MAR13-2012-000801

Abstract for an Invited Paper
for the MAR13 Meeting of
the American Physical Society

Hybrid quantum information processing

AKIRA FURUSAWA, The University of Tokyo

There are two types of schemes for quantum information processing (QIP). One is based on qubits, and the other is based on continuous variables (CVs), where the computational basis for qubit QIP is $\{|0\rangle, |1\rangle\}$ and that for CV QIP is $\{|x\rangle\}$ $(-\infty < x < \infty)$. A universal gate set for qubit QIP is {'bit flip'σ_x, 'phase flip'σ_z, 'Hadamard gate'H, '$\pi/8$ gate', 'controlled NOT (CNOT) gate'}. Similarly, a universal gate set for CV QIP is {'x-displacement'$\hat{D}(x)$, 'p-displacement'$\hat{D}(ip)$, 'Fourier gate'$\hat{F}$, 'cubic phase gate'$e^{ik\hat{x}^3}$, 'quantum non-demolition (QND) gate'}. There is one-to-one correspondence between them. CV version of 'bit flip'σ_x is 'x-displacement'$\hat{D}(x)$, which changes the value of the computational basis. Similarly, CV version of 'phase flip'σ_z is 'p-displacement'$\hat{D}(ip)$, where 'phase flip'σ_z switches the "value" of 'conjugate basis' of qubit $\{|+\rangle, |-\rangle\}$ $(|\pm\rangle = (|0\rangle \pm |1\rangle)/\sqrt{2})$ and 'p-displacement'$\hat{D}(ip)$ changes the value of CV conjugate basis $\{|p\rangle\}$. 'Hadamard' and 'Fourier' gates transform computational bases to respective conjugate bases. CV version of '$\pi/8$ gate' is a 'cubic phase gate'$e^{ik\hat{x}^3}$, and CV version of CNOT gate is a QND gate. However, the origin of nonlinearity for QIP is totally different, here the very basic nonlinear operation is calculation of multiplication and of course it is the heart of information processing. The nonlinearity of qubit QIP comes from a CNOT gate, while that of CV QIP comes from a cubic phase gate. Since nonlinear operations are harder to realize compared to linear operations, the most difficult operation for qubit is a CNOT gate, while the counter part, a QND gate, is not so difficult. CNOT and QND gates are both entangling gates, it follows that creating entanglement is easier for CV QIP compared to qubit QIP. Here, creating entanglement is the heart of QIP. So, it is a big advantage of CV QIP. On the other hand, the fidelity of CV QIP is not so high because perfect fidelity needs infinite energy, which comes from the infinite dimensionality of CV QIP. To overcome the difficulty, "hybrid" approach is proposed. In this approach, qubits are used as inputs for CV QIP. It is possible because qubits can be regarded as a special case of CVs. So, we can circumvent the infinite dimensionality problem of CV QIP by using qubits as the inputs. The basic example is qubit teleportation with a CV teleporter, where the qubit is a so-called "dual-rail" qubit with a single photon; $c_0|1,0\rangle + c_1|0,1\rangle$. We recently succeeded in creating time-bin qubits with single photons, and now we are working on the teleportation experiment with the technology developed for teleportation of highly nonclassical wave packets of light.