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PROSPECTS AND CHALLENGES OF QUANTUM TECHNOLOGY IN FUTURE WARFARE

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Abstract. In a classical computer, information is encoded in bits like 0 or 1, whereas in a Quantum Computer (QC), the memory unit is called a qubit and can be in a superposition of several states. QCs have several advantages over classical computers regarding processing power and speed. Again, Quantum Technology(QT) is an emerging field of physics and engineering based on quantum-mechanical properties, especially quantum entanglement, quantum superposition, quantum tunneling, etc. The second quantum revolution has been characterized by scheming individual quantum systems like atoms, ions, electrons, photons, molecules or even quasi-particles, allowing to reach the standard quantum limit to measurement accuracy at quantum scales—QT is an emergent and potentially unsettling discipline, with the ability to affect many human activities including future warfare. Quantum computing has the potential to revolutionize various fields, including cryptography, chemistry, machine learning, optimization and ship design. Recently, IBM has invented a 433 qubits QC processor(IBM Osprey). QTs will dominate the future warfare in many aspects. Quantum sensing will revolutionize the future warfare in the field of detection, monitoring, and controlling, as well as C5IRS. There are a few distinct challenges both in QC and QT, which is a little discouraging; however, it can anticipate that QTs will use in the field of communication, precision, intelligence, space, medical, chemical, commercial, service and military industries in the future. So, the effective and efficient use of QTsthere will revolutionize change in future warfare and military industry.

Key Words: Qubits, cryptography,nano-optics, machine learning, QKD, QIN, PQC, etc

INTRODUCTION

1. Today 4th generation advanced warfare is characterized by decentralization and the loss of the state's monopoly on war.[1] As we know that defense forces of powerful nations characteristically have accesstostate-of-the-artmilitarytechnologies.[2] Quantum technology (QT) will play an important role and may jeopardize the scenario of future warfare.QTis the well-known modern technology arising out of the second quantum revolution. At present, the first quantum revolution brought technologies that are familiar to everybody, like nuclear power, semiconductors, lasers, magnetic resonance imaging, modern communication technologies, digital cameras, other imaging devices, etc. Today, nuclear and laser weapons are being implemented and tested successfully. The ability to manipulate and control individual quantum systems, such as atoms, ions, electrons, photons, molecules, or other quasi-particles, is what defines the second quantum revolution. The standard quantum limit is the upper bound on the precision of measurements made at quantum scales.[3] Few QTs, like entanglement, superposition and tunneling are related to quantum properties. The quantum computer (QC) is the ultimate and challenging goal for quantum properties. In a classical computer, information is encoded in bits as a value of 0 or 1. In aClassical bits can carry information on 1 number at a time, where qubits carry information on 2n numbers simultaneously.[4] There are few challenges to realize the QC relates to identifying and manufacturing qubits, as well as to error correction. According to Niels Bohr, making predictions is challenging, especially when they include the future.[5] However, quantum-based technologies are likely to make predictions easier and transform important sections. To

actualize the quantum leap, it is crucial that every party involved, including researchers, businesses, government officials, and foundations, exert a tremendous amount of effort.[6]

2. The 'fourth generation modern warfare is characterized by decentralization'[7] and 'the loss of states monopoly on war; militaries of advanced countries characteristically have access to state-of-the-art military technologies. This includes the appearance of quantum technologies on the horizon.'[8] Quantum computing holds great promise as a technology that can significantly enhance the speed of modern computing and various associated technologies, providing an exponential leap forward. Today the challenges and threats we face are global and interconnected. The world was profoundly startled and faced with the most critical security crisis in Europe since World War II (WWII) when Russia initiated its aggression against Ukraine on 24 February. In addition to the traditional kinetic warfare, Russia has conducted large-scale cyber warfare. Now the world is highly connected everywhere, communication and information offered through space capabilities impact people's everyday lives. Russia's war on Ukraine could be jeopardized if existing communication networks are denied. It is an analytical article based on both research and collected information from different sources and it will cover a few interesting aspects of QTs and QC that consist of the chronological development of QT, working principle, potential, prospect, and challenges of QC along with the utilization of QT in intelligence and future warfare.

CHRONOLOGICAL DEVELOPMENT OF QUANTUM TECHNOLOGY (QT)

3. If we pass a beam of light through two slits, it acts like a wave. Again, if we fire that same beam of light into a conducting plate of metal; it acts like a particle. Under appropriate conditions, we can measure either wave-like or particle-like behavior for photons and that is the fundamental quantum of light. So, it confirms the dual and very weird nature of reality. 'This dual nature of reality is also observed in all quantum particles, like electrons, protons, neutrons, and even in atoms. Actually, we can define it; but we can quantify just how "wave-like" a particle or set of particles is.Interestingly, even an entire human being, under the right conditions, can act like a quantum wave.[9] Until around 1900, when Max Planck developed the idea of quanta, energy had been thought to be a phenomenon of continuous flow, and that is basically waves. Quantum theory describes energy as separate, discrete particles. An analogy we could use to explain the wave/quantum idea might be that of analog versus digital. In the analog sense, energy flows in continuous streams or waves, having no specific inherent quantity. The quantum idea explains that the energy is a digital flow, and the waves are actually broken down into discrete, individual bits. The term photon is used for these individual energy particles. Photons contain a specific amount of energy. The more photons, the brighter the light; but all the photons individually have the same amount of energy. Even if our explanation falls short, we must embrace the peculiarities of science if we are to acknowledge the validity of the quantum theory.

