A New Frontier in Warfare:
The Future of Quantum Sensing and Communication

Sunil Tyagi

Introduction

In the annals of military history, pivotal moments often hinge on scientific and technological breakthroughs. World War II serves as a stark illustration of this phenomenon. The strategic dynamics of the war, particularly in the Asia-Pacific theatre, were dramatically altered by the scientific advancements of the United States. Central to these were developments in cryptographic methods and information theory, crucial in intercepting and breaking the Japanese cypher. This achievement played a decisive role in the U.S. securing victory in the Battle of Midway[1]. Additionally, a monumental leap in subatomic physics led to the development and deployment of atomic bombs, which precipitated Japan's surrender and marked a profound and sombre conclusion to the conflict in Asia.

Today, we stand at the precipice of a new scientific revolution with the emergence of Quantum Information Science (QIS). This field represents a fusion of information science and subatomic physics, heralding a new era in military technology. At its core, QIS leverages quantum phenomena, particularly quantum entanglement, to revolutionise the way we acquire, represent, encode, process, and transmit information, extending far beyond the capabilities of classical methods.

This chapter delves into the realm of QIS, critically examining its potential to transform future warfare. Just as the atomic bomb, born from subatomic physics, reshaped military strategy and global politics, quantum information science is poised to usher in a new era of military capabilities. We will explore how quantum sensing



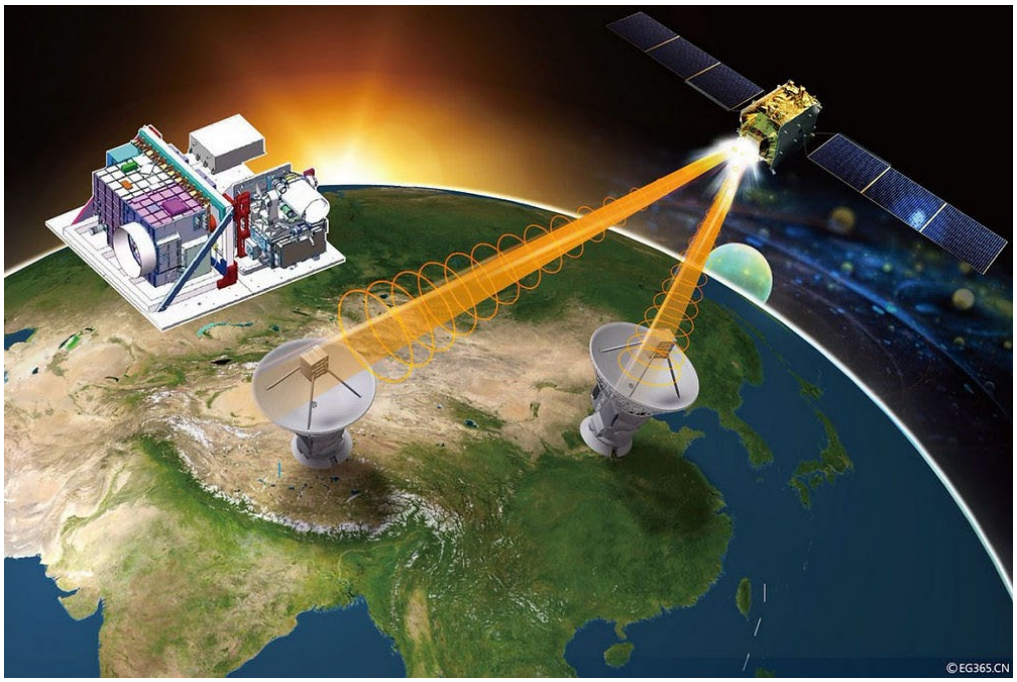


[1] Philip H Jacobsen, 'Navy Cryptology and the Battle of Midway: Our Finest Hour', *The Sextant*, June 2013.

Author's manuscript. Published in: Golani A (ed.), Asian Defence Review 2024: Emerging Technologies and Changing Dimensions of Threats for India. New Delhi: KW Publishers; 2024. pp. 30–57. ISBN 978-81-973214-3-6.

and communication might not only advance military technology but also redefine the global balance of power and security dynamics in this burgeoning quantum age.

China's recent launch of the Quantum Experiments at Space Scale (QESS) satellite is a testament to the QIS revolution[2]. While currently engaged in relatively simple communication tasks and the distribution of entanglement, the satellite serves as a pivotal platform for China to develop and test crucial quantum technologies. These technologies have the potential to be transitioned into highly disruptive intelligence and military systems. A part of the appeal of quantum sensing and quantum communications is their potential for weaponisation, standing in contrast to quantum computation, which presents a set of challenges distinct from those of practical applicability in military contexts. The QESS satellite thus not only marks a significant leap in quantum communication but also signals the dawning of a new paradigm in strategic military technology.



Courtesy: The Hacker News, https://thehackernews.com/2017/08/quantum-satellite-data.html

In this chapter, we look beyond the existing landscape of quantum technologies, such as quantum computers and quantum cryptography, where ample literature is already available. Our aim is to venture into the possibilities in QIS that lie ahead, beyond the horizon, and to consider the limits of the conceivable within the bounds of physics. By engaging in this exploration, we aim to pre-empt any future strategic surprises by our adversaries, ensuring that we not only keep pace with but anticipate the quantum leaps in military technology that the future may hold.

[2] Wang Wei, 'Chinese Quantum Satellite Sends First "Unhackable" Data to Earth', *The Hacker News*.

Quantum Information Science: Beyond Computation to Future Warfare

As we peer into the future of quantum technology, it's essential to broaden our understanding beyond the commonly known realm of quantum computation. While the capability of quantum computers to break traditional cryptographic systems like RSA — exponentially faster than the combined computational power of all existing classical supercomputers — is well-acknowledged[3], the scope of Quantum Information Science (QIS) extends far beyond these crypto-analytical applications.

We aim to explore the potential contributions of QIS to the future battlefield, with a specific focus on sensing and communication. This exploration is not merely an academic exercise; it's a strategic anticipation of the evolving nature of warfare. Recent theoretical research in QIS suggests that, under certain conditions, the science and technology of quantum mechanics could significantly enhance:

- Standoff electromagnetic quantum sensing,
- Underwater quantum communications,
- Quantum gravimetry.

These advancements represent a frontier in military technology, offering capabilities that are currently in the theoretical and experimental stages. The transition from concept to practical application on the battlefield involves overcoming numerous scientific and technological challenges. Extensive research, both theoretical and experimental, is necessary to bring these ideas to fruition.

However, it is imperative that we start contemplating these future possibilities now. The path from theory to application is complex and requires foresight and dedication. By proactively engaging with these emerging technologies, we can ensure that we are not caught off guard by future developments in quantum warfare. As we delve into the specifics of these quantum advancements, we prepare ourselves to meet the challenges and opportunities that lie on the horizon of modern military strategy.

