

2:00 pm - 2:30 pm

Dr. Chitraleema Chakraborty, *University of Delaware*

"Flatland Quantum Materials"

2:30 pm - 3:00 pm Break

3:00 pm - 3:30 pm

Andrew Phillip Conrad, *University of Illinois, Urbana-Champaign*

"Quantum Communication Links between Mobile Platforms"

3:30 pm - 4:00 pm;

Chris Cantwell, *Quantum Realm Games*

"Quantum games"

4:00 pm - 4:45 pm

Dr. Marco Quadrelli, JPL, *Caltech*

"Further Explorations at the Intersection between Space Robotics and Quantum Technology"

4:45 pm - 5:30 pm

Q&A and discussions

Professor Paolo Villoresi, University of Padova

QuantumFuture Research Group, Padua Quantum Technologies Research Center, Department of Information Engineering

Paolo Villoresi is a Full Professor of Physics and Director of the Padua Quantum Technologies Research Center, both at the University of Padova. He studied Physics and Applied Mathematics at University of Padova, where he is permanent faculty since 1994. He proposed in 2002 and then realized the first single photon exchange with a satellite using the ASI-MLRO telescope in Matera. He founded a research group on Quantum Communication (QC) and Quantum Optics, that demonstrated the first QC in Space using orbiting retroreflectors, adopting polarization and temporal modes. His group also have shown the first use of OAM modes in QC, the generation of random numbers using DV and CV quantum processes at tens of Gbps, the study and mitigation of turbulence in free-space QC in the Canary Island links, as well the implementation of novel QKD protocols and of fundamental tests of Quantum Mechanics both in Space and in the Lab. The daylight free-space quantum QKD using integrated photonics circuits as well as QKD inter-modal networking are among QuantumFuture recent results. His past research topics include the Atomic Physics in the attosecond domain, multiphoton ionization, ultrafast optics in extreme ultraviolet and X-rays, often exploiting adaptive optics, exploiting also his 12 industrial patents and patent applications. He is also the founder and President of ThinkQuantum, a spinoff of University of Padova introducing advanced QKD technologies for Space and ground networs. He is a Fellow of Istituto Veneto di Scienze Lettere e Arti.

Title of the talk:

The Space frontier for the quantum communications

Abstract:

As of today, QKD is the most advanced quantum technology, based on the sharing of single photons. QKD has now both a solid theoretical framework and widespread experimental implementation, even for commercial purposes, as the major European project OpenQKD has demonstrated QKD testbeds across Europe.The QKD extension to space is also envisaged in the European roadmap as well as in the ones of different continents. The addressing of the effective complementarity between ground and Space imposes challenging requirements to the space QC technology, mainly photonics, in particular where the high rate of key, the all-day availability and the long service time of operation are asked for the secure communications payloads.In this talk I'll provide insight in the main scientific results and the technologies addressing the reduction of the qubit preparation errors, aiming at the realization of transmitter for high efficiency key-rate and the daylight QKD along free-space links.

Journal of Autonomous Vehicles and Systems (JAVS)

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Professor Ivan Deutsch, University of New Mexico

Ivan Deutsch is Regents' Professor of Physics & Astronomy at the University of New Mexico and the Director of the Center for Quantum Information and Control (CQuIC), one of the longest standing centers for Quantum Information Science. He received his BS from MIT in 1987 and his PhD from UC Berkeley in 1992. After a short postdoc at France Telecom and a postdoc with Bill Phillips at the National Institute for Standards and Technology, he joined the faculty at the University of New Mexico in 1995, where, together with Carl Caves, he established CQuIC. His research interests lie at the intersection of quantum optics, atomic-molecular-optical physics, and quantum information theory, with expertise in quantum control, measurement, and open quantum systems.