4. QT, founded on the quantum-mechanical properties, is a burgeoning realm encompassing physics and engineering, especially quantum entanglement, quantum superposition and quantum tunneling, applied to individual quantum systems and their utilization for practical applications. In the early 20th century, 'the wave theory of light encountered insurmountable challenges. The ultimate death blow was Einstein's explanation of the photoelectric effect. 'Quantum waves' discusses the work of Louis de Broglie, Niels Bohr, and Einstein. It considers the uncertainty and indeterminacy of electron motion, wave function, quantum tunneling, and the phenomenon of entanglement. Quantum theory shows that electromagnetic radiation and electrons are particles. If string theory is correct, it shows that the wave concept is much more than a powerful tool to model the way the world works. The universe, despite its overwhelming complexity, can be understood as simply a vast interconnected web of interacting waves. [10] QT has its foundation in quantum mechanics, a discipline more than one hundred years old. The first applications of quantum mechanics, well known as Quantum Revolution 1.0, include nuclear fission, lasers, semiconductors, digital camera, etc., where the statistical aspects of quantum behaviour are exploited. The 'first quantum revolution had and still continues to exert a deep influence on every facet of society, from the military and international security to the development of atomic weapons, chips, computers, and precise navigation.[11] The only practical use in first-generation quantum networks is Quantum Key Distribution (QKD). A significant advantage of QKD over conventional asymmetric encryption and also called public-key cryptography is that any interception attempt would be noticed instantly. The next-generation quantum network, as called Quantum Information Network (QIN) or quantum internet, differs in its ability to distribute entangled qubits.[12]

5. The first quantum revolution, known as Quantum Revolution 1.0has given birth to nuclear weapons and energy, along with the classical computer that gained a significant role. Presently, laser weapons are being implemented and tested.[13] Thesecondquantumrevolutionischaracterizedbymanipulatingandcontrolling individual quantum systems allowing the standard quantum limit to achieved measurement accuracy at quantum scales.[14] QT will definitely enhances the

measurement capability, sensing, precision and computation power and improve revolutionary in future military technology.[15] Interestingly the most of quantum technologies typically are technologies of dual use. So, the reis incredible potential for militaryapplicationsofQT.[16] Various studies and recommendations are emerging, gesticulating the increasing likelihood of such technology being realized.[17] Today, we are entering Quantum Revolution 2.0, and that is a real era of QT, where we are exploiting the full spectrum of quantum physics. In Quantum Revolution 2.0, we exploit the behavior of individual quantum systems such as the electron, atom, nucleus, molecule, quasi-particles, etc. QTs will not introduce fundamentally new weapons, as happened with nuclear and laser weapons, but rather improve and sharpen present sensing, communication, and computiAlthough most QT's aspects are still in the form of fundamental rather than applied research, we can foresee several highly relevant applications for defense.[18] QTs are at the forefront of advanced nation's long-term defense planning, including the USA, China, the UK, France, Australia, India, Russia, Canada, etc.[19] It's truly fascinating to learn that the pioneers of quantum mechanics never took into account the progress in computation or the creation of the transistor. Today, 'we are absolutely confident that the closer we get to absolute zero, the more the entire field of atomic optics and nano-optics will advance.[20] In the forthcoming times, there could exist a potential to gauge the quantum effects on entire individuals.

WORKING PRINCIPLE OF QUANTUM COMPUTING

6. The field of quantum computing is experiencing rapid growth and possesses the potential to bring about a transformative impact on our problem-solving capabilities, particularly for complex issues that are typically beyond the reach of classical computers. QCs, in contrast to classical computers, employ quantum bits or qubits, capable of existing in multiple states simultaneously, as opposed to the binary digits or bits (0s and 1s) utilized by classical computers for computations.[21] The world is moving towards a hyper technological era, where the needs for higher computational capability are essential. In recent times, more than classical computers are needed to meet the demands of complex computations. The working principle of quantum computing is based on the principles of quantum mechanics. Quantum mechanics deals with the behavior of particles at the atomic and subatomic levels. At this level, particles can exist simultaneously in multiple states, known as superposition.[22] Quantum computers leverage the unique property of qubits to exist in multiple states simultaneously, enabling them to carry out numerous calculations concurrently. The interesting principle of quantum mechanics is entanglement. It is a fascinating occurrence in which two particles become entangled in a manner that the condition of one particle has an impact on the condition of the other particle, irrespective of their significant spatial separation. As a result, QCs use entangled qubits to perform calculations much faster than classical computers. Once more, 'the swap test is a quantum computation procedure employed to assess the disparity between two quantum states, initially introduced in the research conducted by Barencoetal [23],
and later rediscovered by Harry Buhrman, Richard Cleve, John Watrous, and Ronald de Wolf.[24] Today 'computer scientists have shown that existing compilers, thatdescribedQCs how to use their circuits to execute quantum programs, inhibit the computers' ability to achieve optimal performance.'[25]