The Convergence of Information Science and Subatomic Physics

Understanding Quantum Information Science

Quantum Information Science (QIS) represents a radical departure from classical information science, inviting us into a realm where the principles of quantum mechanics redefine the traditional rules of computing and communication. At the intersection of information science and subatomic physics, QIS is not merely an academic curiosity but a field with the potential to revolutionise technology and society.

[3] Captain Sunil Tyagi, 'Future-Proofing Encryption: The Imminent Threat of "Store Now, Decrypt Later" and Quantum Computing', *Expert View*, Vol. 23, no. 16, November 2023, pp. 1–7.

Foundations of Quantum Mechanics



Quantum Information Science (QIS) is deeply rooted in the principles of quantum mechanics, a fundamental branch of physics that studies the behavior of particles at the atomic and subatomic levels. This branch of physics unveils a world far removed from our everyday experiences, where particles like atoms and photons behave in ways that challenge our classical understanding of reality.

In the quantum realm, particles exhibit a duality, behaving as both particles and waves. This duality is akin to a coin spinning in the air, representing the concept of superposition — where, like the spinning coin, quantum particles can exist in multiple states simultaneously. It's only when we 'look', or measure, that the coin (or particle) lands in one of the definite states.

Superposition and Quantum Bits



In classical computing, the bit is the fundamental unit of information, existing in one of two definite states: 0 or 1. A qubit, or quantum bit, is like a super-charged version of a regular computer bit. Thanks to a quantum mechanics principle called superposition, a qubit can exist in multiple states at once—it can be 0, 1, or both 0 and 1 simultaneously. This unique ability allows quantum computers to store and process a vastly larger amount of information more efficiently than traditional computers, making them incredibly powerful for certain types of calculations.

Entanglement: A Quantum Link

In the intriguing world of quantum mechanics, a phenomenon known as quantum entanglement occurs when particles become so deeply interconnected that the state of one instantly influences its entangled partner, regardless of the distance between

them. Albert Einstein famously referred to this phenomenon as 'spooky action at a distance,' emphasising its counterintuitive nature. Far from being merely theoretical, entanglement serves as the foundation for quantum communication systems, including technologies like the QESS satellite.

This phenomenon leads to what is known as quantum correlations, where the behaviours of entangled particles are interlinked in ways that defy classical physics. An extraordinary aspect of entangled particles is their capacity to hold twice the amount of information compared to classical systems[4]. This characteristic not only challenges our conventional understanding of information but also has profound implications for fields like quantum computing and secure communications, where this enhanced information capacity can be leveraged for more efficient processing and unbreakable encryption protocols.

The processing of quantum information involves manipulating qubits to perform calculations. Because qubits can exist in multiple states simultaneously, quantum computers can theoretically solve certain problems much faster than classical computers. Problems that would take classical computers millions of years to solve could potentially be tackled by quantum computers in a matter of seconds.

Advancements in Quantum Sensing: Radar, Imaging, and LIDAR

Quantum Information Science (QIS) holds immense potential to revolutionise standoff electromagnetic sensing, capitalising on the inherent advantages of quantum phenomena like entanglement and superposition. These quantum principles open new possibilities in electromagnetic sensing, including more accurate radar systems, sophisticated imaging techniques, and advanced LIDAR capabilities, all of which hold significant promise for military applications.

Exploiting the Quantum Entanglement Correlations

Quantum entanglement endows quantum systems with the ability to hold twice as much information as classical systems, paving the way for breakthroughs in fields like quantum computing and secure communications. This enhanced level of correlation can be ingeniously utilised in quantum radar technology to discern between signal photons—those carrying useful information—and mere noise photons.



To illustrate, imagine a game of flash where each photon is analogous to a playing card.

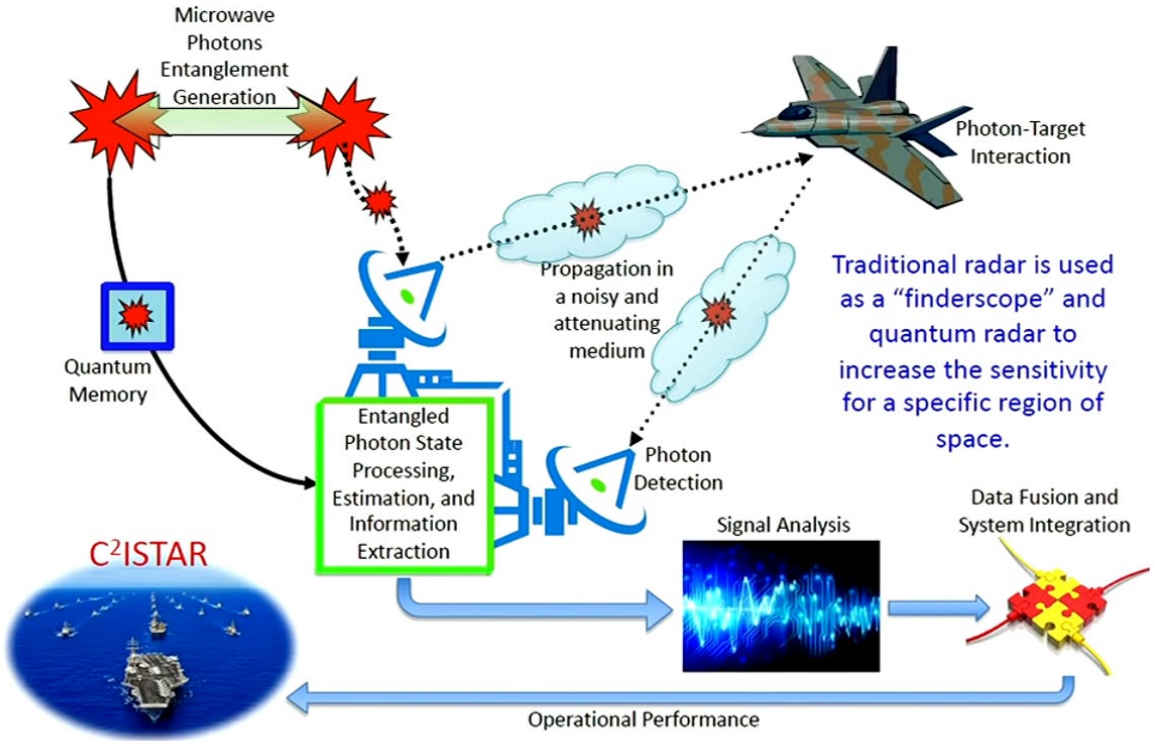
[4] Jeffrey Bub, 'Quantum Entanglement and Information', in Edward N. Zalta and Uri Nodelman (eds.), *The Stanford Encyclopedia of Philosophy*, (Metaphysics Research Lab, Stanford University, 2023).

