December 2021 Edition

Briefing Memo

Military Applications of Quantum Technologies

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Introduction

There has been increasing discussion surrounding quantum technologies[1] in the last few years. Indeed, major countries worldwide, including the U.S. and China, have focused on their potential and are investing heavily in research and development. Quantum technologies are just emerging but are likely to become fundamental to society and thus have the potential to drastically change humankind's socio-economic activities. These technologies may also seriously impact security and military fields.

The Defense Science Board (DSB), an advisory body to the U.S. Department of Defense, released a summary version of its report on quantum technology in December 2019. The report lists quantum sensors, quantum computers, and quantum communications as the quantum technologies with the most significant potential for military applications.[2] This paper will briefly touch on the relationship between these three quantum technologies and quantum mechanics, which form their basis, and then give an overview of their potential military applications.

Quantum Mechanical Concepts and Quantum Technologies

Quantum technologies emerged in the early 20th century and are based on the concept of quantum mechanics, which aims to clarify the unique properties and behavior of electrons and photons (collectively known as quanta) in the microscopic world. According to quantum mechanics, a quantum is a mysterious entity that has the property of acting as a particle and a wave simultaneously. This property is called wave-particle duality and demonstration experiments are still being conducted[3].

In addition to this, quanta have two properties (quantum natures): superposition and entanglement. Superposition is a property that allows a quantum to maintain multiple states simultaneously, while quantum entanglement is a property that allows intertwining between multiple quanta.[4] However, these properties are difficult to maintain because they collapse due to interactions with the environment surrounding the quantum.[5]

Quantum natures, as explained by quantum mechanics, can be applied to a variety of technologies. For example, superposition allows 0 and 1 to be represented simultaneously, unlike only representing 0 or 1 at once, as in conventional computing. Quantum computing attempts to process large numbers of information patterns simultaneously through quantum bits (qubits) that use this property.[6] By comparison, quantum communication attempts to realize high-speed communications between distant points by encoding information on multiple quanta in a state of quantum entanglement. Research and development are also underway to realize quantum cryptographic communications that are in principle impossible to intercept or eavesdrop on through the use of quantum properties.[7]

Quantum Sensors

Of the quantum technologies being developed, quantum sensors are considered the closest to being put to practical use by militaries.[8] Quantum sensors are ultra-sensitive sensors that use properties such as quantum entanglement to measure physical quantities and are expected to be used in applications such as radar in the military.[9]

Quantum radar emits one of a pair of photons in a state of quantum entanglement. When the photon is reflected from the target, the intertwining with the other photon is detected, measuring the target's distance. However, there are many challenges to developing a workable quantum radar, such as the difficulty of maintaining a quantum entangled state during radar operations.[10] For this reason, experts have expressed skepticism about the military applications of quantum radar.[11]

The use of quantum sensors for positioning, navigation, and timing (PNT) will enable highly precise self-positioning and navigation without relying on external PNT signals such as GPS satellites. These sensors could be useful navigation tools for submarines underwater, for example.[12] Additionally, quantum sensors could be used as a backup for military GPS, enabling precise navigation even when satellites are unavailable due to cyber-attacks or electronic jamming.

Quantum sensors are also expected to improve intelligence, surveillance, and reconnaissance (ISR) capabilities. For example, quantum sensors would significantly improve the ability to detect ballistic missile submarines (SSBNs) that carry nuclear missiles. Specifically, experts believe quantum sensors can be used to measure changes in magnetic fields and gravity caused by SSBNs when they are submerged. However, the development of such quantum sensors is currently in the early stages.[13] Experts also point out that these sensors may undermine the residual nature of nuclear deterrence for countries operating SSBNs.[14]

Quantum Computing

Although the possibility of new computational systems using quantum properties has been explored for many years, the concept of a quantum computer was only presented in 1980.[15] In that year, U.S. physicist Paul Benioff published a paper showing that quantum computers were theoretically feasible[16].

