Quantum Computer and Applications for the Society 5.0

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วันที่รับบทความ: 12 เมษายน 2564 / วันที่แก้ไขบทความ: 15 มิถุนายน 2564 / วันที่ตอบรับการตีพิมพ์: 26 มิถุนายน 2564

บทคัดย่อ ควอนตัมคอมพิวเตอร์เป็นอีกหนึ่งเทคโนโลยีที่เราไม่สามารถละเลยได้สำหรับ Society 5.0 ด้วยความสามารถของควอนตัมคอมพิวเตอร์ที่สามารถทำการประมวลผลในสิ่งที่คอมพิวเตอร์ทั่วไปในปัจจุบันไม่สามารถทำได้ การประยุกต์ใช้ควอนตัมคอมพิวเตอร์ที่หลากหลายเป็นสิ่งที่ท้าทายโดยเฉพาะอย่างยิ่งสำหรับ Society 5.0 ซึ่งต้องการการพัฒนาที่ยั่งยืน ประเทศที่ไม่สามารถเป็นผู้นำด้านปัญญาประดิษฐ์และแมชชีนเลิร์นนิ่งสามารถก้าวไปสู่การเป็นผู้นำในยุคคอมพิวเตอร์ควอนตัมได้ บทความนี้มุ่งเน้นไปที่ความสำคัญของควอนตัมคอมพิวเตอร์และการประยุกต์ใช้ควอนตัมคอมพิวเตอร์ในแบบต่าง ๆ สำหรับ Society 5.0 เช่น ความก้าวหน้าในด้านวัสดุศาสตร์ การเกษตร การแพทย์ โลจิสติกส์ การผลิต การเงิน พลังงาน ปัญญาประดิษฐ์และแมชชีนเลิร์นนิ่ง นอกจากนี้ยังได้อธิบายถึงอาชีพใหม่ ทั้งทางฮาร์ดแวร์ ฟิสิกส์ วิทยาการคอมพิวเตอร์ และเคมี ที่ควอนตัมคอมพิวเตอร์ทำให้เกิดขึ้นและการนำไปประยุกต์ใช้

คำสำคัญ : Quantum Computing, Quantum Supremacy, Quantum Advantage, Society 5.0

Abstract Quantum computing is one of the technologies that we cannot overlook for Society 5.0. Appreciations to the capabilities of quantum computing, the processing of today's conventional computers are impossible. The wide range of quantum computing applications is challenging, especially for Society 5.0, which requires sustainable development. Countries that could not be leaders of artificial intelligence and machine learning could break through to be the leader in the quantum computing era. This article focuses on the importance of quantum computing and quantum computers with various applications for Society 5.0, such as advancements in material science, agriculture, medicine, logistics, production, finance, energy, artificial intelligence, and machine learning technologies. Furthermore, new jobs in specialized hardware, physics, computer science, and chemistry that a quantum computer will initiate and apply are explained.

Keywords**:** Quantum Computing, Quantum Supremacy, Quantum Advantage, Society 5.0

1. Introduction

Quantum theory is a type of modern physics that describes the nature, behavior of matter, and energy at the atomic level. It also includes the status of subatomic particles, which may also be referred to as quantum physics or quantum mechanics. So, it can be said that it is a theory to explain atoms' microscopic world [33]. First of all, we must understand that the atomic world laws are entirely different from the world we live in because atoms have properties that we could not imagine were possible. Before understanding these, we must refute any prior knowledge from the familiar classical physics theory; for example, things can only travel to the left or the right for a while. Items cannot go left or right at the same time.

In contrast to the microscopic world of atoms, it can travel left, right, top, and bottom simultaneously. So, it can be seen that it is a movement that we are not familiar with and feel that it is impossible, while atoms move like this. It is an important characteristic used in the development of quantum computing. Quantum theory explains the ability of matter to express the properties of waves and particles.