Title of the talk:

Quantum Computing with Neutral Atoms

Abstract:

One of the earliest proposals for scalable quantum computers was to encode qubits in individual optically- trapped, ultracold neutral atoms. Like their more famous cousins, atomic ions, qubits encoded in the energy levels of neutral atoms are all identical, can have long coherence times, and can be controlled with a variety of magneto-optical fields, with tools that build on decades of development for atomic clocks and precision metrology. Unlike with ions, quantum computing architectures have proceeded more slowly, as neutral atoms are harder to trap and they only weakly interact in their ground state. New developments in trapping and laser technology has now opened the door to high-fidelity operation with potentially hundreds to thousands of qubits - neutral atoms are back in the game! In this seminar I will discuss how high-fidelity quantum logic can be implemented through coherent control of superpositions of atoms in ground and highly excited Rydberg states. I will also describe how optimal control can be used to implement a variety of protocols for quantum information processing with neutral atoms, including the performing quantum logic with “qudecimals" (d=10 dimensional systems) encoded in nuclear spins.

Professor Mohammad Hafezi, University of Maryland

Mohammad Hafezi is the Minta Martin Professor with a joint appointment in the Physics and Electrical and Computer Engineering Departments at the University of Maryland and a fellow of the Joint Quantum Institute and Quantum Technology Center. He studied at Sharif University before completing his undergraduate degree at École Polytechnique. He received his Ph.D. in Physics from Harvard University in 2009. His research interests include quantum optics, topological physics, condensed matter, and quantum information sciences. He is the recipient of several awards including the Sloan Fellowship, the Young Investigator Award of the US Naval Research Office, and the Simons Foundation Investigator.

Title of the talk:

Many-body quantum optoelectronics

Abstract:

Given tremendous progress in controlling individual photons and other excitations such as spin, excitonic, phononic in solid-state systems, it is intriguing to explore whether these quantum optical control techniques could pave a radically new way to prepare, detect and manipulate non-local and correlated electronic states. After discussing several broad theoretical schemes, as the first experimental example, we report on optical and electrical tunable Bose-Fermi mixtures in hetero-bilayer systems and the observation of an excitonic Mott insulator. As the second experimental example, we report on the optical manipulation of quantum Hall states in graphene using twisted light. Specifically, we show that, by going beyond the dipole-approximation in light-matter interaction, one can optically manipulate the electronic wave function.

Dr. Scott Cushing, Caltech

Scott Cushing is an Assistant Professor at Caltech with a multidisciplinary background spanning Chemistry, Materials Science, and Physics. His research focuses on the creation of new scientific instrumentation that can translate quantum phenomena to practical devices and applications. The Cushing lab is currently pioneering the use of attosecond x-ray, time-resolved TEM-EELS, and ultrafast beams of entangled photons for a range of microscopy and spectroscopy applications. Scott has been awarded DOE, AFOSR, Rose Hill, Cottrell, W.M. Keck, and ACS related Early Career awards. As of 2022, Scott has published over 60 papers that have been cited over 8,000 times. Scott holds multiple patents, some of which have led to start-up companies.

Title of the talk:

Exploration of How Entangled Photons Could Change Spectroscopy

Abstract*:*

The inherent quantum correlations between entangled photons can lead to intriguing changes in light-matter interactions for spectroscopy. While entanglement has been utilized for over a decade to improve signal to noise ratios and enable correlation measurements like ghost imaging, this talk will cover the less discussed and newer explorations into how entanglement changes photoexcited states and when, or if, this is useful. Predictions of independent temporal and spectral resolutions, linearizing two-photon and other nonlinear interactions, and the creation of non-classical excited states are experimentally tested. We will also discuss the technical advances that we have developed for experimentally feasible entangled photon spectroscopy, including high-brightness and purity sources, as well as progress towards on-chip entangled photon spectrometers.

Dr. Hilary Hurst, San José State University

Dr. Hilary Hurst is an Assistant Professor in the Department of Physics & Astronomy at San José State University. She is a quantum educator and theoretical physics researcher, with broad interests in condensed matter theory and many-body atomic physics. Her research primarily focuses on the theory of quantum noise and quantum measurement and feedback control. In addition to research, Dr. Hurst is passionate about making quantum physics education more accessible and preparing students to work in the growing quantum technology industry. Dr. Hurst is originally from Greeley, Colorado and received her BS in Engineering Physics from the Colorado School of Mines in 2012. She earned a Masters in Applied Mathematics & Theoretical Physics at the University of Cambridge (UK), and received her PhD in theoretical condensed matter physics from the Joint Quantum Institute at the University of Maryland. Following her doctoral work, she was a National Research Council (NRC) Postdoctoral Fellow at NIST in the Quantum Measurement Division. Dr. Hurst joined the faculty of San Jose State University in Fall 2020.