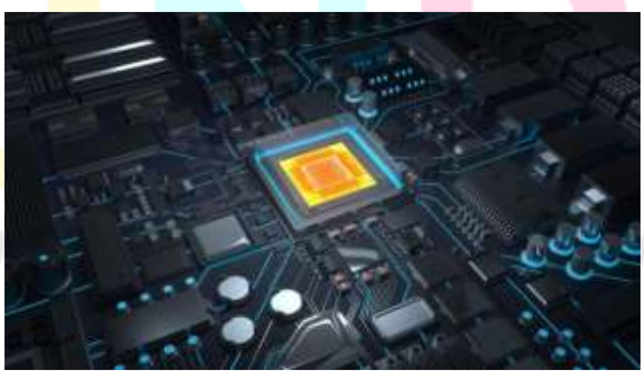

Figure 1: Quantum Computing has endless possibilities [26]

COMPARISON WITH CLASSICAL COMPUTERS

7. QCs have several advantages over classical computers in terms of processing power and speed. Again, they are also subject to several limitations, like error correction and hardware development. However, the potential applications of quantum computing are vast and have the potential to revolutionize several technology and engineering fields in the near future. There are some critical differences between QCs and classical computers, which have been summarized below

a. Data Representation. Classical computers employ bits to represent data, with each bit having the capacity to assume a value of either 0 or 1. Nonetheless, qubits employed by quantum computers (QCs) exhibit the capability to exist in a state of 0, 1, or a combination of both, commonly referred to as superposition. This allows QCs to process much larger amounts of data and perform complex and complicated calculations much faster and easier than classical computers.[27]

b. Parallel Processing. QCs can perform many calculations simultaneously due to quantum superposition and entanglement principles. In contrast, 'classical computers perform calculations sequentially. This allows quantum computers to solve special types of problems, such as optimization and cryptography, much faster and easier than classical computers.'[28]

c. Error Correction. Classical computers can perform error correction easily by copying data and checking for errors. In contrast, 'QCs are highly susceptible to errors due to environmental noise and de-coherence. Developing error correction methods for QCs is an active area of research.'[29]

d. Hardware. Classical computers are built using electronic circuits and semiconductor materials, while QCs are built using quantum bits and specialized hardware. 'Quantum hardware is still in its early stages of development and is much more expensive than classical hardware.' [30]

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e. Applications. Classical computers are used in a wide variety of applications, like data processing, scientific simulations, and gaming. QCs are still in the early stages of development and 'are currently being used primarily for research purposes, such as simulating chemical reactions and developing new algorithms.'[31]

POTENTIALS OF QUANTUM COMPUTING

8. Quantum computing has the potential to revolutionize various fields, including cryptography, chemistry, machine learning, optimization and ship design. Today quantum computing potential has recognized in several aspects.[32] Nevertheless, the initial possibilities presented by quantum computing are merely the tip of the iceberg. With ongoing technological advancements, myriad applications and use cases are bound to arise across diverse fields.

a. Cryptography. Cryptography. QCs have the potential to break many of the currently used encryption techniques, such as the RSA and elliptic curve cryptography.[33] However, QCs can also be used to develop new encryption techniques that are secure against attacks by classical computers.

b. Chemistry. Chemistry. Classical computers currently lack the capability to simulate the behavior of molecules and chemical reactions, whereas quantum computers offer a solution to this limitation. Accelerating the development of new drugs and materials can be facilitated by this.[34]

c. Machine Learning. QCs can be effectively used to perform machine learning tasks, such as clustering, classification, and regression, faster than classical computers. This can facilitate the development of more accurate and efficient machine-learning models.[35] In the future help the medical sector very widely.

d. Optimization. QCs can be used to solve optimization problems, like traveling salesperson problems and the knapsack problem, faster than classical computers. This can lead to more efficient and optimized solutions in various fields, such as logistics and supply chain management.[36]

e. Big Data. Quantum computing has the potential to analyze and process very big datasets at a faster speed than classical computers. The development of more precise and effective data analysis techniques can be a potential outcome of this.[37]

f. Ship Design. Computing Fluid Dynamics or CFD Analysis is used in ship design and ship performance testing grounds. Quantum computing will be more useful to speed up and better analytical process of ship design field.[38] Complicated ship design software can perform better by using a quantum computing system.

PROSPECTS OF QUANTUM COMPUTING

9. The future prospects of quantum computing are very promising. Given the continual technological breakthroughs and the introduction of more powerful quantum computers, quantum computing has great potential to change a wide range of areas and sectors.

a. Material Science. The field of materials science, which has a lot of promise, is one of the most fascinating applications. QCs have the ability to simulate the behavior of molecules and materials at the quantum level, which may enable the development of new materials with novel features that may have significant implications in fields like electronics, energy storage, and renewable energy. This could lead to inventions in areas such as battery technology and solar power.[39]

b. Transformation of Industries. Quantum computing holds the capacity to revolutionize various sectors, including finance and logistics.[40]. QCs can be used to optimize complex financial portfolios and trading strategies, and to solve logistics problems such as route optimization and supply chain management.