Entanglement serves as the secret markings on the back of the cards. Just as a savvy player might identify the value of a card based on its unique markings, entanglement enables us to identify the 'good' photons. This analogy simplifies the understanding of quantum correlations and highlights the strategic edge it provides in quantum sensing—akin to having an ace up one's sleeve.

Quantum Radar

The concept of quantum radar operates on the principle of quantum entanglement, where a pair of photons share a correlated state that allows for an enhanced mutual information capacity, double that of the best classical correlations[5]. In a quantum radar system, one photon from the entangled pair is retained in quantum memory, while its counterpart is dispatched toward a target (refer Fig. 1). This photon's journey through an attenuating medium may result in absorption or scattering, necessitating repeated trials, possibly in the order of billions, to ensure return and detection. Successful return allows us to exploit entanglement correlations to discern if the detected photon is the signal (reflected from the target) or merely background noise. This additional information can significantly augment target detection and characterisation.

Fig. 1: Conceptual description of a quantum radar system.



Source: Marco Lanzagorta, Quantum radar, (Springer Cham, 2023)

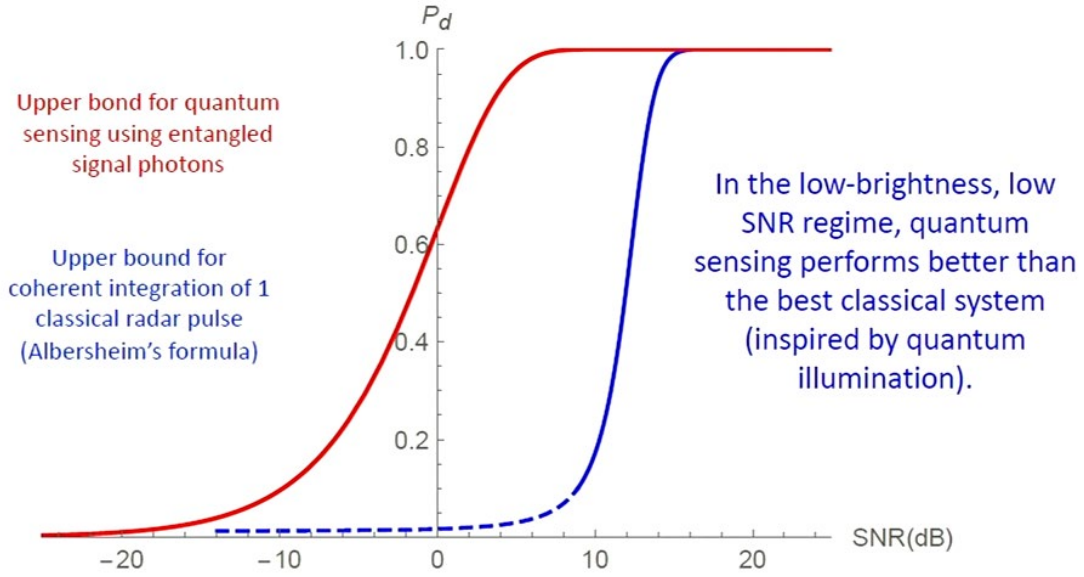
[5] Marco Lanzagorta, *Quantum radar*, (Springer Cham, 2023).

The graph in Fig.2 illustrates the comparative performance of quantum and classical radar systems, depicted by the red and blue lines respectively, with respect to the probability of target detection and the signal-to-noise ratio (SNR)[6]. A detection probability of one indicates absolute certainty of target detection, whereas zero signifies no detection chance. In scenarios where the SNR is high, meaning either the signal is strong or the noise is minimal, both systems perform similarly with high detection certainty.

However, the quantum radar demonstrates a distinct advantage in environments with lower SNR. At zero decibels, a challenging condition for signal discernment, the quantum radar maintains a detection probability of 0.6, a significant improvement over the classical radar, which approaches a detection probability near zero. This enhanced capability, provided by the quantum radar, is attributed to the additional information encoded within the entangled photons.

In practice, these benefits translate to stealthier sensing operations, increased resilience to signal jamming, and improved imaging quality, particularly in synthetic aperture radar (SAR) applications. By effectively cutting through noise and clutter, quantum radar technology promises a substantial leap in detection capabilities, especially in the low SNR regime spanning from -5 to 10 decibels.

Fig. 2: Target Detection Probability and Signal-to-Noise Ratio



Source: Djordjevic, IB., IEEE Access, Vol. 10, 2022.

[6] Ivan B. Djordjevic, 'Entanglement Assisted Radars With Transmitter Side Optical Phase Conjugation and Classical Coherent Detection', *IEEE Access*, Vol. 10, 2022, pp. 49095–49100.

The development of quantum radar technology is grounded in tangible progress, not merely theoretical concepts. It's not a pie-in-the-sky. Researchers across the globe, especially Chinese researchers, are piecing together the various sophisticated technologies required for quantum radar, such as quantum memories and the generation of entanglement. While the current capacity to generate entangled photons, particularly in the microwave regime, remains limited, the trajectory of this research is promising. There is a strong belief within the scientific community that through continued innovation and development, these nascent technologies will mature, paving the way for the practical implementation of quantum radar systems in the future. Reference to some of the cutting-edge technologies that are being developed are as given below:

- Microwave entangled photons generation - Zhong, Han and Jiang, 2020[7].
- Quantum memories - Tian-Shu Yang et al., 2018[8].
- Effects of atmosphere on entangled photons - James and Smith, 2009[9].
- Quantum photon target interaction - Jun Zhang et al., 2015[10].

Quantum Lidar

Quantum LIDAR (refer to schematic shown in Fig. 3[11]), akin to quantum radar, is another transformative application in the quantum sensing landscape. Quantum LIDAR holds promise for stealth underwater navigation and obstacle detection by utilising photons within the blue-green spectrum, the optimal range for penetrating seawater. For instance, submarines traversing the icy waters of the Arctic typically rely on active sonar for ice detection—a method that compromises stealth due to the sonar 'pings'. Quantum LIDAR could offer a discreet alternative by employing entangled photons to probe the environment, repeating the process to confirm the presence of obstacles. This technology signifies a stride towards enhancing covert operations and collision avoidance systems in naval applications. The submarine doesn't have to ping sound for collision detection and navigation.

---

[7] Han-Sen Zhong, Hui Wang, Yu-Hao Deng, Ming-Cheng Chen, Li-Chao Peng, Yi-Han Luo, Jian Qin, Dian Wu, Xing Ding, Yi Hu, Peng Hu, Xiao-Yan Yang, Wei-Jun Zhang, Hao Li, Yuxuan Li, Xiao Jiang, Lin Gan, Guangwen Yang, Lixing You, Zhen Wang, Li Li, Nai-Le Liu, Chao-Yang Lu, and Jian-Wei Pan, 'Quantum computational advantage using photons', American Association for the Advancement of Science, *Science*, Vol. 370, no. 6523, December 2020, pp. 1460–1463.