Title of the talk:

Quantum State Engineering through Weak Measurement

Abstract:

The fragility of quantum states continues to present difficulties for the commercialization of quantum technologies. Superposition and entanglement are essential quantum properties which can be easily destroyed, rendering quantum devices useless. Isolating quantum systems from external disturbances has therefore been the primary mode of preserving quantum coherence, but it is difficult to scale to large quantum systems. New modes of harnessing system-environment coupling can enable robust, entangled quantum phases in open systems. Weak measurement is one such route, which enables the extraction of targeted information from a quantum system while minimizing decoherence due to measurement backaction. However, in many-body quantum systems, backaction from weak measurements can have novel effects on wavefunction collapse. I will discuss a theoretical study of continuously measured non-interacting fermions in one dimension. Repeated measurement of on-site occupation number drives the system from the completely delocalized Fermi sea toward a state with well-defined atom number on each site. We find that the spatial measurement resolution---in relation to the Fermi length---strongly affects both the collapse dynamics and the final state. These results indicate that weak measurement may be a powerful tool for state engineering in many-body quantum systems. As time allows, I will provide a brief overview of the interdisciplinary coursework being developed at San José State University to expand access to training in quantum information science and engineering.

Dr. Tongcang Li, Purdue University

Prof. Tongcang Li is an Associate Professor of Physics and Astronomy, and an Associate Professor of Electrical and Computer Engineering at Purdue University. He was just promoted to a Full Professor at Purdue University, effective in 08/2023. He earned his Ph.D. degree from the University of Texas at Austin in 2011, and conducted postdoctoral research at the University of California, Berkeley from 2011-2014. Prof. Li is an expert in quantum sensing and optomechanics. He has won multiple awards, including the NSF CAREER Award in 2016. Prof. Li has published one book and many high-impact papers in Science, Nature Nanotechnology, Nature Physics, Nature Materials, Nature Communications, and other leading journals. His recent work on GHz rotation of an optically levitated nanoparticle was selected as one of the APS Physics "Highlights of the Year" of 2018. His research on on-chip optical levitation with a metalens was included in 30 breakthroughs in "Optics in 2022" by the Optics & Photonics News.

Title of the talk:

Optically addressable spin qubits in 2D materials

Abstract:

Spin defects in solids, such as diamond nitrogen-vacancy centers, have gained widespread use in quantum sensing and quantum networking applications. The recent discovery of spin qubits in hexagonal boron nitride (hBN), a van der Waals (vdW) layered material, offers exciting new opportunities. Owing to its layered structure, hBN can be easily exfoliated and integrated with various materials and nanostructures for in-situ quantum sensing. We have recently created boron vacancy spin defects in hBN using femtosecond laser writing and ion implantation, demonstrated high-contrast plasmon-enhanced spin defects in hBN for quantum sensing [Nano Letters 21, 7708 (2021)], and explored their excited-state spin resonance [Nature Communications, 13, 3233 (2022)]. Furthermore, we achieved optical polarization and coherent control of nuclear spins in hBN at room temperature [Nature Materials 21, 1024 (2022)], which paving the way for manipulating nuclear spins in vdW materials for quantum information science and technology. I will also briefly discuss additional applications of spin defects in 2D materials.

Dr. Chitraleema Chakraborty, University of Delaware

Chitraleema Chakraborty received her Ph.D. in Materials Science from the University of Rochester in 2018. In 2018, she joined the Research Laboratory of Electronics at MIT as a postdoctoral research associate in Quantum Photonics. Following that she joined the Computational Materials Science Group at Harvard University as a postdoctoral fellow. In 2021, she started at the University of Delaware as Assistant professor in Materials Science and Engineering and Physics.