c. Application of Quantum Machine Learning. The development of quantum machine learning algorithms has the promise of revolutionizing a variety of industries, including audio and image recognition, natural language processing, and recommendation systems.[41] Quantum machine learning algorithms could also be used to analyze large datasets in fields such as healthcare and finance, leading to new insights and innovations.[42]

d. Simulate and Analyze Data. Quantum computing has immense promise for addressing some of the most important issues affecting humanity, such as sickness and climate change. The impacts of climate change may be simulated using quantum computers, and new materials and technologies could be developed to counteract it. They could also be used to analyze genomic data and to develop new treatments for diseases such as cancer and Alzheimer's.[43]

Present Quantum Computers (QCs)

10. Several companies and research institutions have developed QCs. One of the most well-known quantum computers is the D-Wave System, which is a commercial QC. Another example is IBM's Quantum Experience, which is a cloud-based quantum computing platform that allows users to experiment with quantum algorithms. IBM has made several significant contributions to the field of quantum computing. It is one of the leading companies in the development of QCs. IBM has made significant progress in increasing the number of qubits in their quantum computers, with discrete improving the performance and stability of their systems. [44] In 2016, IBM launched the IBM Quantum Experience, which allowed users to access IBM's quantum computing hardware over the internet. ‘This platform has enabled researchers, developers, and students to experiment with quantum computing and develop new algorithms and applications. IBM has also developed several QCs with increasing numbers of qubits.

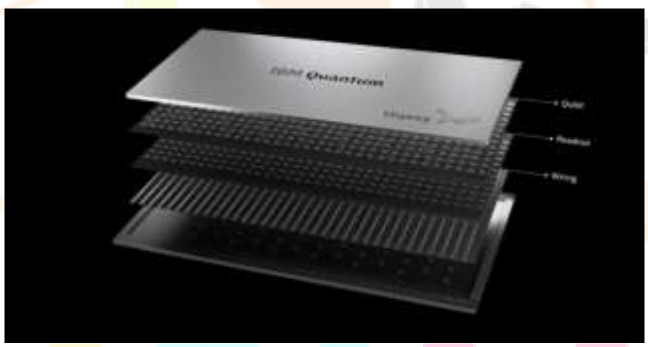

Figure 2:IBM Osprey; IBM’s new 433-quantum bit (qubit) processor[45]

11. In 2017, IBM announced the development of a 50-qubit QC, which was a significant milestone in the field of quantum computing.[46] IBM is a significant contributor to the development of quantum computing and has made significant progress in increasing the number of qubits and improving the performance and stability of their QCs. Very recently, IBM has invented a 433 qubit QC processor(IBM Osprey) and which has been shown in Figure 2 above. InNew York, USA on Nov 9’ 2022 during IBM Quantum Summit 2022, Dr. Darío Gil, Senior VP, IBM and Director of Research has declared, ‘With the introduction of the new 433 qubits 'Osprey' processor, we move one step closer to the day when previously intractable problems will be solved using quantum computers. Together with our partners and clients throughout the world, we are continually scaling up and improving our quantum technology spanning hardware, software, and classical integration to solve the greatest problems of our time. This research will serve as a cornerstone for the upcoming quantum-centric supercomputing age. Future acceptance and expansion of the quantum sector will continue as we continue to scale up quantum technologies and make them easier to operate.[47]

UTILIZATION OF QT IN INTELLIGENCE AND FUTURE WARFARE

12. Science is increasingly succeeding in taking control of this world. Our society and economic future can be shaped by considerable amounts of capital that need to be invested in the research of small but important things. 'The quantum communication with its inherent secure data transmission to QTs with unimagined processing power, quantum simulations of chemical reactions, and quantum sensors for medical diagnostics will revolutionize those fields. At present, engineers are driving the second quantum revolution's wave of metrological possibilities; with the next generations of atomic clocks, even more precise electrical standards and innovative measurement capabilities in medicine as well as engineering fields. [48] To properly understand the potential benefits, we will divide QTs into three categories: 'quantum computing, quantum networks and communications, and quantum sensing and imaging.[49] Actually QTs will dominate the future warfare in many aspects.[50]

Figure 3: QT will change our future by introducing new idea like big brains podcast[51]

13. Quantum computing represents universal programmable QCs, quantum annealers (an imperfect adiabatic computation), and quantum simulators which can provide considerable computational advantage over classical computers. However, 'despite the common misconception that the exponential increase in processing speed will affect and take over all the classical computers' tasks and applications, QCs will definitely be efficient in certain highly complex and challenging computational problems; like quantum simulations, quantum crypto-analyses, faster searching, faster solving of linear or differential equations, quantum optimizations, quantum-enhanced machine learning, etc.[52] The object of quantum networks and communications is to transmit quantum information across various channels, such as fiber-optic lines or free-space communication. The next-generation quantum network, known as QIN or quantum internet, differs in its ability to distribute entangled qubits. In the future, QIN will offer more security-related services, such as secure identification, position verification, and distributed quantum computing[53] which are useful in military applications.

