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Quantum Computing in the Military

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Abstract: Quantum computing represents a paradigm shift in computational technology, poised to revolutionize national security and defense. The military and defense sector is just one of many industries that stand to benefit from the advent of quantum computing. Quantum computing is revolutionizing military strategy by offering unparalleled capabilities in secure communications, super-fast data analysis for intelligence, and advanced war-game simulations. It is at the forefront of most advanced nations' long-term defence planning. Quantum technologies for military applications introduce new capabilities, improving effectiveness and increasing precision, thus leading to "quantum warfare," wherein new military strategies, doctrines, policies and ethics should be established. This paper reviews the possible potential impact of quantum technology on military applications.

Keywords: *Technology, Quantum Computing, Qc, Military, Defense, Warfare*

I. INTRODUCTION

Fourth generation modern warfare is characterized by decentralization and the loss of states' monopoly on war. Armies of advanced countries characteristically have access to state-of-the-art military technologies. This includes the appearance of quantum technologies on the horizon. Quantum technology is an emergent and potentially disruptive discipline, with the ability to affect many human activities. It has the potential to revolutionize fields like medicine, finance, and security. It does not bring fundamentally new weapons or standalone military systems, but rather significantly enhances measurement capability, sensing, precision and computation power, and efficiency of the current and future military technology. It would enable the US military to gain a significant advantage in fields such as logistics, planning, and image analysis.

Consequently, there is tremendous potential for military applications of quantum technology, with the possibility to change the conduct of warfare and the outcomes of battles [1].

II. UANTUM COMPUTERS

A quantum computer (QC) behaves according to the laws of quantum mechanics. Thus, quantum computers are different from binary digital electronic computers based on transistors. A major difference between classical and quantum computing lies in the way they encode data. While a digital computer requires that the data be encoded into binary digits (0 or 1), quantum computers use quantum bits, which can be in superpositions of states [2]. In other words, instead of storing information in bits as conventional digital computers do, quantum computers use quantum bits, or qubits, to encode information. (Qubits are the basic units of quantum information.) In addition to ones and zeros, qubits have a third state called "superposition" that allows them to represent a one or a zero at the same time. Figure 1 shows the comparison between the bit and qubit [3]. The computing power of a QC grows exponentially with the number of qubits it uses.

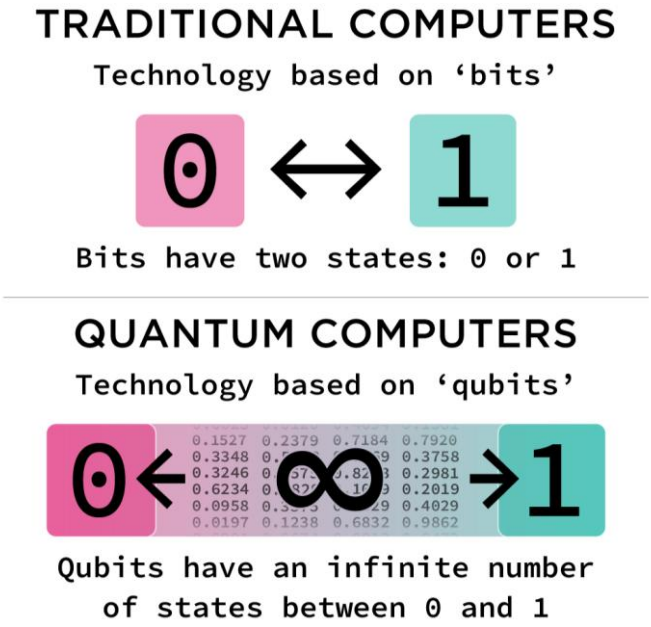


Figure 1: The bit and the qubit [3].

Quantum computers have the potential to perform certain calculations significantly faster than any digital computers. QC consists of a quantum processor which operates at a very low temperature (a few tens of mK) and an electronic controller which reads out and controls the quantum processors, as shown in Figure 2 [4]. Several forms of physical media (optical fibers and free space) can be used to deliver quantum information. Figure 3 shows a representation of quantum computing [5].

