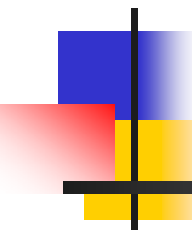


Resent Researches on Quantum Systems Controls based on Lyapunov methods in USTC



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Concepts of Systems Controls

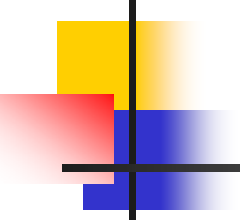
- To design an automatic control system by means of some system control theory and realize it
- Be belong to the area of Electric and Electronic Engineering (EEE)
- Department of Automation (or automatic control)

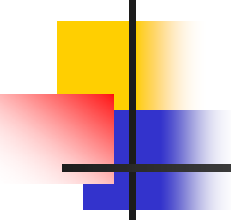
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- All of the system control theories have the same principal, that is:

Negative feedback principle

- It is also called:

The automatic control principle

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- The feedback control system is a closed-loop control system
 - There are two kinds of control systems: open-loop control system and closed-loop control system
 - Open-loop control system can be used in the simple controlled system with lower accuracy and robustness to the noise and disturbance or parameter uncertainty

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- The variable of a feedback control system is always the error between the desired state and output state of the control system
 - The control aim is always to make the error tend to a small value or zero which can be guaranteed if the control system is stable or convergent, and the control aim can be achieved automatically.



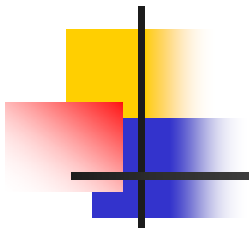
System Control Theories(1)

- Optimal control theory
- Adaptive control theory
- Lyapunov stability theorem (Lyapunov-based control method)
- Proportional, Integral and Derivative (P-I-D) Control
- Variable Structure Control (or Sliding Mode Control)



System Control Theories(2)

- Bang-Bang Control
- Robust Control
- Non-linear Control Theory
- Repetitive Control
- Recurrent Neural Network Control
- Fuzzy Logic Control
- ...

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- Optimal control methods are the most popular approaches that have been widely used specially in quantum chemistry fields.
 - Since the mid 1980s, the quantum optimal control theory has attracted attentions from many researchers.



Lyapunov-based control method

- The Lyapunov indirect stability theorem which is used to judge whether a control system is stable or not without necessary of solving the (partial) differential equation
- People use this theorem to design a control law in the situation that the control system is surely stable



The Lyapunov indirect stability theorem

- For a given dynamical system

$$\dot{x}(t) = f(x)$$

- If one can find a scalar function $V(x)$ has
 $V(x) \geq 0$, for $x \geq 0$

- At the same time there exists

$$\dot{V}(x) < 0 \quad \text{or} \quad \dot{V}(x) \leq 0$$

- Then this system is asymptotically stable (or stable)

The Procedure of Control law design

- For a control system

$$\dot{x}(t) = f(x) + Bu(x, t)$$

- If one can find a Lyapunov function $V(x)$ such that exists $\dot{V}(u(x, t), x) \leq 0$

- By means of the equation $\dot{V}(u(x, t), x) = 0$ one can obtain the control law

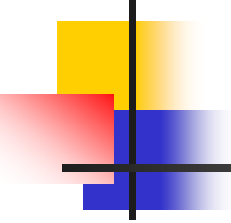
$$u(x, t) = F(x, t)$$



Similarity and difference between the optimal control and Lyapunov-based control

The properties of these two control methods

- **Design procedure:** iterative algorithm to analytical function, or more complex to easier
- **Control strategy:** both are feedback control. The optimal control system is designed by off-line, it is not suitable to the quantum physical control.

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- **Control performance:** global optimal to local optimal (global optimal in the case the Lyapunov function is monotonic in the whole work area)
 - **The convergence:** guarantee (control accuracy depends on the iterative number) to not guarantee (target state can not be achieved especially in quantum control if the Lyapunov function is not monotonic)



Applications

- The most of system control theories developed are based on the mathematical models of controlled systems
- They are universal in some sense.
- They have been applied successfully into the areas including the aeronautics and astronautics



Quantum Control

- eigenstate, superposition state, mixed state, entangled state etc.
- applications such as quantum information, quantum computation, and quantum communication, respectively.
- The transfer of different kinds of states in quantum systems has a important significance.

