PRACQSYS 2008

The Principles and Applications of Control in Quantum Systems

Abstracts

Sean Barrett
Professor of Physics and Engineering, Yale University

Controlling Coherence Using the Internal Structure of Hard Pi Pulses

Pulses are a fundamental tool used broadly throughout magnetic resonance (NMR, MRI, ESR), in atomic physics, and more recently in quantum information processing. In this talk, we show how the tiny difference between hard Pi pulses and their delta-function approximation can be exploited as a new resource to control coherence, enabling novel classes of spin echoes with promising applications in NMR, MRI of solids, and beyond.

Lorenza Viola
Associate Professor of Physics, Dartmouth University

Dynamically error-corrected gates for accurate quantum control and computation

Achieving accurate control over quantum dynamics is a long-sought goal in a variety of quantum physics, chemistry, and engineering settings as well as in quantum information processing applications. Scalable quantum computation in realistic devices, in particular, requires that precise control can be implemented efficiently in the presence of decoherence and operational errors. In this talk, I will present a constructive procedure for designing robust unitary gates on an open quantum system without encoding or measurement overhead. Our results allow for a low-level error correction strategy solely based on Hamiltonian control under realistic constraints and may prove instrumental to reduce implementation requirements for fault-tolerant quantum computing architectures. Illustrative examples will be discussed throughout.

Navin Khaneja
Gordon McKay Professor of Electrical Engineering, Harvard University

Seth Merkel
Ph.D student, University of New Mexico

Control and Measurement of Hyperfine Spins with Coherent Electromagnetic Fields

With long coherence times and well characterized control fields from the ``Quantum Optics Toolbox", cold neutral atoms provide a useful platform in which to explore methods and techniques from quantum control. We study the use of coherent electromagnetic fields to control and measure cold neutral atoms in their electronic ground state. In ^{133}Cs, the two hyperfine manifolds comprise a sixteen dimensional state space that we can manipulate with rf magnetic fields and microwaves. Additionally, we can perform polarization spectroscopy of the hyperfine spins using a laser far detuned from the excited electronic states in order to generate a continuous measurement signal. We look at three problems in this talk: state preparation, unitary synthesis from state preparation, and density matrix reconstruction from a continuous measurement record generated by a single random unitary matrix.

Anne E.B. Nielsen
PhD student, Department of Physics and Astronomy, University of Aarhus, Denmark.

Time evolution of the state of atomic systems subjected to measurements

Probing of the state of an atomic system can be achieved by allowing the system to interact with a light field, which is subsequently subjected to measurements. Due to the back action of the measurements, the time evolution of the state of the system is governed by a stochastic master equation, and here we consider a setup, where the system is enclosed in a cavity, and demonstrate how this equation can be derived directly from the physical interactions. As an application of the stochastic master equation we consider preparation of atomic spin squeezed states and compare the performance of a setup, which includes a cavity, and a setup, where the light field traverses the atoms only once.

Yanbei Chen
Assistant Professor of Physics, California Institute of Technology
Quantum Control in Gravitational-Wave Detectors
I will discuss how optimal feedback control can be used to prepare test-mass quantum state in gravitational-wave detectors, when the interferometer's sensitivity surpasses the Standard Quantum Limit.

John Gough
Professor of Mathematics and Director of Teaching & Learning, Institute of Mathematics and Physics, Aberystwyth University
Quantum Feedback Networks
We introduce the general theory of quantum feedback in networks of input-output systems and describe the architecture of such networks including instances of cascading, feedforward, feedback, and beam-splitter loops. The underlying physics is explained, as well as specific examples and applications to coherent control.

Hideo Mabuchi
Professor of Applied Physics, Stanford University
Experimental coherent-feedback quantum control: opportunities and challenges
I will discuss some promising candidate systems for experimental realization of coherent-feedback quantum control, focusing on practical advantages over measurement-feedback as well as practical obstacles to implementation.

Steffen Glaser
Professor of Chemistry, Technical University of Munich

Ian Walmsley
Professor of Experimental Physics and Head of Atomic and Laser Physics, University of Oxford
Coherent control of decoherence
Coherent control of quantum systems uses the constructive or destructive interference between pathways to manipulate the evolution of the system. The success of any coherent manipulation of the dynamics depends on maintaining the quantum phase relationships between the different parts of the system. The inevitable interaction of any real system with its environment will corrupt the unitary evolution and prevent the coherent control from reaching its objective. We present recent results on the application of closed loop control methods to mitigate the effects of the environment on coherent superposition states, and show experimentally that a coherence surrogate may be effective for identifying the states of the system least sensitive to dephasing. Further we show how a complete map for the system dynamics may be constructed with a small dataset, based on a minimal prior assumption about the system-reservoir coupling.