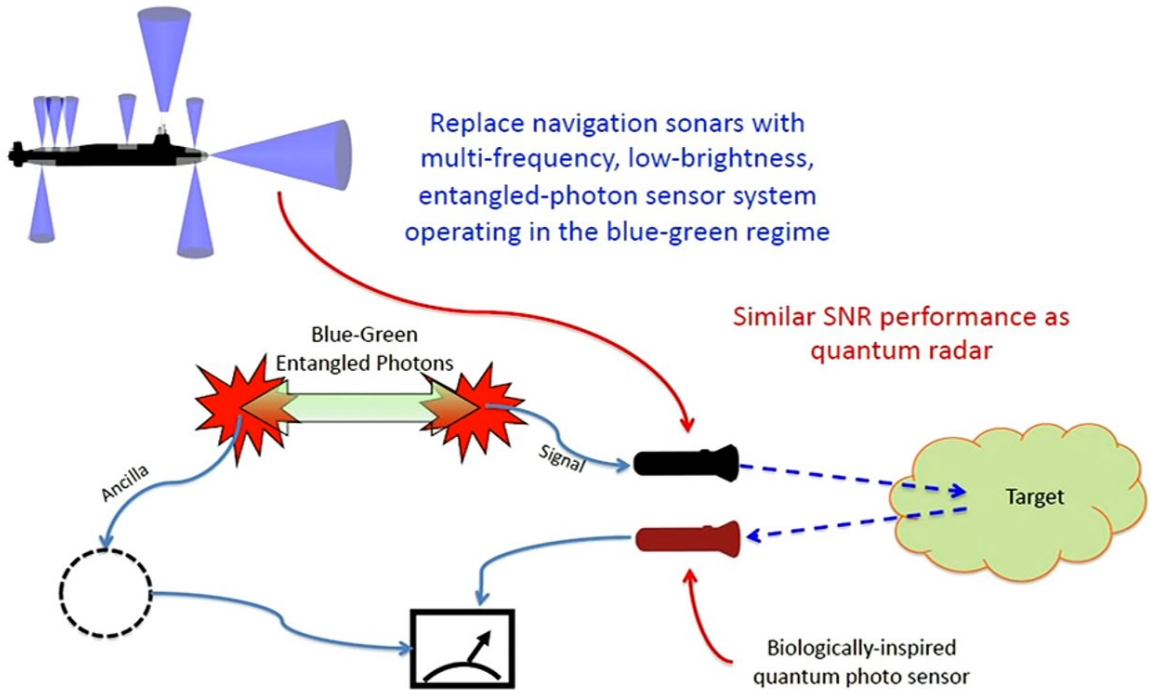
[8] Tian-Shu Yang, Zong-Quan Zhou, Yi-Lin Hua, Xiao Liu, Zong-Feng Li, Pei-Yun Li, Yu Ma, Chao Liu, Peng-Jun Liang, Xue Li, Yi-Xin Xiao, Jun Hu, Chuan-Feng Li, and Guang-Can Guo, 'Multiplexed storage and real-time manipulation based on a multiple degree-of-freedom quantum memory', Nature Publishing Group, *Nature Communications*, Vol. 9, no. 1, August 2018, p. 3407.

[9] James F. Smith Iii, 'Quantum entangled radar theory and a correction method for the effects of the atmosphere on entanglement', in 'Quantum entangled radar theory and a correction method for the effects of the atmosphere on entanglement', *Quantum Information and Computation VII*, Vol. 7342, (SPIE, April 2009), pp. 76–87.

[10] Zhong, Wang, Deng, Chen, Peng, Luo, Qin, Wu, Ding, Hu, Hu, Yang, Zhang, Li, Li, Jiang, Gan, Yang, You, Wang, Li, Liu, Lu, and Pan, 'Quantum computational advantage using photons'.

[11] Marco Lanzagorta and Jeffrey K. Uhlmann, 'Quantum imaging in the maritime environment', *OCEANS 2017 – Anchorage*, 2017, pp. 1–10.

