White Paper

Quantum Hybrid Control: Increasing Efficiency of Silicon Systems with Active Control Lowering Dissipation and Improving Coherence

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Non-Technical Overview

Most advanced business, industry, and military systems are only successful today because they employ feedback control. This twentieth-century technology was propelled to the engineering spotlight by the invention of the feedback amplifier. With this technology, industry and the military had a systematic approach for the design and testing of macroscopic controllers which are supposed to force macroscopic systems to exhibit desired macroscopic behavior. The feedback signal for such systems is computed based on sensor measurements of macroscopic system-state observables such as pressure, temperature, velocity, current and voltage. Macroscopic deviations from desired system behavior are then used to drive the system to meet its performance specifications.

In the last sixty years, materials science developments grounded in quantum mechanics have made possible our computer age. It is now routine, although very expensive, to implement massive networks of nanoscale devices on single chips. This technology has spilled over from computer applications to embedded control of physical devices, scientific chips for DNA analysis, genomics, and other applications.

However, no *systematic* procedures currently exist for constructing quantum-level feedback control for quantum systems analogous to the conventional, i.e., macroscopic, feedback control theory briefly summarized above. The few known cases of nanoscopic control either are feed-forward or are specific feedback controls for nanoscopic processes using nanoscopic sensor readings. The current design technology for such devices is largely an *ad hoc* application of quantum mechanics specific to each problem, relying on ideas codified in the current quantum measurement community. Some prominent quantum optics systems work by what can be viewed as feed-forward control, by preparing a cavity with specific resonance characteristics for producing laser and similar beams. Qubits and quantum motors are among the few existing examples of quantum feedback control.

Proposed NIST RFP

The ‘Grand Challenge’ we propose that NIST address: The development of a toolbox for the design of quantum controllers for the quantum subprocesses inherent in the macroscopic processes described above (processes which force desired macroscopic model behavior based on macroscopic observables). With such a toolbox it becomes possible to attack in new ways the problems of dissipation and decoherence which reduce the efficiency and even feasibility of the following products of unquestioned national importance and urgency:

- Solar-to-electrical energy conversion
- Magnetic batteries
- Non-self-destructing laser cannons
- Quantum feedback controllers for chemical and biological process control
- Quantum feedback controllers minimizing dissipation and managing decoherence in optical and electrical systems
- Quantum feedback controllers altering the structural characteristics of semiconductor materials, e.g., converting cheap silicon crystals into a functionally equivalent high performance substitute for gallium arsenide.
- Controlled metamaterials, as opposed to engineered metamaterials. These are artificial materials that have negative refraction coefficient. They have applications in antenna systems, and in the production of cell phones with very low dissipation and high noise rejection.

We suggest that the RFP concentrate on active quantum level control of solar-to-electrical energy conversion because it is universally acknowledged that a substantial increase in efficiency here meets two vital national needs: to decrease dependence on foreign and domestic gas and fossil fuels, and to decrease contributions to global warming.

Natural photosynthesis can be viewed as a solution to the control problem of transforming photonic energy from sunlight to ATP by passing it through an active filter ("semipermeable membrane"), with a controller that ensures that most of the energy does not pass back through the filter, but remains to be processed with available chemical ingredients into the storage medium ATP. This is a hybrid macroscopic-quantum system with quantum level controllers structured so as to satisfy macroscopic constraints, such as being sufficiently phase coherent or not running too hot, enabling the plant to survive and the system to work. Fundamental quantum mechanics says that natural photosynthesis is nowhere near the theoretical limits in efficiency of solar energy conversion. Solar energy conversion in silicon today is also nowhere near the theoretical limits in efficiency indicated by quantum mechanics. The importance of this as a paradigmatic problem is shown by the world-wide research efforts to improve on photosynthesis; however, these do not involve active quantum control.

We would like NIST to issue an RFP for a Quantum Control toolbox for

1) Developing integrated macroscopic-quantum models;

2) Extracting quantum control algorithms;

3) Developing proof of concept for active feedback control of solar to electrical conversion through Monte Carlo or other simulations;

4) Verifying that current lithographic and chip fabrication technology are sufficiently advanced to support manufacture of silicon devices with acceptable yield.

Proposals should have available expertise in the technical areas above, should have business and research management experience, and should incorporate a post-contract plan for the manufacturability of commercially viable products meeting these perceived national needs.

Detailed Amplification of the RFP goals

To design and build a toolbox and a hardware implementation:

1) For producing integrated models of macrosystems and their quantum subsystems;

2) For extracting and implementing feedback control for such integrated models.

Recognizing that the principal limitation on efficiency and manufacturability of efficient quantum systems on silicon or any other substrate is loss due to dissipation and decoherence, the toolbox should include functionalities:

3) For manufacturing chips with behavior shaped by active feedback control;

4) For active feedback control of quantum processes to decrease dissipation and decoherence of hybrid quantum systems closer to their theoretical limits;

5) For design and Monte Carlo simulation of an efficient actively controlled artificial photosynthesis on silicon.

Finally, the development process should make a preliminary investigation of the commercial feasibility of other targets of opportunity which meet vital national needs.

End of White Paper

Appendix
Quantum Hybrid Control

To state a ‘Grand Challenge’ problem that transcends the limits of all published technologies without indicating why we believe that current solutions are feasible would be disingenuous. We believe the applications bulleted above are within current reach using the newly-developed Kohn-Nerode Quantum Hybrid Control (QHC) theory. This theory stems from two sources. One is Kohn-Nerode's joint twenty years’ experience in the theory and product development of specific (macroscopic) Hybrid Systems. The other is Kohn's 40-year background in quantum dynamics, starting with his MIT PhD thesis titled “Distributed Hierarchical Automata,” which led to the formulation and architectural specification of a quantum wave processor that introduced the idea of Quantum Hybrid Control. In the 1970's, chip and quantum mechanics technology was too primitive to carry this further. This is no longer the case.

Hybrid Systems was based on approximate measure-valued optimal control implemented by digital controllers. Kohn and Nerode then extended these results by creating a corresponding quantum-mechanically based hybrid macroscopic-quantum level control technology (QHC) for solving problems—such as efficient artificial photosynthesis on a chip—which of necessity involve using macroscopic measurements to control quantum processes. Before this current work, there has been no systematic procedure for constructing quantum level feedback control for quantum systems analogous to conventional (macroscopic) feedback control theory.

The long-term intention, then, is to persuade NIST that its interest and support can wed our approach, and any other approaches to quantum hybrid control (QHC) algorithms, with chip manufacturing technology, to meet the outstanding critical national needs listed above.