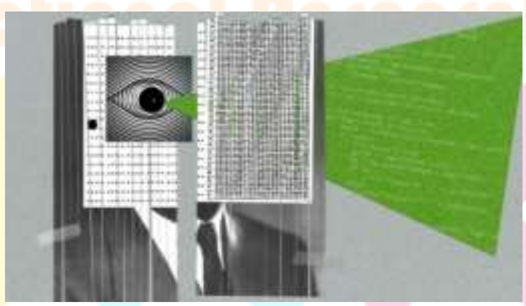

Figure 3: Security Agency spies are trying to shape the future by usingcryptoanalysis and QT [54]

14. Quantum sensing aims for more precise measurements of various physical variables such as magnetic or electric fields, gravity gradients, acceleration rotations, and time. Improved time measurements can be used for more precise clocks, quantum inertial navigation, underground and undersea exploration, more effective radio frequency communication, etc. Quantum sensing is the most developed QT, but the effectiveness of deployed sensors is still very uncertain.[55] Military applications require a portable or mobile solution with low SWaP (size, weight, and power). Again, the spatial resolution of quantum sensors needs to improve, as it is often inversely correlated with sensitivity[56]In future, detecting a submarine from space may be possible, but using a quantum sensor with a valuable degree of precision is unlikely since sufficient spatial resolution will lead to insufficient sensitivity.

So, quantum sensing will revolutionize future warfare in the field of detection, monitoring and controlling. Future C5IRS (Command, Control, Computers, Communications, Cyber, Intelligence, Surveillance, and Reconnaissance) will be highly influenced by QTs.

15. Quantum imaging is a subfield of quantum optics that is active compared to quantum sensors. We know that for any sensor, the Signal-to-Noise Ratio (SNR) represents the fundamental limit of its sensitivity. But, a significantly higher SNR can be reached using quantum entanglement, as the signal itself may be unrecognizable in the background noise without additional knowledge of entanglement.[57] 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. 'Post-Quantum Cryptography (PQC), also known as quantum-resistant cryptography, is nothing quantum at all but an evolution of the present asymmetric cryptography. PQC relies on more advanced mathematics that is more difficult to compute, even for QCs. In the future PQC will be available and resilient against quantum attacks. As an example, based on the National Security Agency (NSA of USA) recommendation, the White House published in 2022 a memorandum providing directions for agencies to start the migration to PQC with full implementation by 2035.[58]

16. As in the past with other technologies, defense applications are again the primary drivers of research and development in the field of QT, particularly in the USA and China, mainly in the air and space domains. Actually, QT has promising potential with real transformational aspirations. However, despite the fact that it is difficult, poorly understood by non-specialists and its importance is often exaggerated and hyped. 'Quantum radar is a quantum imaging system that works similarly to classical radar but at the level of individual photons. Theoretically, it offers various advantages such as higher noise resistance, stealth property as extremely low intensity, low probability of detection, and possible target identification. The principles of quantum LIDAR (light detection and ranging) or RADAR were already demonstrated successfully in laboratories. However, space-based quantum LIDAR applications in the optical regime remain viable in the medium-to-long term.[59] Conversely, more precise quantum or optical atomic clocks can improve the performance of current radars and electronic warfare systems. So, in future warfare in the field of detection and stealth technology, QTs will play a vital role.

17. Free-space quantum communication will be an important channel for future quantum internet and will lead to a higher presence of quantum communication assets in air and space. 'The situation will change with the arrival of reliable quantum memory and high-rate quantum optics. Then, quantum internet with significant space presence may start to build up after 2030. In the future, there is an opportunity to implement quantum communication with laser communication where significant technological overlap exists. Laser communication would offer high-speed data transfer secured by quantum communication.[60] Quantum communication technology will revolutionize the whole communication system by increasing speed and user-friendly application.

18. Intelligence, Surveillance, and Reconnaissance (ISR) is one of the most interesting applications for QT. Individual QTs offer various sensing and imaging systems that significantly improve the extant ISR systems.[61] Quantum magnetometers and gravimeters are two good examples.

So, this technology will revolutionize underwater, submarine and subsurface warfare. In the future detection of submarines may be easier than present. Quantum gravimeters are under the development stage for underground surveillance systems. They are already tested for detecting underground structures like caves, tunnels, bunkers, ammunition stores, secret military assets, research facilities, missile depots, etc. In the future, detection of key points and the enemy's important locations, as well as precision attacks on target places will be easier than before due to better utilization of QTs. So, both types of discussed sensors could be deployed either on airborne systems or on space assets in low Earth Orbit in the near future. So, in the future QT will be a valuable tool to dominate space technology and better utilization of space resources.[62]

19. The quantum radio-frequency (RF) receiver is the closest QT to real deployment. 'For military use, quantum RF receivers could enable reception of advanced Low Probability of Intercept/Low Probability of Detection (LPI/LPD) communications and over-the-horizon RF signals, resistance to RF interference and jamming, RF direction finding, and terahertz frequency imaging.[63] In the future, quantum RF receivers can become the standard RF receiver for multiple systems, such as 5G and the Internet of Things (IoTs). 'Quantum imaging systems could further serve in Intelligence, Surveillance, Target Acquisition, and Reconnaissance roles. These include all-weather, day-night tactical sensing in long/short-range, active/passive regimes, and stealth detection modes. They can work as low-light or low-SNR vision devices in environments with clouds, fog, dust, smoke, and jungle foliage or at night.[64] So, QTs will ease future warfare for detection, Intelligence, Surveillance, Target Acquisition, and Reconnaissance process as a whole.

20. Quantum inertial navigation is another relevant technology for the air domain and is analogous to classical inertial navigation but using quantum sensors.[65] Individual parts are being tested in laboratories and relevant environments with

stabilities sufficient for military use. However, creating a complete quantum inertial measurement unit is still challenging. The first users will probably be submarines with the least restrictive SWaP parameters.[66] In future, we can expect more miniaturization and deployment in planes, drones, and missiles. So, QTs will help for precision targeting and attacking systems and may add another dimension in future warfare.