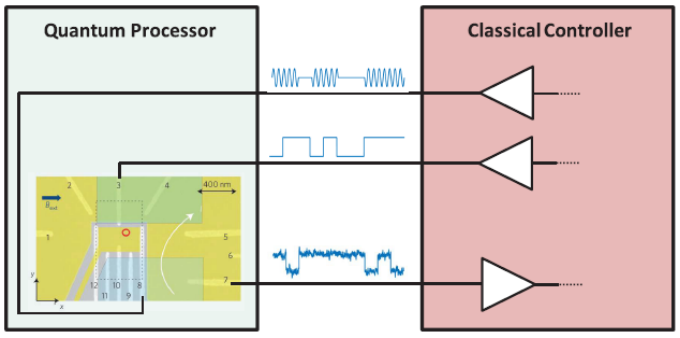


Figure 2: Quantum processor and classical electronic controller [4].



Figure 3: A representation of quantum computing [5].

In quantum system, the computational space increases with the size of the system. This enables exponential parallelism which leads to faster quantum algorithms. Unlike classical computer, QC offers massive parallelism within a single piece of hardware.



Figure 4: A typical quantum computer [6].

A typical quantum computer is shown in Figure 4 [6]. The basic building blocks of quantum computers include quantum gates, quantum memories, quantum CPUs, quantum languages, and quantum languages [7,8]:

- *Quantum Gates:* Quantum computers require quantum gates, which are basically diff erent from classical Boolean gates seen in a conventional computer (AND, XOR and so on). A quantum gate acts on superpositions of diff erent basis states of qubits. The quantum gates perform unitary operations on quantum states and lead to quantum circuits. They are particularly important for quantum error correction and experimental quantum information processing. They can be realized by superconductors, linear optic tools, or quantum dots**.** Common quantum gates are CNOT and SWAP.
- *Quantum Memories:* Quantum memories store the quantum systems in a quantum register for information processing. Quantum memories are formulated by n stationary quantum states. Quantum computers are expected to have limited memory.
- *Quantum CPUs:* These use a quantum bus for the communication between the functional elements of a quantum computer. From a computing perspective, quantum CPUs can be approached through quantum adders.
- *Quantum Languages:* These enable us to create an artificial quantum computer to simulate a quantum computing environment. The programming language should follow a functional programming structure, which can compute the process as a whole entity with a proper bounded structure.
- *Quantum Algorithms:* Quantum algorithms are significantly faster than any classical algorithm in solving some problem. Most of the successful quantum algorithms use quantum Fourier transforms in them because they require less hardware. Popular quantum algorithms include Shor's algorithm (since integer factorization is faster) and Grover's search algorithm.

In ambitious attempts to realize practical quantum computers, enormous efforts are still being expended both in designing software (quantum algorithms) and hardware development (physical implementation).

III. QUANTUM COMPUTING IN THE MILITARY

In recent years, quantum technology has become increasingly important for a variety of military applications. The term "quantum technology" covers a wide range of potential applications, from quantum computing and communication to sensing and metrology. While much of the research in this area is still in the early stages, there are already several potential military applications for quantum technology. It is becoming popular in the military domains of the world to use the processes of quantum computation and quantum information. The military forces of the world are currently focused on funding quantum computing projects in military research centers to tap the real capability of quantum systems [9]. Figure 5 shows some soldiers [10].



Figure 5: Some soldiers [10].

Quantum technology key applications in enhancing operational efficiency in all sectors of the defense will bring optimization of logistics, simulations of weather conditions, etc. It is increasingly being used to compute military data and detect enemy submarines. Establishing this compute power near the battlefield will be a balance of tactical decision making versus enabling technological requirements. Given the sensitivity of defense and military communications, the application of quantum encryption and QKD could revolutionize these sectors. The processing capabilities of quantum computers could bring transformative impacts across various other military domains, including logistics, strategic planning, and real-time decision-making. Quantum computers could also potentially predict enemy movements more accurately [11].