Furthermore, quantum theory explains that apart from atoms can be in multiple locations simultaneously, known as superposition states [11]. The atoms also have another unique and distinctive feature that we didn't think possible in the quantum entanglement property [11]. It means that two atoms distant from each other can be perceived to each one or are incomplete coexistence, without any signaling or information being required. Additionally, superposition, which is one of the fundamental quantum theories, supports quantum computers, enabling them to process things that conventional supercomputers cannot do. Currently, most common computers use a bit system, a system that uses 0 or 1 as a value. For example, when we talk about a 1-megabyte image, it means an eight-million-bit image. Generally, conventional 0 or 1 computing is the same as being able just to be left or right. While quantum computing can be left and right, data can be both 0 and 1 simultaneously [19] and can be stored simultaneously, called a qubit. Therefore, it is necessary to differ across systems, programming languages, and capacity; quantum computing performance increases exponentially as the number of qubits increases [34]. With quantum computers, particles are used to perform calculations known as quantum bits or qubits, indicating superposition and entanglement. A superposition enables the qubit to be multiple states at once [35], while its implication means that atomic particles can interact with other nuclear particles. Consequently, one particle's behavior can be predicted by looking at the other particles involved, even if they are separated and distant.

The superposition and entanglement capabilities that make 2 bits in a typical computer versus two qubits in a quantum computer have the more different processing power. That can be seen quantum computers' potential is very high compared to conventional computers today. The ability to solve problems that most potent conventional computers cannot solve is called Quantum supremacy or the Quantum advantage [31]. Quantum supremacy is an improved version of the quantum computer that outperforms the world's first supercomputer to solve problems that conventional computers cannot solve.

Quantum advantage is the potential for faster problem-solving. For that quantum computing, scientists framed the theory in 1982 by Paul Benioff [5]. Ten years later, Peter Shor of AT&T's Bell Labs discovered an algorithm that permits quantum computers to quickly extract large numbers of integers, bringing the quantum computer into the attention [26].

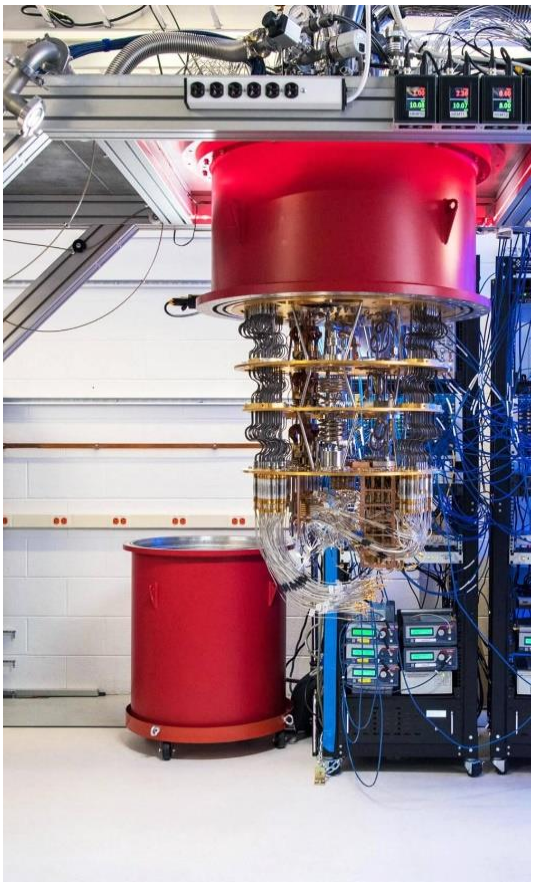

Fig. 1 Google's Quantum chandelier and Quantum Computing Service [12]

Next, the first 16 qubits quantum computer was developed, called Orion, by D-Wave[8]. They are also actively developing quantum computers in collaboration with NASA, Google, and universities. That same year, Microsoft released the free Quantum Development Kit: QDK [4], as well as a programming language and a quantum computing simulator for anyone who wants to get started with writing applications. Furthermore, Intel also released a 49 qubits superconducting quantum chip under Tangle Lake's product name [16]. Google recently released a 72 qubits quantum chip called Bristlecone, a high-speed evolution in the field of quantum computing [36].