CHALLENGES OF QUANTUM COMPUTING

21. Quantum computing has many potential advantages, as well as there are also few disadvantages and challenges. The cost of building and operating QCs is currently very high. This limits the accessibility of quantum computing technology to only a few large corporations and research institutions. So, 'there are several significant challenges that need to be addressed and solved before the use of technology is widely adopted around the world.

Quantum computing also faces several challenges, including hardware limitations, error correction, and scalability, which need to be addressed and solved before realizing and utilizing the full potential of quantum computing.[67]

a. Error Correction. QCs are prone to errors due to the delicate nature of quantum states, and these errors can accumulate over time, leading to incorrect results. Before using quantum computing to address real-world issues, this major obstacle must be removed.[68] QCs are also very sensitive to their environment, and any interference or noise can cause calculation errors. This calls for the employment of specific tools and infrastructure to keep the computer's quantum states stable.

b. Availability of Qubits. Another challenge is the limited number of qubits currently available in QCs. While the number of qubits in QCs has been increasing, it is still much smaller than the number of bits in classical computers. This means that QCs can only solve a limited number of problems beyond classical computers' capabilities.

c. Primitive Stage. The development of quantum algorithms is still in its early stages, and a minimal number of algorithms have been developed that can take advantage of the unique properties of QCs. This limits the types of problems that QCs can currently solve. While quantum computers have shown impressive performance for some tasks, they are still relatively small compared to classical computers. So, scaling up QCs to thousands of qubits while maintaining high levels of consistency and low error rates is remains a major challenge' still today.[69]

d. Hardware and Software Development. Developing high-quality quantum hardware, such as qubits and control electronics, is a major challenge. There are many different qubit technologies, each with its own strengths and weaknesses, and developing a scalable, fault- tolerant qubit technology is a major focus of research. Again quantum algorithms and software development tools are still in their infancy, and there is a need for new programming languages, compilers, and optimization tools which can effectively and successfully utilize the power of QCs.

Fig 4: Concepts of quantum warfare using various QTs based systems[70]

e. Classical Computer Interfaces and Protocols. QCs won't replace classical computers; they will serve as balancing technology. Developing efficient and reliable methods for transferring data between classical and quantum computers is essential for practical applications. Again, as the field of quantum computing matures, there is a need for standards and protocols for hardware, software, and communication interfaces. 'Developing these standards will be essential for ensuring compatibility and interoperability between different quantum computing platforms. We need to do benchmarking; as it is the ability to measure performance standards is still in its infancy for quantum computing design, development and operation.[71]

f. Training and HR Development. The number of people properly educated and trained to enter the quantum workforce is small and spread across the world. Finding the right workers and training the new people is a challenge. In the present scenario, government and business owners won't increase the number of people motivated to enter the quantum workforce until they have more practical quantum computers. They won't have more practical QCs until more people are motivated to become part of the quantum workforce.

g. Capital and Cost. Expense remains as a main roadblock for quantum computing industry or QT development. Quantum talent and training are expensive. Quantum hardware and software development is expensive. Supply chains are complex, vulnerable and expensive. Dealing with these expenses and finding investments to offset these costs will remain the biggest challenge, which somehow failed to encourage the institutional scientists and commercial entrepreneurs for the future.

CONCLUSION

22. Quantum computing is a promising technology that has the potential to revolutionize several industries. Quantum computing operates on qubits, which can exist in multiple states simultaneously, allowing quantum computers to perform operations exponentially faster and user-friendly manner than classical computers. IBM is one of the leading companies in the field of quantum computing and has developed several quantum computers. As quantum computing continues to evolve, it is essential to address the challenges and develop solutions to ensure the commercialization and adoption of quantum computing. The development of quantum computing will significantly impact several industries, and it is essential to ensure that the potential of quantum computing is realized. QT is an engineering system which utilizes the quantum properties of photons, electrons, atoms, or molecules. Today, the challenges discussed above are a little discouraging, but there are many reasons for hope and trust. Funding agencies and interested government agencies are rising to the occasion to invest in solving these quantum computing challenges. Scientists and researchers are making advances in engineering and technical challenges to create practical QCs. However, we can anticipate that QTs will use in the field of communication, precision, intelligence, space, medical, chemical, commercial, service and military industries in the future.

23. QTs hold great promise in the long term for a broad range of applications, from sensing to communications including computing, but should not be unspecified to revolutionize defense applications in the predictable future. Even though principles were proven successful in laboratories, the transition from laboratory to real-world applications is still in progress. Again, necessities, like low SWaP, mobility, and cost, still represent significant restrictive factors. Above all limitations and challenges, for a good reason, QTs have captured government and business owners of potential nation's attention and mind's eye. Based on theoretical and laboratory work, scientists and researchers have an appreciation of the technology and its possible uses in real-world applications. Actually, the role of potential nations and entrepreneurs is to set goals and standards to encourage development and ensure interoperability. Meanwhile, potential nations and entrepreneurs must invest in the necessary research and look for dual-use opportunities to speed development and reduce costs.
With this understanding, scientists, researchers, engineers and technologists need to pursue the great promise of QTs with a realistic understanding of the timeline and effort involved. Quantum computing has great potential in many applications, such as improved machine learning and artificial intelligence, better aerodynamic designs for the aircraft and shipbuilding industry, faster simulations, and many more. We hope that there will be a revolutionary change in future warfare and military industry by the effective and efficient use of QTs in full extent.