Hendra Nurdin
Research Fellow, Department of Engineering, Australian National University
Network synthesis of linear dynamical quantum stochastic systems
In this talk I will describe recent joint work (with M. R. James and A. C. Doherty) on a network synthesis theory for linear dynamical quantum stochastic systems that are encountered in linear quantum optics and in phenomenological models of linear quantum circuits. In particular, such a theory will enable the systematic realization of coherent/fully quantum linear stochastic controllers for quantum control, amongst other potential applications. I will show how general linear dynamical quantum stochastic systems can be constructed by assembling an appropriate interconnection of one degree of freedom open quantum harmonic oscillators and, in the quantum optics setting, discuss how such a network of oscillators can, in principle, be approximately synthesized and implemented in a systematic way from some linear and nonlinear quantum optical elements. An example will be provided to illustrate the theory.

Masahiro Yanagisawa
Research Fellow, The Australian National University

Dan Stamper-Kurn
Professor of Physics, University of California, Berkeley
Quantum cavity micro-mechanics with ultracold atoms
I will discuss a new offshoot of ultracold atomic physics in which we address the problem of quantum opto-mechanics, i.e. studies of the quantum motion of macroscopic objects using optical probes and the associated aspects of quantum metrology, using a gas of ultracold

atoms within a high finesse optical resonator. Experimental observations of opto-mechanical bistability and of measurement backaction on a macroscopic variable will be presented.

Michael G. Raymer
Knight Professor of Liberal Arts and Sciences and Professor of Physics

Photon Wave Mechanics and Spin-Orbit Interaction in Single Photons

We often use the term "photon" in reference to individual quantum objects, or particles of light, rather than as excitations of the electromagnetic field. Yet, quantum mechanics textbooks contain no satisfactory wave equation for the photon wave function. I review the analog of the Dirac equation for a photon, which completely describes the evolution of the photon's quantum wave function in coordinate space.

Single photons carry orbital angular momentum as well as spin angular momentum. When a single photon travels in a multimode optical fiber, its spin and orbital angular momenta interact, modifying the shape of the photon wave function as it travels. Close analogy of this behavior can be found with that of an electron in a cylindrical potential, in spite of the fact that a photon has no magnetic moment.

We are carrying out related experiments to illustrate the usefulness of the photon wave function concept.

Haidong Yuan
Postdoctoral Associate, Massachusetts Institute of Technology

Howard Wiseman
Director, Centre for Quantum Dynamics at Griffith University

What is quantum about quantum trajectories?

Quantum trajectory equations are stochastic equations for the state of an open quantum system conditioned on a monitoring i.e. a continous-in-time measurement of a bath to which it is coupled. They are closely related to classical stochastic equations for classical probability distributions called filtering equations (e.g. the Kalman filter) and indeed are also called quantum filtering equations. Given this close relation, the question arises: what is quantum about quantum trajectories? In this talk I suggest that the answer lies in the ability of an experimenter to choose different monitoring schemes. Moreover, I propose that there is an experimental way to distinguish between cases where this choice does demonstrate the quantum nature of the noise to be demonstrated, and those where it does not, making use of the concepts in the recent work: H. M. Wiseman, S. J. Jones, and A. C. Doherty, "Steering, Entanglement, Nonlocality, and the EPR Paradox", Phys. Rev. Lett. 98, 140402 (2007).

Ian Petersen
Scientia Professor, University of New South Wales

Coherent H infinity control for a class of linear complex quantum systems

This paper considers a coherent H infinity control problem for a class of linear quantum systems which can be defined by complex quantum stochastic differential equations in terms of annihilator operators only. For this class of quantum systems, a solution to the H infinity control problem can be obtained in terms of a pair of complex Riccati equations. The paper also considers complex versions of the Bounded Real Lemma, the Strict Bounded Real Lemma and the Lossless Bounded Real Lemma. For the class of quantum systems under consideration, the question of physical realizability is related to the Bounded Real and Lossless Bounded Real properties.