Title of the talk:

Flatland Quantum Materials

Abstract*:*

Quantum degrees of freedom in flatland 2D materials are promising building blocks for quantum information processing, quantum communications, and quantum sensing. Especially quantum emitters in 2D materials, when compared to three-dimensional materials, have the advantage of reduced total internal reflection and easy coupling with interconnects. In this talk, I will share the story of the discovery and control of quantum emitters in two-dimensional materials. The possibility of leveraging van der Waals heterostructure for charging these emitters with a single electron will be discussed. This lays the foundation for optically addressable spin qubits in flatland materials. Further, I will also discuss the possibility of ab-initio prediction, deterministic generation, and integration with photonic devices, which offers a compelling solution to scalable solid-state quantum photonics. Our work opens the frontier of quantum optics in two-dimensional materials with the potential to revolutionize solid-state quantum devices.

Robotic Applications theme:

Andrew Phillip Conrad, University of Illinois, Urbana-Champaign

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, and he has earned the Paul D. Colemen Outstanding Research Award 2022-2023. His research interests include drone-based Quantum Communications including Quantum Key Distribution (QKD), Entanglement Distribution, Quantum Position Verification (QPV), and remote Quantum Sensing. 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. His master's thesis investigated detecting the presence of electronics by stimulating their unintended Radio Frequency (RF) emissions. Mr. Conrad has experience working as a student intern at the National Geospatial-Intelligence Agency (NGA), 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.

Title of the talk:

Quantum Communication Links between Mobile Platforms

Abstract*:*

Quantum communication links between mobile nodes can enable secure communication, distributed quantum sensors, and distributed quantum computing. As work progresses developing the future quantum internet, most of the efforts have been concentrated on fixed links, e.g., fiber-optic connections. It is expected that the benefits of future quantum networks will also need to interface with free-space links to extend the coverage to mobile platforms such as cars,

planes, ships, satellites, drones, etc. Imagine a quantum internet that goes where you go. However, free-space quantum communication links have unique challenges over fixed quantum links such as limited size, weight, and power (SWaP) for quantum systems on mobile platforms. In this talk, I will discuss our efforts to realize Quantum Key Distribution (QKD) between flying drones, and between a moving drone and moving car. I will also discuss our recent demonstration of a quantum link between two cars traveling at 70 mph on a U.S. Interstate Highway, which is a first. I will discuss our quantum transmitter and receiver setup including critical subsystems including our compact QKD source which is based on resonant-cavity LEDs, our custom optical system, our novel Pointing, Acquisition, and Tracking (PAT) system, single-photon detectors, FPGA-based time-tagger, and our qubit-based time synchronization algorithm. Finally, I will discuss our next-steps including entanglement distribution between mobile nodes, and entanglement-based Quantum Position Verification (QPV) – which can be used to authenticate the position of mobile platform using the principles of quantum mechanics.

Chris Cantwell, Quantum Realm Games

Chris studied quantum computing, and high performance computing, at the University of Southern California (B.S. Electrical Engineering, B.S. Physics, M.S. Physics). During his studies, Chris came to believe that quantum phenomena seem confusing because people don't consciously interact with it. Chris developed a mathematical framework for the design of quantum games, and built Quantum Chess as a proof of principle. Chris went on to enhance the game to run on Google's quantum computing hardware.

Abstract:

Chris Cantwell will share his experience in engineering the first example in a new genre of games, and what he had to learn along the way. He will discuss his journey, from inspiration, to game design, through the challenges of running on actual quantum hardware. Chris will also discuss how he and his colleagues now apply their knowledge to other projects: from designing an open source library with a low barrier to entry, to consulting for corporate quantum workforce upskilling in areas like finance.

Dr. Marco Quadrelli, JPL, Caltech

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, and precision pointing for optical systems. His current research interests are in the areas of multi-domain, multi-physics, multi-body, multi-scale physics-based 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.

Title of the talk:

Further Explorations at the Intersection between Robotic Space Exploration and Quantum Technology

Abstract:

In this talk, Dr. Quadrelli will present an overview of robotic systems for planetary exploration being developed at JPL, the trends driving the current developments in planetary robotics, some of the technical challenges involved, recent progress with his collaborators, and some of his personal thoughts on possible applications of quantum-related technologies in this area.