IV. APPLICATIONS OF QUANTUM COMPUTING IN THE MILITARY

The application of quantum technology in the military is an area of active research and development. The potential applications of quantum technology in the military are numerous and varied. We provide below a basic overview of possible quantum computer applications in the military [12-14]:

- *Quantum Sensing:* An area where quantum technology is having a major impact is in the realm of quantum sensing, which is playing an increasingly important role in military operations around the world. Quantum sensing uses the principles of quantum physics within a sensor. Quantum sensors can detect extremely small changes in physical

parameters, such as magnetic fields and electric fields. This makes them ideal for applications such as detecting enemy submarines or detecting mines. Quantum sensors have the potential to revolutionize military operations by providing unprecedented levels of precision and accuracy. For example, quantum sensors could detect the specific location of an enemy missile launch or identify the signature of a nuclear weapon. Quantum sensing could provide alternative positioning, navigation, and timing options that could in theory allow militaries to continue to operate at full performance in GPS-degraded environments. Quantum sensors could potentially be used in an intelligence, surveillance, and reconnaissance role. Quantum sensing can also play a crucial role in identifying and neutralizing underwater mines.

- *Quantum Communication:* Another area of application is quantum communication, which could create secure channels for information transfer that are resistant to eavesdropping. Long-distance communication has revolutionized the world. Nearly all financial, agricultural, energy, and governmental organizations and industries rely heavily on their digital infrastructures for transmitting and receiving data. Quantum communication refers to a quantum information exchange via a quantum network that uses optical fiber or free-space channels. It could theoretically enable the secure networking of quantum military sensors, computers, and other systems, thus improving performance over that of a single quantum system or classical communications network. Quantum cryptography secures communication by using the principles of quantum mechanics to encode data in a way that is impossible to copy or intercept without changing the state of the system. In communications, quantum encryption could protect sensitive information from being intercepted. This would be particularly important for military communications, which are often targeted by adversaries.
- *Quantum Cryptography:* Two of the most talked-about subfields of quantum computing are quantum cryptography and quantum algorithms. Both have the potential to revolutionize the way military and defense organizations operate. Quantum cryptography, also known as quantum key distribution (QKD), is a method of secure communication that uses quantum mechanics to exchange keys between two parties. It could securely transmit classified information between two parties. In recent years, there has been an increased focus on the need for post-quantum cryptography in the military and defense sectors. This is because quantum computers will soon be able to break traditional cryptography, making it necessary to find new ways to protect information. Post-quantum cryptography represents an area of encryption techniques that should resist future quantum computer attacks. The ongoing revolution in quantum computing has considerable implications for cybersecurity, particularly in the highly sensitive areas of defense and military operations. Quantum technology has the potential to revolutionize military cybersecurity and enhance national security in the future. Figure 6 shows quantum technology in cyber [15].

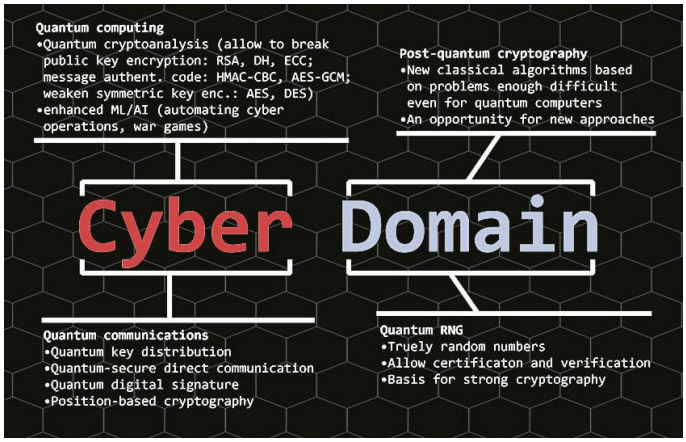


Figure 6: Quantum technology in cyber [15].

