Optimal tomography of two-level and generalized Pauli channels

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Abstract

The accurate description of different quantum phenomena is a key issue in their potential use in modern IT-technologies. The parameter estimation of quantum channels plays a major role in quantum information processing. In quantum mechanics, both dynamical changes and communication is treated using quantum channels that are trace preserving completely positive mappings. The Pauli channels form a relatively wide family of quantum channels.

The tomography of Pauli channels has a huge literature but - because of the hardness of the topic - the papers are mostly dealing with special cases. In this paper we present a family of channel estimation methods for quantum bit Pauli channels with unknown channel directions. The efficiency of these estimations is measured with three quantities: the mean squared error of the estimated contraction parameters and angle parameters, and the mean distance of the estimated and the real channel matrix.

The optimization of the different loss functions needs different mathematical techniques. The mean squared error of the estimated contraction parameters and the estimated channel matrix is minimized analytically. In the case of Pauli channels with unknown channel directions this analytical concept is new. The mean squared error of the estimated angle parameters is optimized with numerical methods.

The main result of this work is that we determined the optimal measurement configurations for quantum bit Pauli channels with respect to the most relevant loss functions. For optimally estimating the contraction parameters and the channel matrix we should have input qubits and measurements in the channel directions, however, for optimally estimating the channel directions, we should use different tomography conditions: from simulation investigations and analytical results in special cases we conjecture that using input and measurement directions that are complementary to the channel directions would give a nearly optimal result.

As the first steps of the further investigations we defined the channel directions and the angle parameters for generalized Pauli channels that are given with maximal commutative subalgebras.