Fig. 3: Submarine Navigation and Obstacle Detection with Quantum Lidar



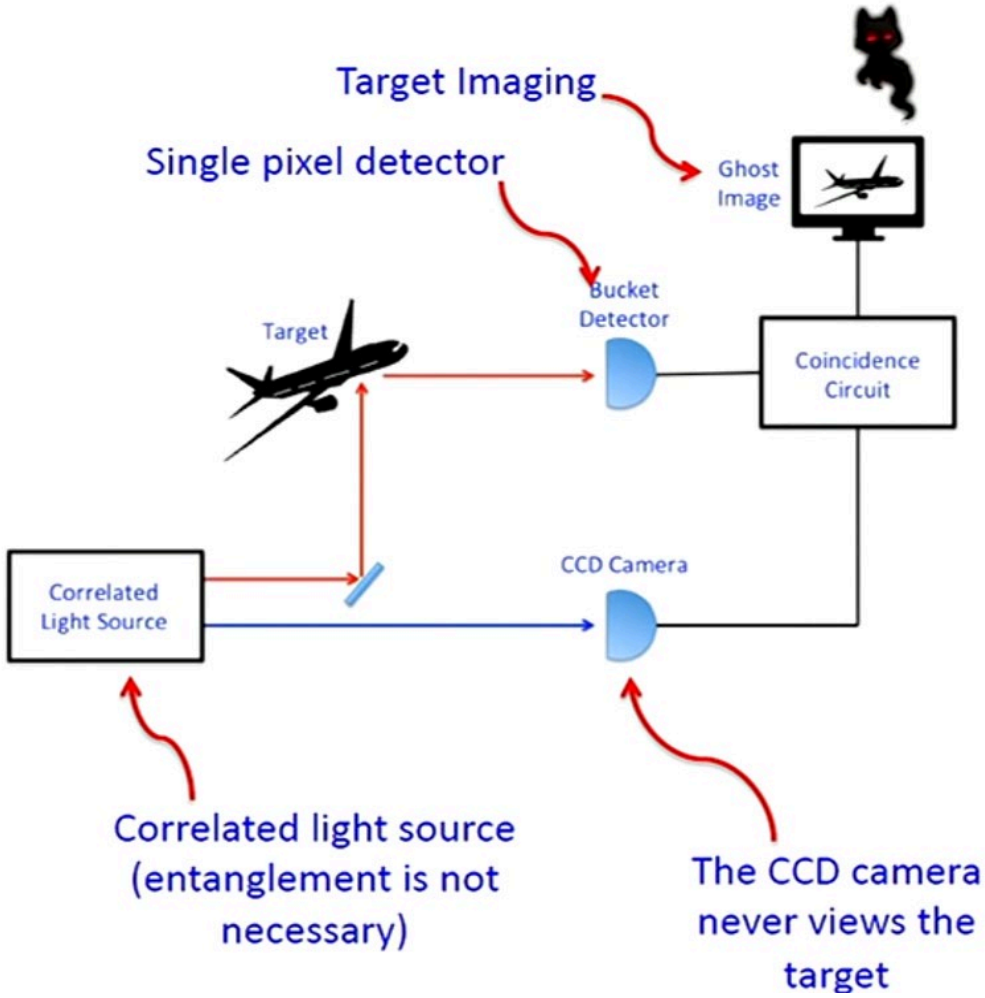
Source: OCEANS 2017 – Anchorage

Ghost Imaging

Ghost imaging[12], as depicted in Fig. 4, leverages a correlated light source and a unique configuration involving a CCD camera, which intriguingly never views the target directly. Instead, part of the beam from the light source is directed to the target and then captured by a single-pixel detector, known as a bucket detector. The remainder of the beam is sent to the CCD camera. Through a coincidence circuit, these separate paths are correlated, enabling the reconstruction of the target's image. This method illustrates a remarkable application of quantum principles, where mere fragments of light interacting with the object allow for detailed imaging, embodying the concept's name by creating a "ghost" image of the target.

[12] Ming Zhao, Jeffrey Uhlmann, Marco Lanzagorta, Jayanth Kanugo, Aditya Parashar, Oliverio Jitrik, and Salvador E Venegas-Andraca, 'Passive ghost imaging using caustics modeling', in 'Passive ghost imaging using caustics modeling', *Radar Sensor Technology XXI*, Vol. 10188, (SPIE, 2017), pp. 179–187.

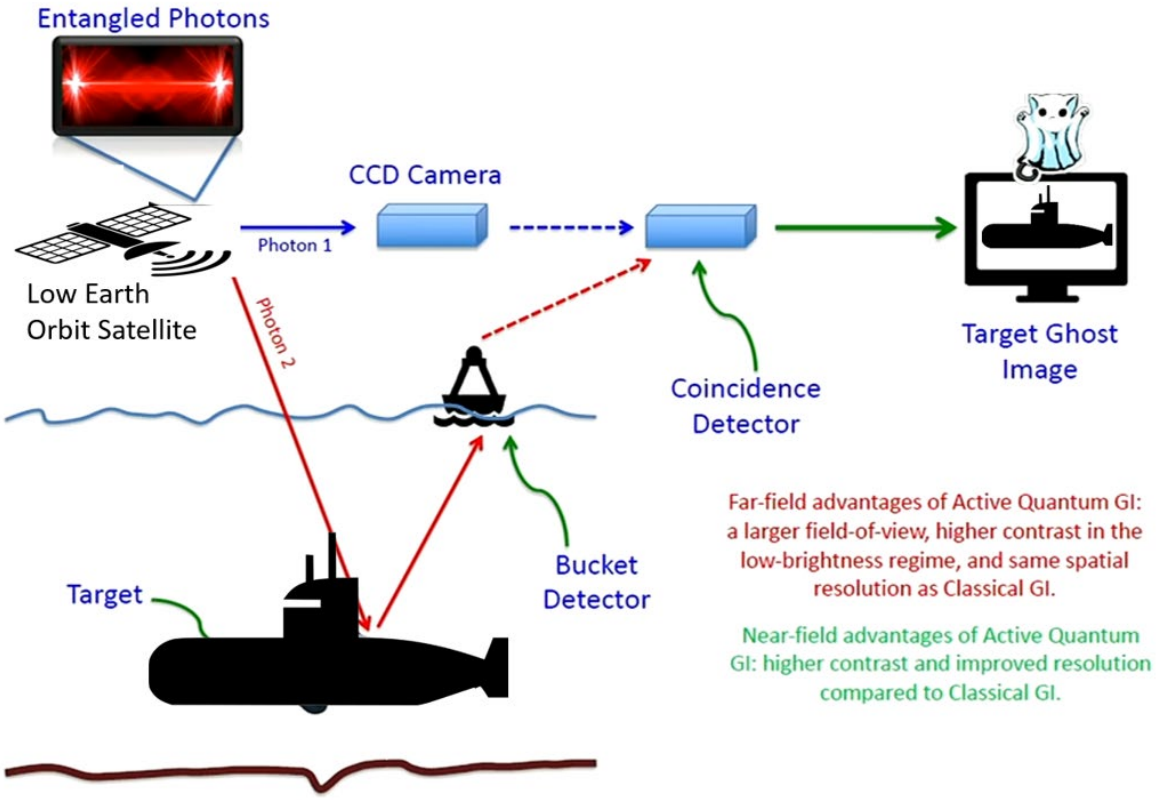
Fig. 4: Ghost Imaging



Source: Zhao et. al. https://doi.org/10.1117/12.2262656

So, for satellite-based Synthetic Aperture Radar (SAR) imagery, using blue-green light (instead of radio waves) is very effective in the maritime environment when you want to detect objects in the ocean, like submarines. Using quantum-correlated visible light, you can scan vast areas of the sea and get better contrast and resolution. It could prove to be very effective for submarine detection, as depicted in Fig. 5. Active quantum ghost imaging, as depicted in the schematic, utilises entangled photons to capture an image of a target without direct observation. One photon from the entangled pair is directed towards the target, and its interaction is captured by a bucket detector. The other photon is sent to a CCD camera. A coincidence detector then correlates the information from both detectors to reconstruct an image of the target, known as the "ghost" image. This technique offers advantages in submarine detection, such as improved resolution and contrast, which is especially useful in challenging visibility conditions like underwater environments.

Fig. 5: Active Quantum Ghost Imaging



Source: Zhao et. al. https://doi.org/10.1117/12.2262656

Advancements in Quantum Underwater Communications

In the realm of underwater communications, particularly with submarines, traditional methods have relied heavily on electromagnetic waves at very low frequencies (VLF, 3–30 kHz) and, until its obsolescence, extremely low frequency (ELF, 1 Hz to 300 Hz). Despite their utility, these methods are hampered by significant limitations, including the need for vast antenna arrays for both transmission and reception, a drastically constrained bandwidth and the requirement of specific course and speed alterations. For instance, VLF communication requires a cumbersome towed array antenna. Still, it only enables transmission of approximately 300 bits per second at a depth of 100 meters. At the same time, ELF's capabilities are even more restricted, allowing only a few characters per minute. ELF is also rather impractical to implement due to the requirement for a huge antenna size for transmission.

