

QUANTUM COMPUTING: A COMPREHENSIVE REVIEW OF PRINCIPLES, TECHNOLOGIES AND EMERGING APPLICATIONS

Sudipta Bhanja¹, Tanmay Kumar Behera², Subhadip Das³, Aditi Karmakar⁴, Deblina Roy³,
Atasi Dutta³ and Kousik Roy^{3*}

¹Department of Information Technology, Kalyani Government Engineering College Kalyani,
West Bengal

²Department of Computer Science and Engineering, NIT Mizoram, India

³Department of Computer Science and Engineering, Bengal College of Engineering and
Technology, Durgapur, West Bengal

⁴Department of Computer Science Engineering, Kalinga Institute of Industrial Technology,
Bhubaneswar, Odisha

*Corresponding Author Email ID: kousikroy002@gmail.com

ABSTRACT

Quantum computing represents a transformative approach to computation leveraging fundamental principles of quantum mechanics such as superposition, entanglement and interference to store and process information in ways that classical computers cannot achieve. This paper attempts to provide a bona fide bibliographic overview of the principles, computational models, hardware technologies, and potential applications of quantum computing. It analyses how quantum algorithms could outperform classical algorithms in cryptographic analysis, optimization, and big data analysis. The survey integrates viewpoints from recent works; it presents system architectures, software development challenges, and quantum-assisted applications in healthcare, artificial intelligence, cybersecurity, and industrial optimization. Meanwhile, it examines hybrid quantum-classical systems that would allow quantum technologies to be deployed in the near term skirted by the limitations currently posed by quantum hardware. Moreover, the paper discusses foremost hurdles in scaling, error-correction, and maintaining coherence. From reviewing the recent developments and whether possible, this present review work informs researchers, engineers, and practitioners alike on the current state, as well as on the long-run viability, of quantum computing.

Keywords: *Quantum Computing, Qubits, Quantum Hardware, Quantum Cryptography, Quantum Error Correction, Quantum Algorithms, Hybrid Quantum-Classical Systems*

1. INTRODUCTION

Quantum computing uses principles of quantum theory including superposition entanglement and interference to perform tasks beyond the capabilities of classical computers. Employing quantum bits (qubits), these computers theoretically deliver an exponential speed-up to a certain set of problems when compared against traditional computers. Quantum computing, with this power, has thus been considered a main driver for applications in cryptography, artificial intelligence, optimization, and scientific simulations. Recent years have seen rapid developments in both theoretical and practical aspects of quantum technologies. Gbenle et al. [1] gave a detailed review on the present developments and future prospects of quantum computing technologies. Zhao et al. [2] outlined modern quantum system architectures, emphasizing the technical challenges of scalability and fault tolerance. The application of quantum computing in handling massive datasets was discussed by M. Ilyas and R. Ilyas [3], who highlighted its role in big data analytics. Gill et al. [4] systematically categorized existing literature to evaluate the maturity of various subfields. Quantum security is a growing area of concern, with Khan et al. [5] analysing potential threats and mitigation strategies in a