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1. LindWetal,Thechangingfaceofwar:intothefourth generation, In:Marinecorpsgazette 1989
2. Lind WS, Understandingfourthgenerationwar,MilRev,2004
3. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015, accessed on 21 Mar 2023
4. https://www.weforum.org/agenda/2021/04/quantum-technologies-transform-innovation-and-mitigate-climate-change-gtgs, accessed on 25 Apr 2023
5. Biercuk, M. J. and Fontaine, R., The Leap into Quantum Technology: A Primer for National Security Professionals, War on the Rocks, 17 November 2017
6. https://www.amnh.org/exhibitions/einstein/legacy/quantum-theory, accessed on 22 Apr 2023
7. Lind WS, Understanding fourth generation war, Mil Rev, 2004;84:12, Dec 2022
8. https://quantumcomputingreport.com/google-goal-error-corrected-computer-with-1-million-physical-qubits-by-the-end-of-the- decade, accessed on 21 Apr 2023
9. https://education.jlab.org/qa/quantum_01.html, accessed on 22 Apr 2023
10. https://academic.oup.com/book/978/chapter-abstract/137838934?redirectedFrom=fulltext, Mar 23, 2023
11. https://epjquantumtechnology.springeropen.com/articles/10.1140/epjqt/s40507-021-00113-y#Sec1
12. Wehner, S., Elkouss, D. and Hanson, R., 'Quantum Internet: A vision for the road ahead', Science, Vol. 362, no. 6412, 19 October 2018
13. Affan Ahmed S, Mohsin M, Muhammad Zubair, and Ali S, Survey and technological analysis of laser and its defense applications, Defence Technology, 2020
14. Jonathan P. Dowling and Gerard J. Milburn, Quantum technology: the second quantum revolution, In Philosophical Transactions of the Royal Society of London, Series A, Mathematical,Physical and Engineering Sciences,June 2003
15. TillandJ.Pritchard,*UKquantumtechnologylandscape2016*.DSTL/PUB098369,UKNationalQuantumTechnologiesProgramme,20
16. Stuart A., and Wolf et al., Overview of the Status of Quantum Science and Technology and RecommendationsfortheDoD,InstituteForDefenseAnalyses,June2019
17. Andrew Davies, and Patrick Kennedy, Specialreport,fromlittle things: Quantum technologiesandtheirapplicationtodefence,ASPI(AustralianStrategicPolicyInstitute),2017
18. JacobBiamonteetal., Quantummachinelearning,In:Nature549.7671, Sep2017
19. 'Emerging and Disruptive Technologies', NATO, December 2022. https://www.nato.int/cps/en/natohq/topics_184303.htm accessed on 3 Feb 2023
20. https://www.forbes.com/sites/melissacristinamarquez/2023/03/23/rare-shark-beheaded-on-british-beach-prompts-appeal-scientists-to-help-locate-it/?sh=3b33c9681226, accessed on 1 May 2023
21. Nielsen MA, Chuang IL, Quantum computation and quantum information: 10th anniversary edition, Cambridge: Cambridge University Press, 2010, ISBN 9781139495486
22. DougFinke,GoogleGoal:BuildanErrorCorrectedComputerwith1MillionPhysicalQubitsbytheEndoftheDecade,QuantumComputingreport2020
23. Adriano Barenco, André Berthiaume, David Deutsch, ArturEkert, Richard Jozsa, andChiaraMacchiavello, Stabilization of Quantum Computations by Symmetrization, SIAM Journal on Computing, 26 (5): 1541-1557, 1997
24. Harry Buhrman, Richard Cleve, John Watrous, and Ronald de Wolf , Quantum Fingerprinting, Physical Review Letters, 87 (16): 167902, 2001
25. https://www.sciencedaily.com/releases/2022/08/220804130547.html, accessed on 19 Apr 2023
26. https://www.google.com/imgres?imgurl=https%3A%2F%2Fcdn.mos.cms.futurecdn.net , accessed on 1 May 2023
27. AndrewW.Crossetal., Validatingquantumcomputersusingrandomizedmodelcircuits,In: PhysicalReview,*A*100.3,Sep2019
28. Whitfield, J. D., Biamonte, J., and Aspuru-Guzik, A., Simulation of Electronic Structure Hamiltonians Using Quantum Computers. Molecular Physics, 109(5), 735-750, 2011
29. Shor, P., Polynomial-Time Algorithms for Prime Factorization and Discrete Logarithms on a Quantum Computer. SIAM Journal on Computing, 26(5), 1484-1509. doi: 10.1137/S0097539795293172, 1997
30. Roberson, T., 'Talking about responsible quantum: Awareness is the absolute minimum … that we need to do', arXiv.org. https://doi.org/10.48550/arXiv.2112.01378 , accessed 18 Mar 2023
31. Preskill, J., Quantum computing in the NISQ era and beyond, Quantum, 2, 79, 2018
32. JuanYinetal,Satellite-to-GroundEntanglement-BasedQuantumKeyDistribution,In:Phys-icalReviewLetters, 119.20, Nov2017
33. HaraldAndas,Emergingtechnologytrendsfordefenceandsecurity,FFI-RAPPORT,Apr2020
34. AustinG.Fowleretal.,Surfacecodes:Towardspracticallarge-scalequantumcomputation,In: PhysicalReview, A86.3,Sep2012
35. Philip Inglesant, Marina Jirotka, and Mark Hartswood, Responsible Innovation in Quantum Technologies applied to Defence and National Security, NQIT (Networked Quantum Information Technologies),2018
36. AustralianArmy,ArmyQuantumTechnologyRoadmap,Apr2021
37. E.M. National Academies of Sciences et al., Quantum Computing: Progress and Prospects, NationalAcademiesPress,2019,ISBN:9780309479721
38. FrankAruteetal.,Quantumsupremacyusingaprogrammablesuperconductingprocessor,In: Nature 574.7779, Oct 2019
39. Cao, Y., Romero, J., Olson, J. P., Degroote, M., Johnson, P. D., Kieferová, M., and Aspuru-Guzik, A., Quantum chemistry in the age of quantum computing, Chemical Reviews, 119(19), 10856-10915, 2019
40. Electronics for You, Dec 2022
41. India Electonics Week, 23-25 Nov, 2022
42. Opcit
43. Preskil et al, Quantum computing in the NISQ era and beyond. Quantum, p 2, 79; 2018
44. N D Mermin,QuantumComputerScience:AnIntroduction,CambridgeUniversityPress,2007, ISBN:9781139466806
45. JayGambetta,IBM'sRoadmapForScalingQuantumTechnology,IBM,2020
46. ATARC Quantum Working Group. Applied quantum computing for today's military, White paper, May 2021
47. https://newsroom.ibm.com/2022-11-09-IBM-Unveils-400-Qubit-Plus-Quantum-Processor-and-Next-Generation-IBM-Quantum-System-Two, accessed on 07 May 2023
48. 48.https://www.ptb.de/cms/fileadmin/internet/forschung_entwicklung/Innovationscluster_der_PTB/Innovationscluster_Quantentechnologie/Info_Sheet_Quantum_Technology.pdf, accessed on 23 Apr 2023
49. Krelina, M., Quantum Technology for Military Applications, EPJ Quantum Technology, 8 December 2021
50. VedranDunjko and Peter Wittek, A non-review of Quantum Machine Learning: trends and explorations, In:Quantum Views 4, Mar 2020
51. https://www.google.com/imgres?imgurl=https%3A%2F%2Fnews.uchicago.edu, accessed on 01 May 2023