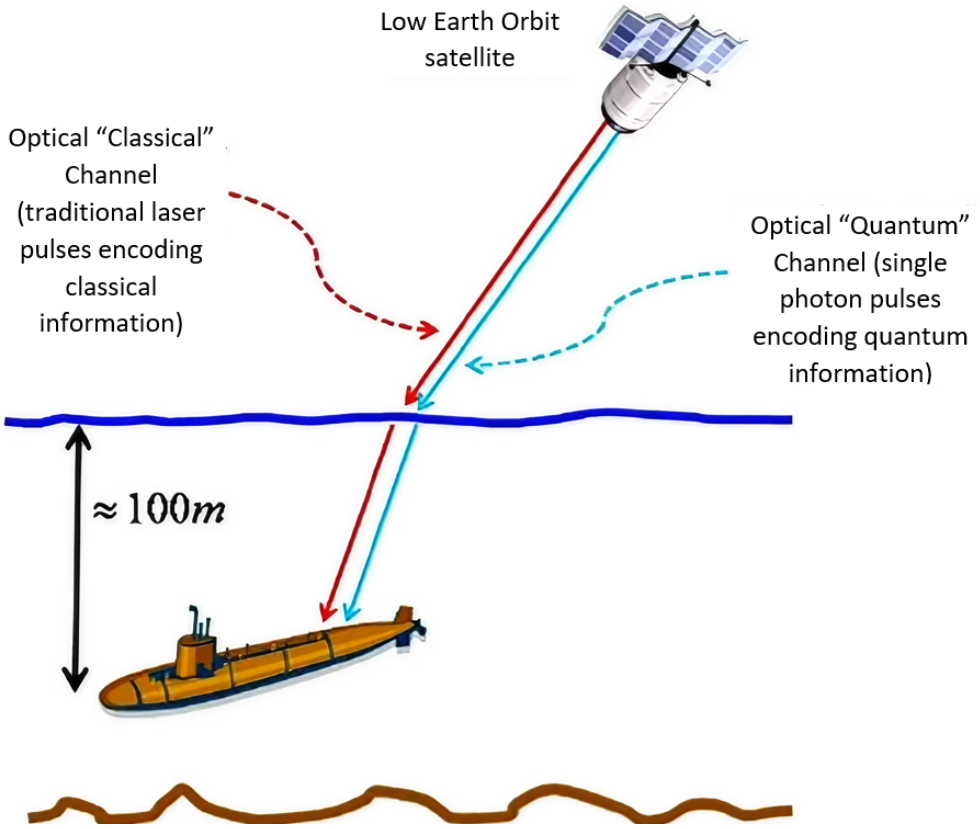
However, the advent of optical channels, potentially augmented by space-based platforms, heralds a new era of submarine communication[13]. By leveraging quantum photodetectors—innovations inspired by the natural quantum processing observed in photosynthesis—this approach promises to transcend the bandwidth and

[13] Marco Lanzagorta, 'Underwater Quantum Communications', in 'Underwater Quantum Communications', *Underwater Communications*, (Springer International Publishing: Cham, 2013), pp. 75–91.

logistical limitations inherent to VLF and ELF systems. These quantum-inspired photodetectors could facilitate highly efficient, classical, and quantum communications through the optical window of seawater, enabling communication over a 100-meter water column to an airborne or satellite receiver.

Theoretical models suggest the potential for unconditionally secure communication rates of up to 170 kilobytes per second at 100 meters depth, a seismic improvement approximately 600 times greater than what VLF offers. This quantum leap in communication technology not only enhances operational bandwidth but also significantly simplifies the logistical challenges of underwater communication, marking a pivotal advancement in secure and efficient submarine communication systems.

Fig. 6: Quantum Underwater Communication

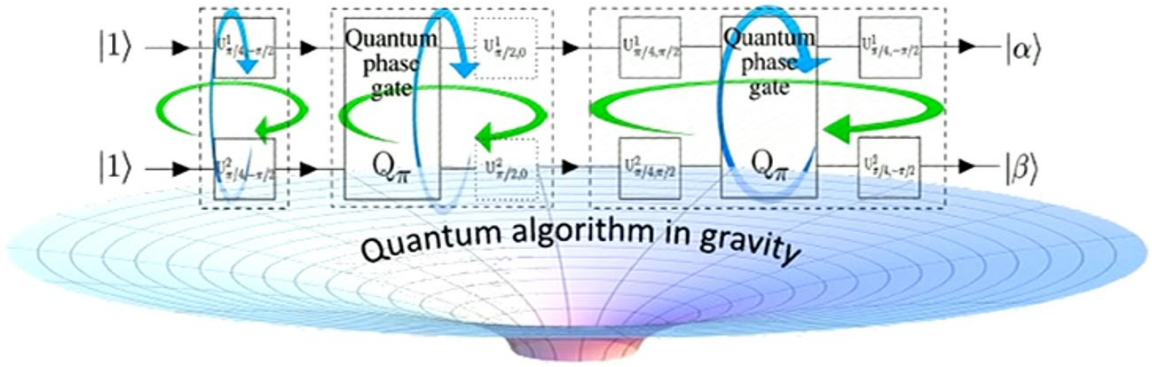


Source: Lanzagorta, https://doi.org/10.1007/978-3-031-01678-3_7

Quantum Gravimetry for Submarine Detection

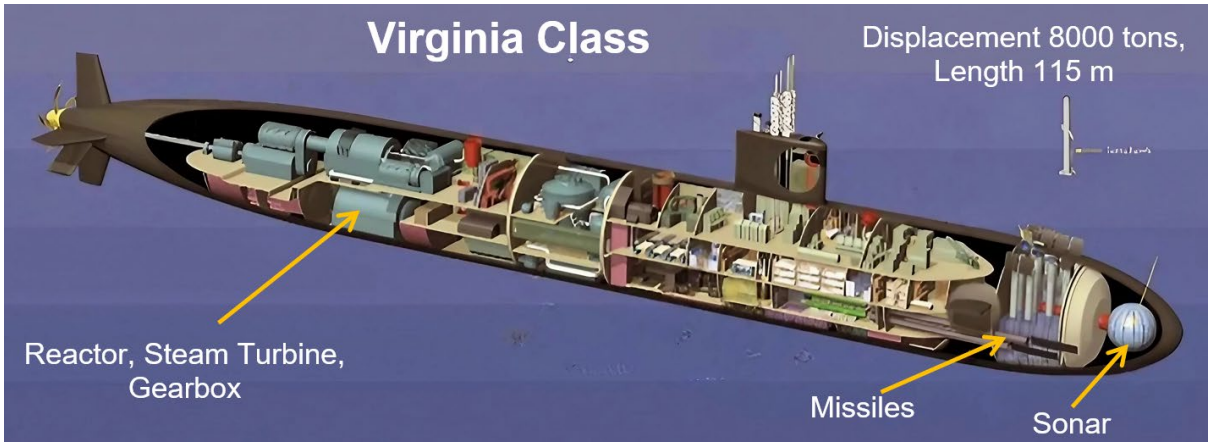
Quantum gravimetry, an advanced application of quantum mechanics, hinges on the concept of qubits, which are the fundamental units of quantum information. Often represented by the intrinsic property known as spin, qubits offer a unique perspective on measuring gravitational fields. To accurately grasp spin, one must delve into relativistic quantum field theory, where spin's relationship with special and general relativity becomes apparent. In this refined context, spin is understood not just in terms

of particle motion but as a quantum property closely tied to the fabric of spacetime itself. As conceptualised by Einstein's theory of general relativity, the interaction of quantum particles with gravitational fields alters their spin. This allows for the measurement of variations in the gravitational field by observing changes in the quantum state of particles.