2. The Society 5.0

The Society 5.0 is a scheme for personal and social development concerning sustainability being a national design [9]. Additionally, the researchers conclude that the ideas or at least the underlying purposes will be reached to every nation. For the implementation of Society 5.0 to be a political-ideological theory, it also seems to be unavoidable to blend different dimensions, such as alteration plan from the government view, entrepreneurial quality from society view, and entrepreneurial experiences from public society and businesses [38]. It is a concern with the future unrestricted [17] that whether a profound societal change will act, and the resistance of social assent will be burst down is an issue that will be responded to in the future. In this regard, they were performing forecasts would be a western conceit on our part and a great

impression. That is a model we could envision in other portions of society.

3. Trends, Evolutions, and Applications of Quantum Computers for the Society 5.0

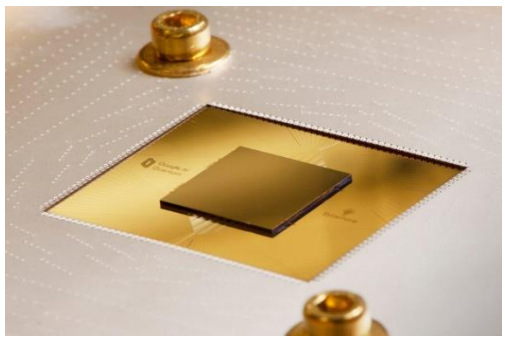

Fig. 2 Google's newest quantum processor, Bristlecone [12]

3.1 Global Quantum Computing Development and Application Trends

Research shows that quantum computers will achieve quantum supremacy, with more than 50 Qubits expected by 2020. Then, as quantum supremacy befalls, within two to five years or 2022 to 2025, the global quantum computing market will grow by more than 50 percent and reach $ 1.3 billion in 2025. The United States' National Quantum Initiative Act of 2018 [14] required $ 1.2 billion to be allocated for the project to achieve Quantum Information Science's goals and its applications in the next ten years. For the key players in this market, a platform for developing quantum algorithms and usage models will benefit in the long run. IBM, the world leader in quantum computing, has released a 20-qubit quantum processor and a simulator capable of simulating up to 49 qubits. In collaboration with the California University of Santa Barbara, Google released a 72 Qubit chip called Bristlecone [36], [28] in 2018; however, the chip is still being tested. Other companies [28], such as Intel, Microsoft, and Yale, also drive quantum technology development.

Quantum simulations is another market that can grow to $ 20 billion, especially in the pharmaceutical field by 2030, with an investment of more than 7 billion dollars. It can also thrive in other industries. In the future, whether it is in chemicals and materials science, research is estimated that the market will grow by 20 billion dollars [32]. The development of applications in discovery and machine learning will eventually replace GPU-based platforms as quantum computing methods. It made this SEO application of interest to both Google and IBM to develop the quantum computing SEO platform [20]. The Quantum Artificial Intelligence Lab, a member of NASA's Ames Research Center [29], collaborates between NASA, Universities Space Research Association (USRA), and Google Research. Its primary focus is research studies to understand possible application models for integrating quantum computing, machine learning, and other computer science advancements to address dilemmas. With quantum computing technology, scientists are expected to lead to a paradigm shift towards the Quantum supremacy state. That all application for new technology to industrial

and other sectors achieve leapfrog development. It will create a recent history, whether it is Google's Quantum AI Lab [13], lead to broad and diverse applications of quantum computers in other fields.

