Experimentally Realizable Characterizations for Quantum Information Processing

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Before they are actually performed, quantum information processes require three basic measures of fidelity, entanglement, and purity to examine how close the produced state is to the intended state, how much the produced bipartite state is entangled, and how much the prepared state has quantum coherence. In first part of the presentation, we present realizable experimental schemes for the measures for a continuous variable state (CV).(1)

Entanglement has been at the heart of the current development of quantum information processing. Entanglement for CV has attracted interests because it easy to realize such an entangled state by experiment. For example, a non-degenerate parametric amplifier (NOPA), which has become a standard technique to produce a non-classical field, may produce an entangled Gaussian continuous variable state.(2) If two independent input fields onto a beam splitter are appropriately squeezed, the two output fields may be entangled.(3) Even though it has been said that bipartite-mixed states of infinite-dimensional systems are generically inseparable, there has not been a scheme to directly test the entanglement of a CV. Of course, even though a nonclassical fidelity may indicate the quantum correlation of the channel, it is only indirect proof of entanglement. In this presentation we propose an experimentally feasible scheme for direct test of entanglement. Concerning the role of entanglement, we think it is important to be able to tell the entanglement directly from a set of measurements.

Reid and Drummond(4) calculated the transmitted spectrum of fluctuations in the difference between the signal and idler quadrature amplitudes of a NOPA state and found the noise reduction below the quantum limit. They pointed out that such a nonclassical quadrature-phase correlation is a direct consequence of nonlocality. Banaszek and Wodkiewicz(5) proposed a test of nonlocality, which is directly related to the two-mode Q and Wigner functions. Their nonlocality test may be used to any CV even including non-Gaussian mixed states but it does not bear the maximum violation of Bell's inequality for the original Einstein-Podolsky-Rosen state.

A critical problem with any test of nonlocality lies in its observable dependence: Entanglement is only a necessary condition to violate a nonlocality test. For quantum-mechanical nature of correlation inherent in a state, its entanglement has to be tested. Even though the entanglement condition for any CV is still to be unravelled, for a class of CV's there is a well-established entanglement condition, which has been obtained based on Peres-Horodecki criterion of positivity.(6) We find how such the theoretical formula can be realized by experiment using joint homodyne measurements. We also study how robust our scheme is against an imperfect detection efficiency. We think that we can use the homodyne detectors to measure the decoherence of a two-mode field. We find some interesting properties of entanglement for Gaussian fields in various conditions.

In the second part of the presentation, we propose an operational measure of distance, based on the notion of complementary measurement.[7] Mathematical formulations of all the fundamental physical theories are based on the concept of an abstract space. The structure of the space and the theories is characterized in terms of its metric. For example, the Minkowski metric defines the mathematical structure of the special theory of relativity and the Rieman metric defines the structure of the general theory of relativity. What is a natural measure of distance for quantum theory? In particular, two metrics have been applied to the wide realm of quantum information processing: Hilbert-Schmidt distance[8] and Bures metric which corresponds to fidelity.[9] Here, we present an operational measure of distance of two quantum states, which conversely tells us their closeness. This is defined as a sum of differences in partial knowledge over a complete set of mutually complementary measurements for the two states. It is shown that the measure is operationally invariant and it is equivalent to the Hilbert-Schmidt distance. The operational measure of distance provides the remarkable interpretation of the information distance between quantum states, that is deduced from the information content.[10] The operational distance is realizable in experiments. The experimental scheme for the operational distance is closely related with quantum tomography of quantum state.[11]

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