- *"Quantum Race:"* Quantum computing in warfare raises important strategic concerns, particularly the potential for a quantum arms race. Just like arms and armaments, it is a race that is all about advancing ahead of the geopolitical rivals. As nations strive to develop advanced quantum capabilities, there is a growing risk that the rapid pace of technological innovation could escalate into a race for quantum dominance. Quantum-enabled autonomous systems has the potential to disrupt the balance of power, creating pressure for nations to outpace one another technologically. The United States' national strategy has shifted its focus toward competing with China. The Pentagon, Chinese People's Liberation Army (PLA), and NATO are among the leading military bodies investing heavily in quantum technology. The US, China, and other nations are heavily funding R&D, recognizing quantum tech as crucial for future military superiority. In recent years, the US has made significant investments in quantum technology research and development. These investments lead to the creation of several national programs that are designed to promote quantum technology innovation. China is investing heavily in QKD and completed construction of an approximately 1,250 mile Beijing-Shanghai quantum network in 2016.
- *National Security:* Nations need to develop quantum capabilities to avoid being vulnerable to adversaries who might achieve a quantum advantage, especially in cryptography. How mature are US competitor efforts to develop military applications of quantum technologies? What measures should the United States take to ensure that the quantum workforce is sufficient to support US competitiveness in quantum technology? Due to the importance of technology in national security, the US government continues to invest billions of dollars each year to fund defense laboratories such as the Defense Advanced Research Projects Agency (DARPA), the Office of Naval Research, and the Army Research Laboratory. Close ties to Microsoft, IBM, Intel, and other tech giants give the US a key advantage in developing quantum technology for military applications.
- *Irregular Warfare:* Quantum computing's potential to optimize complex operations is particularly relevant to the logistical and decision-making demands of irregular warfare. As quantum computing begins to emerge from theoretical research into practical application, it has the potential to

significantly alter the landscape of irregular warfare and gray zone conflict. For example, quantum-enabled data processing could allow adversaries to analyze vast amounts of intercepted data in real-time, uncovering operational patterns or vulnerabilities. Understanding the possible applications of quantum computing in irregular warfare is essential for anticipating future threats and developing effective countermeasures, especially as adversaries seek to exploit these technologies for their own strategic gain. This emerging technology could enhance strategic capabilities and provide a competitive edge in an increasingly complex and unpredictable conflict environment. Quantum computing could revolutionize modern conflict by enabling predictive conflict management, where geopolitical, economic, and social variables are analyzed concurrently to forecast potential conflict zones or flashpoints. One of the most speculative but intriguing applications of quantum computing in irregular warfare is the development of quantum-powered artificial intelligence controlling autonomous systems. Figure 7 shows quantum-enabled warfighting [15].

- *Simulation:* The ability to simulate and model complex battlefield environments is another critical area where quantum computing is poised to make a major impact. Traditional simulation methods frequently struggle to capture the inherent unpredictability of conflict that employs decentralized and fluid tactics. Quantum-enhanced wargaming could revolutionize this process by enabling military strategists to run numerous potential scenarios in parallel, exploring not only known strategies but also new and unforeseen outcomes. These simulations would offer unprecedented insights into adversary behaviors, operational risks, and tactical opportunities, leading to more effective strategic planning. Figure 8 shows military research [11].

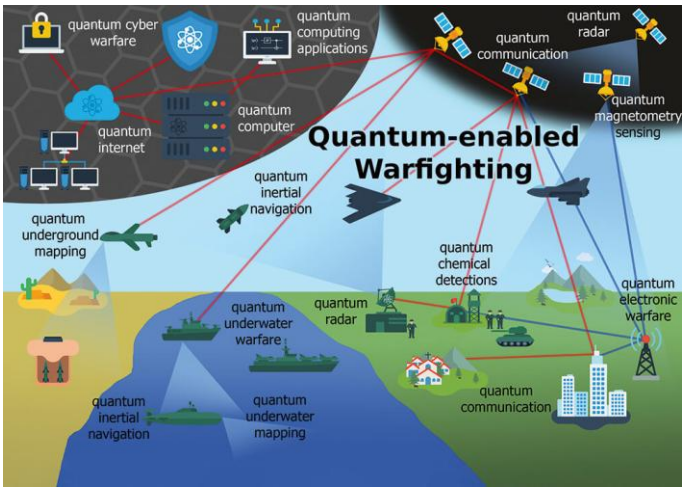


Figure 7: Quantum-enabled warfighting [15].



