Chapter 8
Optimal Circuit Decomposition of Reversible Quantum Gates on IBM Quantum Computers

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ABSTRACT

A critical task in utilizing quantum physics in many application fields is circuit design using reversible quantum gates. Using decomposition techniques enables transformation of unitary matrices into fundamental quantum gates. Any 3x3 reversible quantum gate can be decomposed into single-qubit rotation gates and two qubit CNOT gates. In this chapter, quantum implementations of FRSG1, URG, JTF1 and R gates into CNOT gates and single qubit U3 gates with different optimization levels on a platform provided by IBM have been discussed. FRSG1 and JTF1 gates are important in applications like Stochastic computing, fingerprint authentication system, and parity generation circuits. URG gate is better in terms of number of complex functions and can be utilized to design quantum comparator circuits. R gate plays an important role in inverting and duplicating a signal. In FRSG1, URG, JTF1 and R gates, the implementation count of single qubit gates decreases by 56%, 11%, 71%, and 62%, respectively and the count of two qubit gates reduces by 15%, 26%, 41%, and 5% respectively after optimization.

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INTRODUCTION

Quantum Computing was first pointed out by Richard Feynman (Feynman, 1982) in his inspiring work on simulating quantum physics with quantum machines. A quantum computer performs computations based on quantum mechanics to achieve secure communication and faster speed than classical computers. Moreover possesses the ability to store a huge amount of information due to its inherent parallel processing. Qubit, quantum gates, quantum reversibility, no-cloning, dense coding, quantum teleportation and quantum algorithm are all significant features of quantum computing. Quantum computers work on the basis of principles such as superposition and entanglement. Quantum circuit synthesis is based on the reversible logic hypothesis, which is supported by reversible logic gates, each of which realizes a specific unitary function with no information loss during computation (Jiang, 2016). Quantum computing is attracting researchers because it is thought to have no information loss during computation. As a result, the fundamental quantum operation circuit structuring is a serious issue for improving quantum computing hardware. Qubits are manipulated by operating on a set of unitary transformations known as quantum gates. Each quantum gate operates on a unique single qubit state or pair of qubits, and combining these quantum gates results in complex unitary transformations known as quantum circuits (Bhat, 2022). The difficulty of manipulating a large number of qubits has limited the experimental growth of a "quantum central processing unit (QCPU)," affecting theoretical research as well. As a result, the design of quantum processors is still in its early stages. With the aforementioned issues in mind, it is motivating to investigate some promising implementation of quantum reversible gates. In reversible stochastic computing, the FRSG1 gate performs multiplication in three formats. One of its outputs performs bipolar multiplication, while the other performs unipolar and inverse bipolar multiplication for the desired inputs (Khanday, 2019), (Akhter, 2019). As a result, this gate can serve as a universal gate to accomplish multiplication operations in all three formats. Moreover this gate can be used to design reversible fingerprint authentication system. URG gate is better in terms of number of complex functions and can be utilized to design quantum comparator circuits (Vasudevan, 2006). The JTF1 gate has the least quantum cost of the 3x3 reversible quantum gates and could be used to design nanoscale quantum parity checker and parity generator circuits (Reshi, 2019). R gate plays an important role in inverting a signal and duplicating a signal (Monastar, 2015). Moreover, R gate can also be used in designing quantum adder and subtractor circuits. Any 3x3 reversible quantum gate can be decomposed into two-qubit CNOT gates and single-qubit rotation gates. In this paper optimal quantum implementations of FRSG1, URG, R and JTF1 gates into CNOT gates and single qubit U_3 gates have been presented, which finds applications in stochastic computing and in designing quantum parity checker and generator circuits respectively. URG gate is better in terms of number of complex functions and can be utilized to design quantum comparator circuits. R gate plays an important role in inverting and duplicating a signal. Implementation of these gates has been obtained using a standard quantum computational gate model. Apart from well-known CNOT gates the depicted implementation uses U_3 gates, where U_3 gate is an explicit parametrization of a universal one qubit unitary. In addition, optimization of these gates has been obtained which reduces the count of elementary gates.

The organization of the chapter is as follows: In section II, we provide some background knowledge and methodology relevant to the paper. In section III, we propose the optimal quantum implementation of FRSG1, URG, R and JTF1 reversible quantum gates. The performance comparison of implementations with optimal quantum implementations have been discussed also in this section. We draw the conclusion in section IV and provide recommendations for future work.