Physical realizability and coherent LQG control of linear quantum systems

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Abstract: A linear quantum system is a special class of quantum system whose dynamics are described by the laws of quantum mechanics where quantum mechanics serves as a platform for comprehending and explaining the workings of the universe at the atomic scale. Control problems in the quantum domain are often more challenging compared to their classical counterparts, primarily due to the additional constraints imposed by quantum mechanics. A linear quantum system generally need not correspond to a physically meaningful system unless it satisfies some additional constraints which then a quantum system will be termed as a physically realizable quantum system. One way to implement a linear time-invariant (LTI) system as a physically realizable system is to include additional quantum vacuum noise channels. The presence of quantum vacuum noise channels in the controller places limits on the performance. Hence it is desirable to minimize the number (or effect) of these noises.

The first part of this talk is to improve current approaches for implementing physically realizable quantum systems. In this context, we present an optimal method to implement a strictly proper LTI system as a physically realizable quantum system. This method focuses on the extent to which the additional quantum noise affects the system output. We also give a necessary and sufficient condition for when a quantum system corresponding to a given LTI controller can be made physically realizable in the presence of both direct feedthrough quantum vacuum noise and additional quantum vacuum noise such that the additional quantum noise does not affect the controller output. Additionally, we give a frequency domain condition to physically realize a given transfer function matrix using only direct feedthrough quantum noise.

Coherent quantum control is a unique feedback control paradigm with no counterpart in classical control systems. Physical realizability and coherent quantum control are closely related concepts since the condition for a quantum controller to be considered coherent is that the controller must be physically realizable. The second part of this talk considers the quantum equalization problem. We have proposed a method to find a physically realizable suboptimal coherent linear quadratic Gaussian (LQG) controller that minimizes a cost function related to the system equalization error. We have implemented a gradient descent approach in searching for an optimal solution for the quantum equalization problem.

Bio: Rebbecca Thien completed her Bachelor's (2016) and Master's (2018) degrees in Mechanical and Aerospace Engineering at Gyeongsang National University, South Korea. She recently completed her PhD in Australian National University in May 2024.

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