Organizers:

Organizer: Dr. Marco Quadrelli, JPL, Caltech

Organizer: Dr. Farbod Khoshnoud

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, Riverside. 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.

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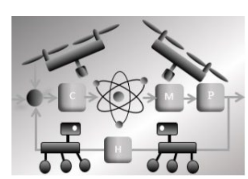

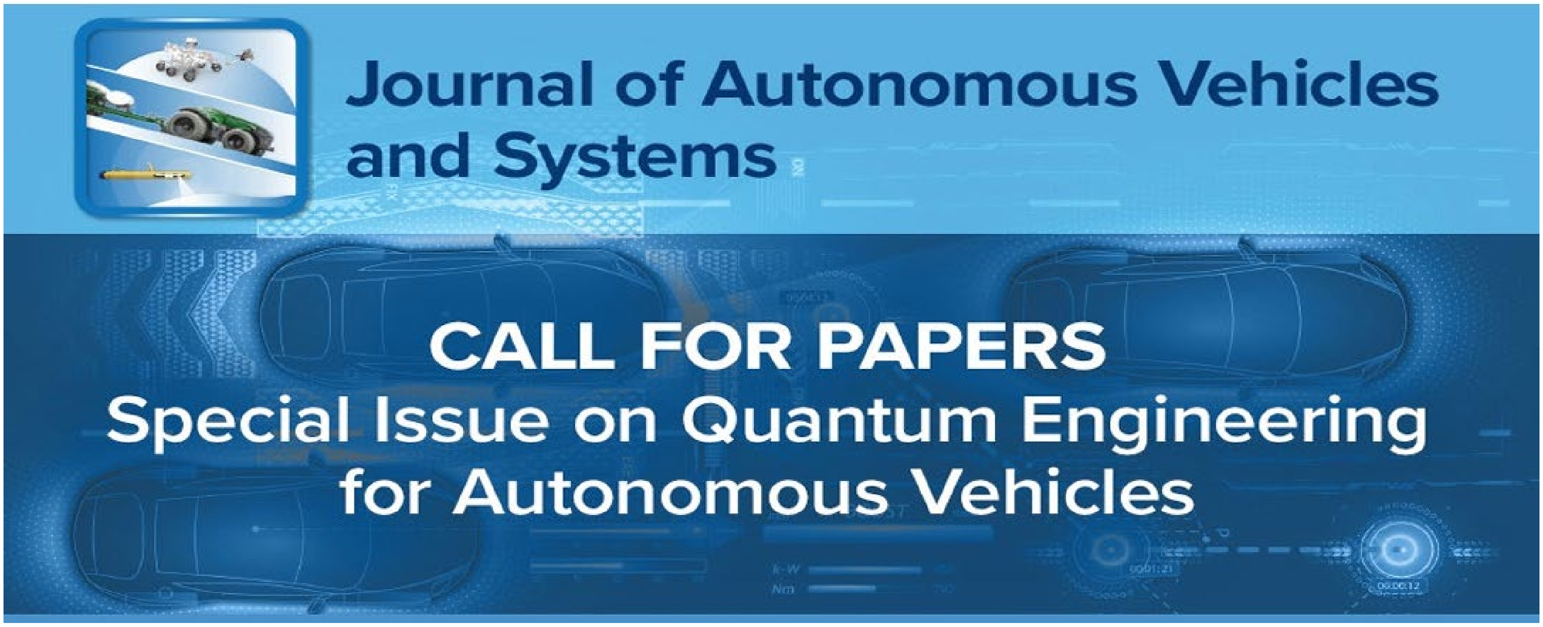

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- Quantum games
- Quantum communication
- Cryptography
- Teleportation
- Network and distributed sensing, etc. which can potentially be used as enablers of novel guidance, dynamics, control, estimation, and system identification of enhanced autonomous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

Publication Target Dates

Paper submission deadline August 15, 2023
Initial review completed November 3, 2023
Special Issue publication date January 2024
Submission Link

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