The bottom line is that the Qubits can be understood as if they were gyroscopes under the presence of a gravitational field. Hence, a quantum computer is basically this set of tiny quantum gyroscopes. In particular, you could use many of these 'gyroscopes' to amplify the effect of the gravitational interaction. It has been shown that if you have a qubit in orbit, this qubit gets a slight change in rotation when it interacts with the gravitational field, and it's minimal, but if there are several Qubits inside a quantum computer, it's possible to amplify this signal through interaction. This process is termed Wigner Gravimetry[14].

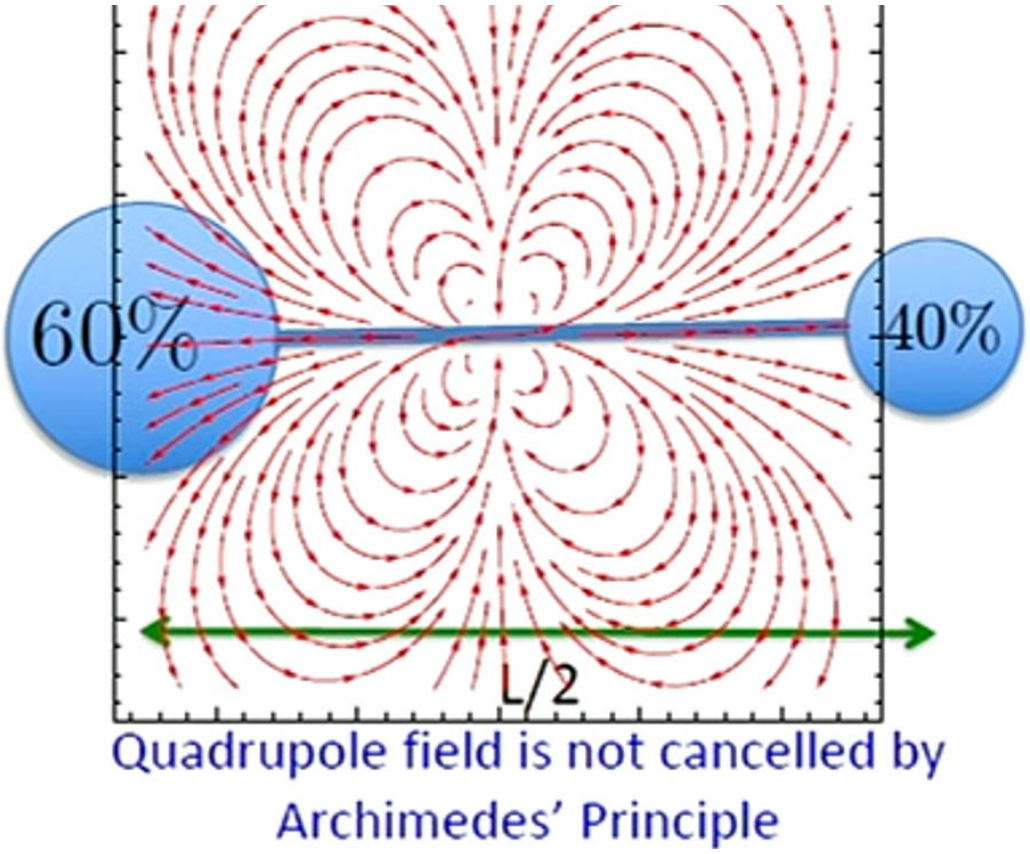
Consider the Virginia-class submarine as a case study for a simplified gravitational model. The distribution of mass within such a submarine is notably uneven—denser at both ends due to the presence of the engine and reactor at the rear, and missiles and sonar at the front. In contrast, the central section is predominantly filled with air, making the vessel's mass distribution resemble that of an asymmetric dumbbell.



[14] Jeffrey Uhlmann and Marco Lanzagorta, 'Theoretical Foundations for Design of a Quantum Wigner Interferometer', *IEEE Journal of Quantum Electronics*, Vol. 55, no. 1, 2019, pp. 1–7.

The submarine's uneven mass distribution gives rise to a distinctive gravitational feature known as the gravitational quadrupole moment, effectively acting as the submarine's specific gravitational signature. Although the overall gravitational force exerted by the submarine, referred to as the monopole moment, is counterbalanced by buoyant forces as per Archimedes' principle—achieving equilibrium within the water—the quadrupole moment, attributed to this asymmetrical mass layout remains unaffected by such buoyancy. The quadrupole moment stands out, similar to the magnetic lines of force emanating from a magnet, as depicted in Fig. 7.

Fig. 7: Quadrupole Gravitational Filed formed by Uneven Distribution of Mass – Virginia Class Submarine