3.2 The Trends and Applications of Quantum Computing for the Society 5.0 [3, 18]

Based on the success in quantum computing that IBM has achieved since the beginning of 2019. The Q System One, the world's first approximated quantum processor, is also launched for scientific and commercial applications. Its components are designed to work together as a single unit, not by assembly, as in previous quantum computers. While traditional, commonly utilized computers use a modular assembly that is designed to work together. IBM also used the same principles to develop the first integrated quantum computing system. IBM Q systems are designed to handle more complex and voluminous problems than traditional computers can manage. There are some examples of future applications for quantum computing, such as finding new ways to simulate financial data, isolate risk factors for better return investments, find the best routes from systems worldwide for the most efficient transportation, and optimize freight management cars, etc.

Over the long term, quantum computers will likely be used to create various new computation and business process models. For solving various processing problems, that cannot be modified at present, including coding and chemical format changes. That makes it possible to drive advancements in material science, agriculture, and medicine, as well as artificial intelligence and machine learning technologies. The technology for society 5.0 is expected to be used in logistics, production, finance, and energy.

3.3 The Vital Role of Quantum Technology in Society 5.0

Quantum computing technology could contribute to society 5.0 [30] in the future, as it will begin to be widely used over the next ten years. It boosts processing speed, enabling solutions to solving many problems, especially in scientific and technological leaps, causing many breakthroughs. Likewise, quantum computing will impact economic growth due to replacing more secure encryption algorithms and being applied in various industries. Therefore, quantum computing technology is a technology that supports other advanced technologies to develop at leaps and bounds and provides excellent solutions to problems in the digital age.

Besides advancing the first quantum computing based on the number of qubits, the next five years of technological development will increase with the development duration, which will improve computing and greater security 100 million times [24].

In the next 15 years, as Quantum supremacy becomes more readily available, applications to leverage the potential of other advanced technologies will take place either using Quantum computing with machine learning or in combination with

cybersecurity [37]. The technology leader will continue to launch Quantum computing products' experimental and future development in the next five years. For example, Google introduced a 72 qubits quantum processor [36]. Meanwhile, Microsoft announced the Quantum Development Kit (QDK) [4] for developers to test quantum programming. In the next ten years, the global quantum computing market will grow more than double before 2030 [34]. Researchers estimate that more than 20 percent of organizations worldwide will invest in quantum computing projects [25]. Furthermore, the global use of AI and machine learning is expected to grow more than 40-60 percent annually. When combined with quantum computing, it delivers dramatically higher efficiency [1].

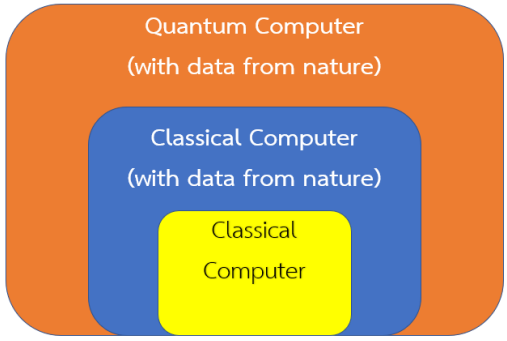

Fig. 3 The advantage of quantum computers in AI problems [12]

Case studies under practical applications involving quantum computing, those large companies offer everyone the opportunity to experiment on the free platform. In the next ten years, smartphones, computers, tablets, and enterprise computing devices will be driven by quantum computing via cloud computing [7]. However, quantum computers must be developed in tandem with cybersecurity systems and research to analyze the molecular behavior of quantum.

4. Importance of Quantum Technology for the Society 5.0

Quantum computing has been selected as one of the names of critical technologies for Society 5.0 by many countries' digital economies. Due to the potential for exponential growth and impact on the country in the future, this technology will have case studies of more applications and its implications for future economies and job markets. Although it is an experimental technology, it is expected to create applications, have a strategic appeal, and significantly impact the population.

