QUANTUM LEAP: WHEN COMPUTERS TRANSCEND THE LIMITS OF CLASSICAL LOGIC

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Abstrak

The rapid evolution of information technology has entered a new phase that increasingly challenges the limits of classical computational logic. Quantum computing has emerged as a new computational paradigm that exploits the principles of quantum mechanics to address problems that are computationally infeasible for conventional computers. This study aims to analyze the fundamental concepts of quantum computing, recent technological developments, and its potential implications for the field of information technology. A Systematic Literature Review (SLR) method was employed by analyzing peer-reviewed journal articles and research reports published between 2019 and 2025. The results indicate that quantum computing demonstrates significant potential in areas such as cybersecurity, artificial intelligence, and big data analytics. However, critical challenges remain, including qubit instability, decoherence, quantum error correction, and high implementation costs. This study concludes that quantum computing represents a transformative technological leap that is expected to reshape the future trajectory of global information technology, provided that existing technical and infrastructural challenges can be effectively addressed.

Kata Kunci : quantum computing; information technology; qubits; superposition; artificial intelligence.

1. Pendahuluan

Over the past several decades, computer technology has undergone rapid and continuous development. Since the invention of the transistor in 1947 and the emergence of modern microprocessors, classical computers based on binary logic have become the backbone of global information processing systems. These systems have enabled major advancements across scientific research, industrial automation, business intelligence, and digital communication. However, the exponential growth predicted by Moore’s Law has begun to slow as semiconductor technologies approach their physical and material limits.

The increasing complexity of data-intensive applications, such as cryptographic systems, artificial intelligence, and large-scale simulations, has exposed the inherent limitations of classical computing architectures. Classical computers operate strictly on binary states (0 and 1), which restricts their efficiency in solving highly complex and multidimensional problems. Arute et al. (2019) demonstrated that certain computational tasks become practically infeasible for classical supercomputers due to these physical constraints.

In response to these limitations, researchers have explored alternative computational paradigms. Quantum computing has emerged as a promising approach by leveraging quantum mechanical principles such as superposition, entanglement, and quantum interference. These properties enable quantum computers to process vast solution spaces simultaneously, offering potential exponential speedups for specific problem classes. Leading technology companies and research institutions, including Google and IBM, have made substantial progress in developing quantum processors capable of outperforming classical systems in specialized tasks (Preskill, 2021).

The advancement of quantum computing carries significant implications for various domains within information technology, particularly cybersecurity, artificial intelligence, and big data processing. At the same time, the technology introduces new technical, economic, and ethical challenges. Therefore, this study seeks to examine the opportunities and challenges associated with quantum computing and to analyze its potential impact on the future development of information technology.

2. Metode Penelitian

This study employs a Systematic Literature Review (SLR) approach to comprehensively analyze recent developments and applications of quantum computing in the field of information technology. Literature sources were obtained from reputable scientific databases, including IEEE Xplore, SpringerLink, ScienceDirect, Nature, and Google Scholar. The review focused on publications released between 2019 and 2025 to ensure the inclusion of up-to-date and relevant research.

The initial search yielded a total of 42 articles. After removing duplicates and applying inclusion and exclusion criteria, 25 articles were selected for detailed analysis. Inclusion criteria required that studies explicitly discuss quantum computing concepts, implementations, or impacts related to information technology. Exclusion criteria eliminated non-peer-reviewed publications and studies that addressed quantum theory without practical relevance to computing or information systems.

Data analysis was conducted through critical evaluation of each selected study, focusing on research objectives, methodologies, findings, and limitations. The synthesis process adopted a descriptive and thematic analysis approach to identify recurring patterns, technological challenges, and future research directions in quantum computing.

Table 1. Summary of Selected Studies in the Systematic Literature Review

No.	Author(s) & Year	Research Focus	Methodology	Key Findings
1.	Arute et al. (2019)	Quantum supremacy	Experimental	Demonstrated quantum advantage using a superconducting processor for specific computational tasks.

2.	Preskill (2021)	Progress and challenges of quantum computing	Conceptual review	Identified near-term opportunities and long-term challenges in quantum hardware and algorithms.
3.	Chen et al. (2022)	Post-quantum cryptography	Technical report	Highlighted the vulnerability of classical cryptography and proposed quantum-resistant algorithms.
4.	Broughton et al. (2021)	Quantum machine learning	Framework development	Introduced TensorFlow Quantum as a hybrid quantum–classical ML framework.
5.	Kandala et al. (2023)	Error mitigation techniques	Experimental	Showed that error mitigation can extend the computational capabilities of noisy quantum processors.