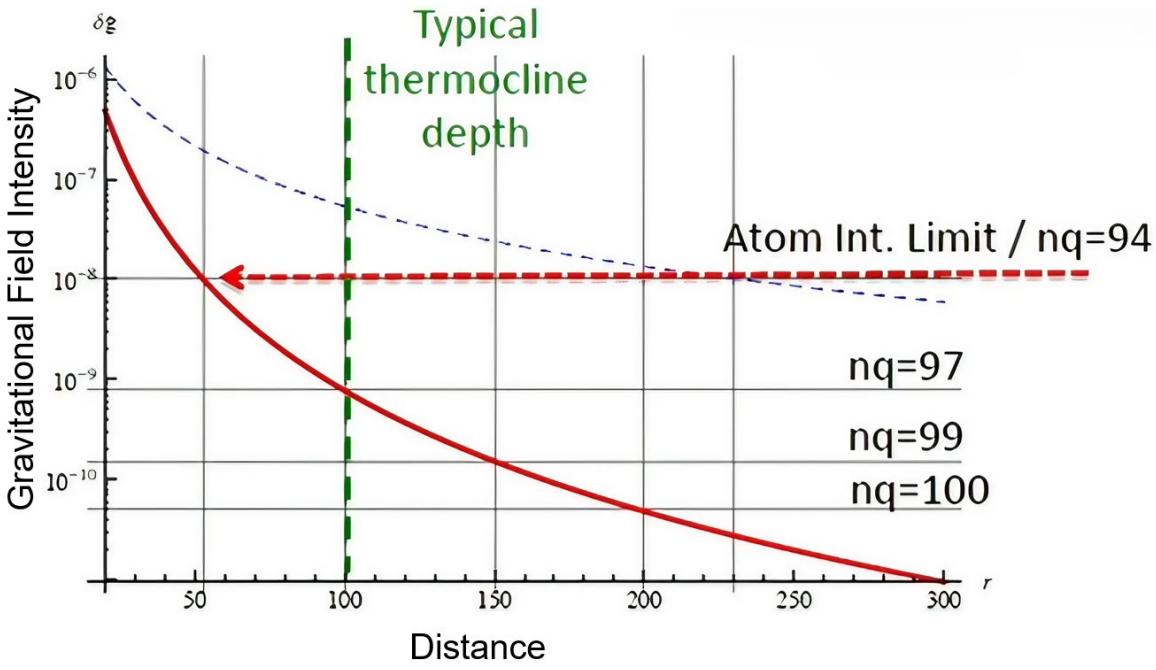


It's the unbalanced nature of the quadrupole moment, albeit smaller than the monopole moment, that presents a novel opportunity for detection. This subtlety in gravitational signature offers a window into leveraging quantum gravimetry for identifying the presence of submarines based on their inherent mass distribution characteristics.

The plot in Fig. 8 shows the variation in the intensity of the gravitational field produced by a nuclear submarine of the size of Virginia class with respect to the distance. On the Y-axis is the intensity of the gravitational field produced by the submarine, and on the X-axis is the distance from it. The Blue dashed curve represents

the monopole moment, and the solid red curve represents the quadrupole moment. It can be seen that the quadrupole is much weaker than the monopole, but since it is unbalanced, it provides an opportunity to be detected.

Fig. 8: Variation of Gravitational Field of Nuclear Submarine with Distance



If we use the best-known gravimetric technique known today, which is 'heavy atom interferometry', its minimum detectable threshold is about 10-8 kg-m2, so you can see in the plot in Fig. 8 that you can detect the quadrupole moment of a nuclear submarine by 'heavy atom interferometry' at a distance of about 50 meters. However, this detection range is insufficient for strategic applications. Further, the acoustic signatures of a stealthy nuclear submarine, like the Virginia class, blend into ambient ocean noise beyond a 100-meter threshold, rendering conventional acoustic detection methods (passive sonars/hydrophones) ineffective. This limitation underscores the necessity for a more advanced detection technology capable of surpassing the 100-meter mark to effectively detect stealth submarines.

In this context, Wigner gravimetry, powered by an ensemble of 100 noiseless, error-free qubits, emerges as a promising solution, potentially enabling submarine detection at distances around 200 meters (refer Fig. 8). The detection range increases exponentially with increase in number of noiseless, error-free qubits. However, assembling a quantum computer with 100 noiseless, error-free qubits presents a significant technological challenge, marking a crucial step in advancing underwater detection capabilities.

Major Challenges

Transforming these innovative ideas into practical realities is contingent upon overcoming a series of significant challenges. Initially, there's a pressing need to refine

the mathematical frameworks that articulate quantum information science, making it more comprehensible for individuals without a quantum physics background.

In the realms of quantum radar and LIDAR, a crucial requirement is the rapid and efficient generation of entangled qubits across both microwave and optical frequencies. While we possess highly effective detectors for optical frequencies, our capabilities in the microwave spectrum require enhancement, which is essential to implement quantum ghost imaging. Additionally, a lot of effort is underway to develop reliable quantum memories that are noiseless and error-free in the quantum computing sector, but these technologies are also essential for broader quantum sensing and communication applications that we have discussed in this chapter.

Furthermore, the advancement of efficient, fault-tolerant quantum hardware is vital. Such hardware must support the full spectrum of operations needed for sophisticated sensing and communication tasks. Alongside hardware improvements, there's a parallel need for innovations in signal processing techniques. Quantum Information Science introduces an entirely new paradigm, necessitating novel signal processing and data analysis approaches.

Lastly, a deeper comprehension of the interactions between qubit, target, and environment is essential. This understanding is just the tip of the iceberg regarding the challenges facing quantum technology's application in sensing and communication fields.

Advancements in Quantum Information Science: The Chinese Initiative

The pursuit of advancements in quantum information science is marked by significant global competition, particularly between the United States and China. Through the deployment of the Quantum Experiments at Space Scale (QESS) satellite, China has embarked on an ambitious journey to navigate the challenges inherent in quantum information science. While the stated purpose of the QESS satellite focuses on conducting quantum key distribution (QKD) experiments—a cornerstone for secure communication—the implications of this technology extend far into the realm of military applications. This initiative is not merely about enhancing communication security; it signifies a broader endeavour to pioneer disruptive quantum technologies, potentially including quantum radar, among others.

The race to harness quantum information technologies has seen China rapidly assimilating and building upon research developments originating from the United States. For instance, following the publication of a seminal book on quantum radar by the US Naval Research Laboratory (NRL) in 2011, Chinese researchers secured the rights to an official translation, underscoring their keen interest in this field. Similarly, the NRL's 2017 publication on underwater communications, which introduced the concept of underwater QKD for submarine communications, was promptly acquired and translated by Chinese publishers, indicating a proactive approach to adopting and integrating quantum advancements.

In certain areas, such as quantum gravimetry, Chinese efforts are perceived to be at the forefront, highlighting their strategic importance on quantum technologies in enhancing their military and scientific capabilities. The experimental achievements of Chinese researchers further demonstrate their commitment to quantum science. Notably, their successful long-range (over 143 km) entanglement experiment in 2012, which involved transmitting entangled photons between the Canary Islands[15], set a precedent for their capabilities in manipulating quantum states over considerable distances.

The development of the QESS satellite and the subsequent achievements in quantum key distribution across vast geographical spans exemplify China's progress in operationalising quantum communication. Moreover, announcements from China's Ministry of Defence regarding the development of quantum radar capable of detecting stealth aircraft[16], although met with scepticism, underscore the nation's investment in quantum research and its potential military applications.

As advancements continue, China's experimentation with underwater QKD and the projected operationalisation of such technologies by 2025 highlight quantum information science's dynamic and competitive nature on the global stage. This narrative reflects the technological strides being made by China and emphasises the strategic dimensions of quantum science in shaping future military and communication networks.

[15] Xiao-Song Ma, Thomas Herbst, Thomas Scheidl, Daqing Wang, Sebastian Kropatschek, William Naylor, Bernhard Wittmann, Alexandra Mech, Johannes Kofler, Elena Anisimova, Vadim Makarov, Thomas Jennewein, Rupert Ursin, and Anton Zeilinger, 'Quantum teleportation over 143 kilometres using active feed-forward', *Nature*, Vol. 489, no. 7415, September 2012, pp. 269–273.

[16] Matt Swayne, 'Chinese Scientists Say Quantum Radar Could End Stealth Advantage', *The Quantum Insider*, September 2021.