In 1994, Peter Shor, an applied mathematician from America, developed Shor's algorithm, which uses quantum properties to factorize large numbers much faster than conventional computers. Interest in quantum computers grew rapidly when it became clear that RSA encryption (public-key encryption), the current standard encryption system, could be deciphered once a quantum computer using this algorithm became a reality. Since this time, various research and development efforts by Google, IBM, and other companies have now succeeded in developing quantum computers with tens of qubits.[17]

One possible military application of this technology is a quantum attack, in which the decryption capabilities of a quantum computer are used to steal critical information from an enemy's RSA-based communications network.[18] It is estimated, however, that a quantum computer with 20 million qubits will be needed to break the RSA cipher. This technology is not expected to be realized until around 2030 to 2040 at the earliest.[19]

There are concerns about this technology leaking from the U.S. For example, the U.S. Department of Commerce added eight Chinese companies to its list of companies with which it has security concerns (entity list) in November 2021 for obtaining U.S.-made quantum computers to help modernize the Chinese People's Liberation Army. Specifically, their activities reportedly involved improving the PLA's decryption capabilities.[20]

Quantum Communication

Quantum communication is attracting attention as a next-generation communication technology that can prevent information leakage due to interception and cyber-attacks. Quantum key distribution (QKD) is a relatively well-known method of encrypting information using quantum properties.[21] China is vigorously working on the practical use of quantum cryptography using this method.

China claims to have launched the world's first quantum science experimental satellite, Mozi, in August 2016 and completed a quantum key distribution communication trunk line connecting Beijing and Shanghai in August 2017.[22] A month later, in September 2017, image encryption transmission between Beijing and Vienna (Austria) using the quantum key distribution method was carried out via Mozi, enabling video conferencing between the two locations.[23] In addition, in January 2021, China announced a successful 4,600 km long transmission using satellite-to-ground quantum communication via Mozi.[24]

However, China's quantum communication is only a commercially-based business. There are many hurdles to be overcome in realizing quantum communication that can be used for military purposes. According to the aforementioned DSB report, quantum key distribution has not yet achieved sufficient security to be used by the U.S. military[25].

However, when quantum key distribution reaches a militarily practical level, it is expected to be used for wireless communications between ships and aircraft, as well as for optical fiber communications between fixed facilities such as ground command facilities and naval and air bases. However, the collapsible nature of quantum properties means wireless communication through free space has some challenges, such as being limited to within the line-of-sight without any obstacles along the transmission line.[26]

Experts point out that quantum cryptography may be introduced into communications with SSBNs, creating a secret communication method that cannot be intercepted. However, complex challenges must be overcome to achieve this, such as protecting quantum properties from collapsing during transmission through the ocean.[27]

Conclusion

This paper has examined the potential military applications of quantum sensors, quantum computers, and quantum communications. In addition, other quantum technologies are also expected to be applied to various areas of military and warfare in the future. As a result, it is predicted that quantum warfare will emerge as a new form of warfare.[28] However, we should avoid overestimating the impact of quantum technology on the future of military operations at this time, as it is still in the development stage and many of the challenges to its practical application are yet to be resolved. Therefore, a deeper consideration of the impact of quantum technology on Japan's national security is required while following future development trends. In addition, discussions regarding potential military applications must also be held.

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[1] Quantum technologies are already seeing practical use in familiar devices such as semiconductors and lasers. This usage is referred to as quantum technology 1.0. The quantum technologies discussed in this paper are referred to as quantum technology 2.0. They aim to greatly expand the range of practical applications by maximizing the unique properties of quantum physics. "Quantum Technology 1.0," *Physicus Minimus*, July 31, 2020, https://physicus-minimus.com/en/quantum-technology-1/; Yoshiaki Shimada, *Ryoshi Gijutsu 2.0 Kara Ryoshi ICT e: Ryoshi Rikigaku o Joho Shori ni Ikasu* [From Quantum Technology 2.0 to Quantum ICT: Applications for Quantum Mechanics in Information Processing], Tsukuba Science News, November 1, 2018.

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