52. https://epjquantum technology.springeropen.com/articles/10.1140/epjqt/s40507-021-00113-y#Ack1, accessed on 16 Jan 2023
53. Wehner, S., Elkouss, D. and Hanson, R., 'Quantum Internet: A vision for the road ahead', Science, Vol. 362, no. 6412, 19 October 2018
54. https://www.technologyreview.com/2022/02/01/1044561/meet-the-nsa-spies-shaping-the-future, accessed on 01 May 2023
55. ATARC Quantum Working Group, Applied Quantum Computing for Today's Military, White paper,May2021
56. https://doi.org/10.1126/science.aam9288, accessed on 23 Feb 2023
57. KelleyM.Sayler,DefensePrimer:QuantumTechnology,IF11836,June2021
58. https://www.whitehouse.gov/wp-content/uploads/2022/11/M-23-02-M-Memo-on-Migrating-to-Post-Quantum-Cryptography.pdf, accessed on 23 Feb 2023
59. Daum, F., Quantum Radar Cost and Practical Issues, IEEE Aerospace and Electronic Systems Magazine, Nov 2020
60. https://warontherocks.com/2017/11/leap-quantum-technology-primer-national-security-professionals, accessed on 12 Apr 2023
61. Middleton A, Till S, Steele M. Quantum Information Processing Landscape 2020: Prospects for UK Defence and Security. DSTL/TR121783, June 2020
62. https://doi.org/10.1126/science.aam9288, accessed on 22 Apr 2023
63. Travagnin, M., 'Cold Atom Interferometry for Inertial Navigation Sensors', Joint Research Centre, European Commission, 2020
64. Wehner, S., Elkouss, D. and Hanson, R., 'Quantum Internet: A vision for the road ahead', Science, Vol. 362, no. 6412, 19 October 2018
65. MicheleMoscaandMarcoPiani,QuantumThreatTimeline,GlobalRisk Institute,2019
66. Australian Army, Army Quantum Technology Roadmap, Apr 2021
67. https://www.act.nato.int/articles/nato-exploring-quantum-technology-future-challenges.accessed on 12 Apr 2023
68. Preskill, J., Quantum computing in the NISQ era and beyond, Quantum, 2018
69. MarkusReiheretal.,Elucidatingreactionmechanismsonquantumcomputers,In:ProceedingsoftheNationalAcademyofSciences,114.29, Jul2017
70. https://www.japcc.org/articles/quantum-technology-for-defence, accessed on 05 May 2023
71. https://thequantuminsider.com/2023/03/24/quantum-computing-challenges, accessed on 6 May 2023