By 2030, quantum computing will affect more than 45 percent of people and create dramatic changes across sectors, including coding, chemical development, artificial intelligence, and machine learning [21] [28]. Quantum computing technology will create new jobs in specialized hardware, physics, computer science, and chemistry. On the other hand, it will drop jobs in many fields over the next decade. Personnel selection is an intensive process because it requires in-depth skills, and they need to be trained before the job. Therefore, student's and professionals' training for quantum computing jobs will be in great demand over the next 15 years. Working in quantum computing requires a system developer who can program and have expertise in chemistry and physics [2, 28]. Therefore, it needs government support, both in funding and policy, to help

companies and universities work together to produce personnel in this area. Since it collaborates with IBM and Google, that has opened up access to an open-source quantum computing cloud for the public to test and experience quantum computing, which opens up the opportunity to accumulate knowledge at the beginning.

Before the coronavirus crisis, many students and professionals would like to attend quantum computing training for future job opportunities. That suggests that quantum computing may not directly impact the education sector as a whole but may affect specific courses that require technology to support research, especially in the fields of scientific research [27, 28]. Accordingly, quantum technology will inevitably contribute to education in the future to expand the scope of research in a broader semester and with an increasingly accelerated rate. As for health, the research evaluates whether they can use quantum computers to analyze molecular behavior [32]. This capability will be significant for the healthcare market and will inevitably significantly impact health jobs. Its main effects include creating new medicines, diagnosis and prevention, new treatment methods and response, and comprehensive healthcare services to manage hospitals to provide health care [22]. Therefore, the healthcare business is one of the businesses most affected by quantum computing. Due to more effective medicines, normal medicine development takes 8-10 years to complete. We must test various reactions on the human body with millions of tests through medical research and development. Thanks to quantum computing capabilities, it can significantly reduce the time and costs of research and development. It will consider curing disease by mapping proteins in DNA [15, 28], a key technology for the medical community in treating illness and healthcare.

That can apply quantum computing to a wide range of industrial businesses [23], mainly information technology, telecommunications, aerospace, defense, energy, finance, and investment. That will account for nearly 70 percent of the total market's quantum computing applications [28]. The sensor and manufacturing sector will see a 54 percent growth, was followed by the chemical and materials science industries, with applications growing at 40 percent by 2025. Machine learning jobs will grow exponentially with a 34 percent growth rate in 2027. As an example, it shows the potential of quantum computing due to its application in different sectors. In 2025-2030, quantum computing will be commercialized worldwide at an accelerated rate of more than 50 percent [23]. The aerospace, military, energy, finance, and investment industries and IT and telecommunications are the most affected sectors. The global quantum computing market will reach $ 50 billion by 2030. However, the researchers expect this growth rate to come to its peak approximately in the next 25 years. But it's hard to predict how much the world will change in the next 25 years. However, with quantum computers being used exponentially over the next ten years, the technology may contribute to the future of

Social 5.0 [30]. That will be the era of fully connecting humans to the IoT, creating a high-tech sharing economy [28]. AI, machine learning, cloud computing, AR, VR, and IoT all need quantum computing technology to support their operations. That enables us to raise the level of processing speed and solve various problems of human beings, especially in science, technology, and innovation that will occur worldwide. Quantum computing technology will also work with IoT to analyze the safest paths for everyday use [6]. It also supports the function of Blockchain in the field of cybersecurity [10]. Therefore, quantum computing is a technology that supports the next 10-20 years of entry into the digital quantum era through application to enhance the capabilities of other advanced technologies in the future of society 5.0.

5. Summary

Quantum computing is an emerging technology that can improve the performance of other advanced technologies. Therefore, it is likely to be used in Society 5.0 to increase significantly in the future. In particular, it is expected to continue to be applied to the healthcare industry and other advanced industries with high economic value. Although now only large multinational companies such as Google, Microsoft, and IBM have started developing this technology. However, the technology will also advance by leaps and bounds with increasing numbers of qubits. Therefore, it is concluded that the market for quantum computing technology in Society 5.0 will grow exponentially by 2030.

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