Title:	Novel techniques for efficient quantum state tomography and quantum process tomography and their experimental implementation
Authors:	Gaikwad, Akshay
Keywords:	Tomography Quantum Process Novel Techniques
Issue Date:	Dec-2023
Publisher:	IISER Mohali
Abstract:	The study carried out in this thesis focuses on designing and experimentally imple- menting various quantum tomography protocols to efficiently characterize and recon- struct unknown quantum states and processes using spin ensemble based nuclear mag- netic resonance (NMR) quantum processors and superconducting technology-based IBM quantum processors. The task of reconstructing quantum states is achieved with the help of quantum state tomography (QST) protocols while quantum processes are characterized using quantum process tomography (QPT) protocols. Both QST and QPT are essential to check the reliability and to evaluate the performance of a quan- tum processor. However, both QST and QPT are cursed with a fundamental difficulty, i.e., the computational complexity increases exponentially with the size of the system which makes them infeasible to perform experimentally, even for smaller dimensional systems. Besides this, having finite size of ensembles and inevitable systematic errors will lead to unphysical density matrices and process matrices. To tackle such issues, numerous QST and QPT protocols have been proposed. However, most of them are yet to be experimentally demonstrated. The prime objective of the study undertaken in this thesis is to design experimental strategies to efficiently implement tomography protocols on NMR and IBM quantum processors. Generalized quantum circuits are proposed to efficiently acquire experimental data to perform QST and QPT and further demonstrated for two- and three-qubit quantum states and quantum processes. To tackle the issue of the unphysicality of experimentally reconstructed quantum states and processes using standard tomography techniques, the tasks of QST and QPT are converted into a constrained convex optimization (CCO) problem and the CCO problem is solved to reconstruct valid quantum states and processes which in case of QPT allows us to compute the complete set of Kraus operators corresponding to a given quantum process. Further, the compressed sensing (CS) and artificial neural network (ANN) techniques have also been employed to perform tomography of quan- tum states and gates from a heavily reduced data set as compared to standard meth- ods. CS and ANN based tomography methods are promising techniques to deal with complexity issue to characterize higher-dimensional quantum gates. Moreover, the problem of selective and direct estimation of desired elements of process matrix char- acterizing quantum process has also been explored, where partial knowledge about underlying unknown quantum process can be acquired efficiently using selective and efficient quantum process tomography protocol (SEQPT). A generalized quantum al- gorithm and quantum circuit to perform SEQPT has been proposed and successful experimental demonstration has been shown on NMR and IBM quantum processors. In addition to that, we also proposed an efficient direct QST and QPT scheme based on weak measurement approach and demonstrated experimentally using a three-qubit NMR system. The thesis also investigates the problem of experimentally simulating dynamics of open quantum systems based on dilation techniques. To show the efficacy of above-mentioned quantum tomography and simulation protocols, experimental re- sults are compared with theoretically predicted results in case of several two-and three- qubit quantum systems. The content of this thesis has been divided into eight chapters as described below: Chapter 1 The initial section of this chapter presents an overview of quantum computing and in- formation processing. It encompasses essential principles and the physical realization of quantum processors using NMR. Additionally, it provides a brief introduction to various tomography and simulation protocols. Finally, it concludes with closing re- marks that outline the objectives and motivations behind the research conducted in this thesis. Chapter 2 This chapter focuses on the problem of invalid experimental density and process ma- trices. It introduces the constrained convex optimization (CCO) method for QST and QPT which allow us to reconstruct valid (positive semi-definite) density and process matrices charactering unknown quantum states and processes respectively. It also im- proves the fidelity of density and process matrix characterization. The chapter dis- cusses the NMR quantum information processor-based implementation of QST and QPT using the CCO method. Chapter 3 This chapter addresses scalability issues in QST and QPT by employing the application of compressed sensing (CS) algorithms. The CS algorithm allows for full as well as valid QST and QPT from incomplete data sets, resulting in high fidelity estimates of density and process matrices. The chapter also discusses the characterization of small-dimensional quantum gates in higher-dimensional systems. The experimental viiidemonstration of CS based QST and QPT for 2- and 3-qubit system is given using NMR ensemble quantum processor and superconducting based IBM cloud quantum processor. Chapter 4 This chapter explores the application of artificial neural network (ANN) techniques in QST and QPT to attempt to overcome scalability issues. The Feed-Forward Neural Network (FFNN) architecture is used to reconstruct density and process matrices from noisy experimental data obtained from NMR quantum processor. The results show efficient as well as high fidelity QST and QPT as compared to the standard linear inversion method. Chapter 5 This chapter introduces a scheme for selective and efficient quantum process tomogra- phy (SEQPT) using local measurements without ancilla. The method estimates specific elements of the process matrix by a restrictive set of subsystem measurements, reduc- ing the experimental resources required. The efficacy of the scheme is demonstrated experimentally on NMR and IBM processors for 2- and 3-qubit systems. Chapter 6 This chapter presents an efficient weak measurement (WM) scheme for direct quantum state tomography (DQST) and direct quantum process tomography (DQPT) without projective measurements. A generalized quantum circuit is proposed and implemented on an NMR ensemble quantum information processor to directly measure multiple selective elements of density and process matrices in a single experiment which enable us to efficiently extract desired information from the system. Chapter 7 This chapter investigates the experimental simulation of open quantum system dynam- ics using dilation techniques. The Sz-Nagy's dilation (SND) algorithm is experimen- tally implemented on an NMR quantum information processor to simulate the action of a 2-qubit pure phase damping channel, correlated amplitude damping channel and magnetic field gradient pulse (MFGP). The algorithm successfully simulates the dy- namics using only one ancilla qubit, and the experimental fidelity is assessed using CCO-QPT. Chapter 8 This chapter describes the summary of the thesis and some future directions.
URI:	http://hdl.handle.net/123456789/5849
Appears in Collections:	PhD-2016

Files in This Item:

File	Description	Size	Format	
Akshay_PH16010_thesis.pdf		16.21 MB	Adobe PDF	View/Open

Show full item record

Admin Tools

Edit...

Export Item

Export (migrate) Item

Export metadata