3. Hasil dan Pembahasan

The findings of this review indicate that quantum computing has demonstrated the potential to significantly accelerate computational processes compared to classical computing, particularly for complex optimization, simulation, and machine learning tasks. Studies on quantum supremacy highlight cases in which quantum processors, such as Google’s Sycamore, successfully completed specific computations within seconds that would require thousands of years using classical supercomputers. Although these demonstrations remain task-specific, they provide strong empirical evidence of quantum advantage.

In the field of cybersecurity, quantum computing presents a dual impact. On one hand, quantum algorithms such as Shor’s algorithm threaten widely used public-key cryptographic systems by enabling efficient factorization of large integers. On the other hand, this threat has accelerated research into post-quantum cryptography, which aims to develop encryption methods resilient to quantum attacks (Chen et al., 2022). Consequently, quantum computing is not only a disruptive force but also a catalyst for innovation in information security.

Practical implementation of quantum computing has begun through cloud-based Quantum-as-a-Service (QaaS) platforms offered by companies such as IBM and Google. These platforms allow researchers and industry practitioners to experiment with quantum algorithms without requiring substantial hardware investments. Several sectors, including finance, logistics, and pharmaceuticals, have explored quantum-based solutions for portfolio optimization, supply chain management, and molecular simulations.

Despite these promising developments, significant challenges remain. Qubit instability and decoherence continue to limit computational accuracy and scalability. Error mitigation and quantum error correction techniques have shown progress but remain resource-intensive and difficult to implement at scale (Kandala et al., 2023). Additionally, the requirement for extreme operating conditions, such as cryogenic temperatures, contributes to high operational costs. These challenges underscore the need for sustained interdisciplinary collaboration to achieve practical, large-scale quantum computing.

Table 2. Opportunities and Challenges of Quantum Computing in Information Technology

Aspect	Opportunities	Challenges
Computational Speed	Exponential speedup for specific problems such as optimization and	Limited to problem-specific use cases and small-scale systems

	simulation	
Cybersecurity	Development of quantum-safe and post-quantum cryptographic algorithms	Threat to existing public-key cryptography systems
Artificial Intelligence	Enhanced machine learning through quantum parallelism	Limited availability of scalable quantum ML frameworks
Hardware Technology	Innovation in qubit design and quantum processors	Qubit instability, decoherence, and hardware noise
Infrastructure	Cloud-based Quantum-as-a-Service (QaaS) enables broader access	High operational costs and requirement for cryogenic environments

Table 3. Applications of Quantum Computing Across Industry Sectors

Industry Sector	**Application Area**	**Potential Benefits**	**Current Status**
Finance	Portfolio optimization, risk analysis	Faster optimization and improved risk modeling	Early-stage research and pilot implementations
Healthcare & Pharmaceuticals	Drug discovery, molecular simulation	Accelerated simulation of complex molecules	Experimental and proof-of-concept studies
Logistics & Transportation	Route optimization, supply chain management	Reduced costs and improved efficiency	Limited trials using hybrid quantum–classical models
Energy	Material	Enhanced	Primarily

	simulation, energy grid optimization	efficiency and sustainability	research-based applications
Cybersecurity	Cryptanalysis, quantum-safe encryption	Stronger future-proof security systems	Transition phase toward post-quantum cryptography

4. Kesimpulan dan Saran

Quantum computing represents a transformative technological breakthrough that extends beyond the fundamental limitations of classical computational logic. By exploiting quantum mechanical phenomena such as superposition and entanglement, quantum computers offer the potential for substantial improvements in computational efficiency and problem-solving capability. Nevertheless, widespread adoption of this technology depends on overcoming critical challenges related to qubit stability, error correction, scalability, and cost efficiency.

Future research should focus on developing more robust quantum hardware, improving error correction techniques, and exploring hybrid quantum-classical computing models. Collaborative efforts among computer scientists, physicists, engineers, and policymakers will be essential to fully realize the potential of quantum computing and to ensure its responsible integration into the future landscape of information technology.

Daftar Pustaka

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