Figure 8: Military research [11].

V. BENEFITS

As we enter the era of quantum computing, the defense and military sector stands to benefit significantly from this transformative technology, particularly in encryption and cybersecurity. In addition to its encryption capabilities, quantum computing can enhance various military operations. For example, it can optimize logistics and supply chain management, ensuring efficient deployment of resources in critical situations. Other benefits include the following [1]:

- *Quantum Advantage:* This refers to a case when a quantum computer is able to solve real-world problems that classical computers cannot. Quantum advantage in cyber warfare can provide new vectors of attack on the current asymmetric encryptions and, theoretically, on symmetric encryption.
- *Quantum Supremacy:* This is a case where a particular problem is solved by a quantum computer significantly faster than by a classical computer. Experiments from companies like Google and IBM have demonstrated early examples of quantum supremacy, where quantum computers outperform classical systems on specific tasks.
- *Quantum Warfare* (QW): This is warfare that uses quantum technologies for military applications that affect intelligence, security and defense capabilities of all warfare domains, and it ushers in new military strategies, doctrines, scenarios, and peace as well as ethics issues. The space domain is gaining in importance and will be an important battlefield used by advanced countries. Space used to be a place mainly for satellites for navigation, mapping, communication and surveillance, often for military purposes, as shown in Figure 9 [11]. Quantum technologies can significantly interfere in underwater warfare, with enhanced magnetic detection of a submarine or underwater mines.
- *Quantum Simulator:* This is used for the study and simulation of other quantum systems that generally are less accessible and is usually built as a single-purpose machine. In comparison with a quantum computer, the quantum simulator can be imagined as a non-programmable quantum circuit. The main task for the quantum computer was considered the simulation of other quantum systems. Quantum simulation is probably the most practical near-term application of quantum computers. Thus, quantum simulations are the first and still perhaps the most promising application for quantum computers. In the

current trend of innovation and development in quantum warfare, one will hope that the defense sector will yield better accuracy and efficiency in their simulation of battles and real time analysis of data.

- *Quantum Information Science:* This is an information science related to quantum physics, and deals with quantum information. It describes the quantum information flow in quantum computing and quantum communications. Quantum computing refers to the utilization of quantum information science to perform computations. The usual channels for quantum information transmission are specialized low-loss optic fibers or the current telecommunication optic fiber infrastructures with higher loss. The free-space quantum channel is more challenging. Quantum communication at long distances requires quantum repeaters due to photon loss and decoherence. Quantum key distribution (QKD) is the most mature application of quantum communication. At present, QKD technology is commercially available as a point-point connection at short distances or by using trusted repeaters at large distances. QKD is an example of a technology that is already commercially available but is challenging to deploy. Figure 10 shows Army research laboratory in one of the Department of Defense Quantum Information Science Research Centers [16].
- *Quantum Network:* A quantum network refers to the connection of quantum computers and sensors that enables the distribution of quantum information. The aim of the quantum network (sometimes called quantum Internet or quantum information network (QIN)) is to transmit quantum information via numerous technologies across various channels. A quantum network is the most effective way of communication between quantum computers and/or quantum clouds. It allows direct secure quantum communication between quantum computers, where quantum data can be directly exchanged. The most commonly considered and realized quantum network scenario is using quantum satellites. Quantum Internet stands for a quantum network with various services which have significant implications.
- *Quantum Imaging:* This is a subfield of quantum optics that is active compared to quantum sensors that measure some external quantity. For any sensor, the signal-to-noise ratio (SNR) represents the fundamental limit of its sensitivity. Quantum imaging can improve the existing technology, such as quantum radars, three-dimensional cameras, around-the-corner cameras, gas leakage cameras, and low-visibility vision devices. Quantum imaging systems could further serve in Intelligence, Surveillance, Target Acquisition, and Reconnaissance roles.
- *Quantum Optimization:* This is a very actively explored topic, given the possibility of solving NP-level complex problems. Quantum computing is likely to be efficient in optimization problems. An example of such an NP problem is the travelling salesman problem. In the military sector, examples of quantum optimizations could be logistics for overseas operations and deployment, mission planning, war games, systems validation and verification, new vehicles' design and their attributes such as stealth or agility. There have been many demonstrations, use cases, and proofs of concept for quantum optimizations, especially in connection with analogue quantum computing that currently offers the most quantum computing resources for such applications.
- *Quantum Strategy:* While the fundamental nature of war remains constant, military strategies continue to evolve in response to capabilities enabled by new technologies. The future users of military quantum technologies will have to think carefully about whether, where, and when to invest time and resources. The goal of the defense forces is not to develop military technology but usually only to specify requirements and their acquisition. As a foundation, it is ideal to have a national quantum ecosystem in place composed of industry and academic institutions. There should be a great deal of cooperation between academia, industry, and the military.