Some achievements in closed quantum system control

- The preparation and transfer control method design of the different kinds of states :

- 1) Eigenstate transfer
- 2) Superposition states preparation
- 3) Pure state control
- 4) Mixed state transfer
- 5) Purification of mixed state
- 6) Transfer from arbitrary pure state to target mixed state



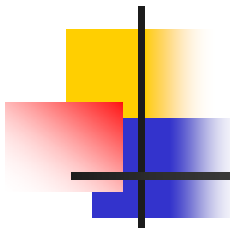
Some research results on open quantum System control (1)

- Design of control sequence of pulses for the population transfer of high dimensional spin $1/2$ quantum systems
- Purity and coherence compensation by using interactions
- Purity preservation of quantum systems by resonant field



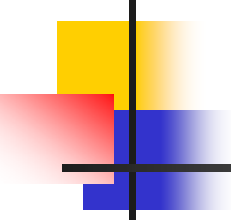
Some research results on open quantum System control (2)

- Phase decoherence suppression in arbitrary n -level atom in Ξ - configuration with Bang-Bang controls
- Preparation of entanglement states in a two-spin system by Lyapunov-based method



The cooperation with the HNLPSM in real quantum device implementation

- Hefei National Laboratory for Physical Sciences at the Microscale in USTC
- Jiangfeng Du, Xing Rong, Nan Zhao, Ya Wang, Jiahui Yang & R. B. Liu, **Preserving electron spin coherence in solids by optimal dynamical decoupling**, Nature, 08470, 29 Oct. 2009

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- 1) Nuclear Magnetic Resonance spectrometer (NMR)
 - 2) Electron Paramagnetic Resonance Spectrometer (EPR), also called Electron Spin Resonance (ESP)
 - 3) Optical Detection of Magnetic Resonance (ODMR)



What we are doing is

- 1) Decoherence Suppression in a Cs (Cesium) $7/2$ molecular with Bang-Bang Controls on NMR
- 2) Coherence Preservation on EPR by means of a new optimized dynamical decoupling strategy proposed



Conclusion

- Study the quantum system models existed
- Develop and propose the quantum control methods and technologies by means of combining them with the quantum system controlled properly
- Apply the proposed system control strategies into the actual experimental devices.

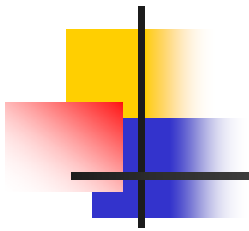


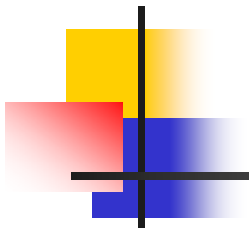
List of the publications

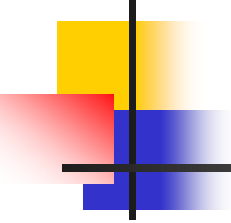
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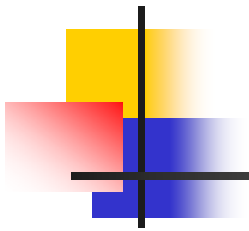
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- 3) Shuang Cong, Yuan-yuan Zhang, Lyapunov-Based Optimal Quantum Pure State Control Strategy, International Conference on Automation, Robotics and Control Systems(ARCS-09), July, 2009, Florida, USA, pp. 89-96
 - 4) Shuang CONG, Yuanyuan ZHANG, Optimal control of mixed-state quantum systems based on Lyapunov method, BIOSIGNALS, ROME, ITALY, Jan. 26-29, 2011, 22-30.

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 - 6) J. WEN, S. CONG, Transfer from Arbitrary Pure State to Target Mixed State for Quantum Systems, the 18th World Congress of the International Federation of Automation Control, Sep. 2011, Milano, Italy.

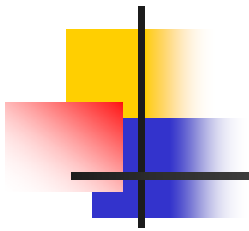
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- 7) Cong Shuang and Lou Yuesheng, Design of control sequence of pulses for the population transfer of high dimensional spin $1/2$ quantum systems, *Journal of Systems Engineering and Electronics*, 2008, 19(6):1226-1234
 - 8) Yuesheng Lou, Shuang Cong, Purity and coherence compensation by using interactions, *Journal of the Graduate of the Chinese of Science*, 2008, 25(5): 687-697

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- 9) Y. S. Lou, S. Cong, and R. X. Xu, Purity Preservation of Quantum Systems by Resonant Field, Proceedings of the 7th Asian Control Conference, Hong Kong, Chian, August 27-29, 2009, pp. 959-963
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 - 12) Fei YANG, Shuang CONG, Preparation of Entanglement States in a Two-spin System by Lyapunov-based Method, Journal of Systems Science and Complexity, to be published



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Thanks