Figure 9: Satellites for navigation, mapping, communication, and surveillance [11].

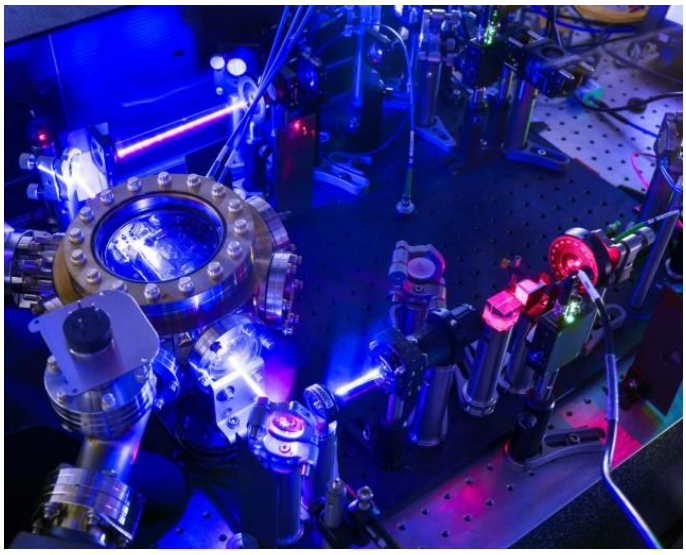


Figure 10: Army research laboratory in a research center [16].

VI. CHALLENGES

There are significant challenges that need to be overcome before quantum computers are useful in practical applications, especially in the military. Military technologies have more demanding requirements than industrial or public applications. The transfer of successful laboratory proofs of concept to real "outside" application faces many technical and technological challenges. Another challenge is the physical realization of qubits. Other challenges include the following [1]:

- *Massive Data*: A technical challenge will be the enormous amount of data. Quantum technologies, through all quantum sensors, quantum imaging, quantum communication, and computing, will produce a lot of classical and quantum data that will increase requirements for data transmission, processing, and evaluation. These requirements should be considered during the planning of quantum infrastructure.
- *Scalability:* Current quantum computers remain in the experimental phase, with most systems only capable of processing a limited number of qubits. This limitation restricts their capacity to handle the large-scale computations necessary for complex defense scenarios.
- *Environmental Noise:* Current quantum computers are extremely sensitive to changes in their environment, which means they need to be carefully isolated from any external noise or interference. Quantum systems are highly sensitive to environmental factors such as temperature and electromagnetic interference, which can cause qubits to lose their quantum state in a process known as decoherence. This instability severely impacts the reliability of quantum computers, posing a substantial hurdle to their widespread use.
- *Strategic Deception:* Taking the concept of misinformation and deception to an entirely new level, quantum mechanics could be harnessed to create misinformation or decoy signals that appear legitimate until observed, a phenomenon deeply rooted in quantum mechanics itself. This could revolutionize deception operations. Strategic deception at the quantum level would offer a tactical advantage by forcing adversaries to waste resources and time on misleading targets.
- *Regulation:* As quantum computing evolves, the establishment of international frameworks to regulate its use in conflict will be critical to mitigating the risks associated with unchecked quantum advancements.
- *Standardization:* Another challenge will be standardization. The standardization process is important for the interoperability of devices manufactured by different producers. It can also include security verification, such as in the post-quantum cryptography standardization process. Within the process of standardization, all algorithms should be rigorously tested and analyzed, including the implementation.
- *Integration:* The integration of quantum technology into a military platform is challenging. The integration and deployment of quantum sensing, imaging, and networks faces several challenges posed by the increased demands of military use. For example, the military level requirement of precise navigation necessitates fast measurement rates that can be quite limiting for the current quantum inertial sensors. The harmonization of quantum technologies as well as military strategy will shape the future generation of defense.
- *Quantum Workforce*: A significant challenge could be the quantum workforce. The quantum workforce does not need to comprise physicists or scientists with a doctorate. However, they should be quantum engineers with knowledge of quantum information science and a quantum technology overview who can understand and be able to process and evaluate the outgoing data from quantum sensors, computers, and communications. It can be difficult to get these people to work in the army. Therefore, the basic principles of quantum information and quantum technology should also appear as part of the curriculum at military colleges of modern armies, where quantum technologies are or will be deployed.
- *Quantum Threat*: Scientific researchers across the world are racing to build some of the most complex and counterintuitive machines ever built: quantum computers. It is hard to estimate the consequences that might occur if a bad actor acquired the ability to use a quantum computer to break today's cryptography. Imagine all the sensitive information that gets transmitted over the Internet: personal emails, medical records, financial information, social security numbers, credit card numbers, cryptocurrency transactions, etc. All of them could become vulnerable to a large-scale quantum computer. The cryptography that protects classified national security information is also vulnerable to quantum-computing attacks.
- *Quantum Readiness:* Transitioning from classical to quantum systems necessitates comprehensive preparation—often referred to as "quantum readiness." This shift includes not only hardware and software adaptations but also significant changes in staff training and protocol development. The defense industry must equip its personnel with the skills to operate quantum systems and develop new procedures for quantum communication and encryption.

VII. FUTIRE OF QUANTUM COMPUTING IN THE MILITARY

While the abilities of quantum computing still remain largely theoretical, significant progress is being made. Quantum computing will introduce new capabilities to the current classical computing services, helping with computational problems of high complexity. In the future, quantum computers could have a major impact on many different areas of science and technology.

The future of quantum technology is shrouded in potential but also considerable uncertainty. Despite this, defense and military organizations are eager to explore the possibilities that quantum computing might offer and are likely to invest heavily in this area in the coming years. Quantum technology will play an important role in the future of military and defense. It can be expected to have strategic and long-term impacts. The role of military in advancement of quantum computing is expected to revolutionize warfare strategies and tactics, improve technologies and technology use, and determine their future usage. Quantum computing market in aerospace and defense is poised to expand especially with militaries around the world embrace quantum technology [9].

CONCLUSION

Military leaders must be aware of emerging and disruptive technologies to maintain forces that are relevant. One such technology is quantum computing. Although quantum computing is still in its early stages, businesses and governments are investing heavily in research and development. It has already attracted significant interest from governments around the world. It could hold significant implications for the future of military sensing, encryption, and communications.

Quantum computing is a fast developing sector, and new revolutionary quantum algorithms are still waiting to be discovered. In spite of some challenges, the potential benefits of quantum computing for the defense and military sectors are too significant to ignore. By offering a new level of encryption and cybersecurity, quantum computing can revolutionize military communications and operations. As quantum technology continues to advance, it is essential for military organizations to stay ahead of the curve and harness its potential. More information about quantum computing in the military can be obtained from the books in [17-19].

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