PRIMER

Entangled Frontiers

Quantum–AI Convergence in Defence and International Security

WENTING HE

Acknowledgements

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About UNIDIR

The United Nations Institute for Disarmament Research (UNIDIR) is a voluntarily funded, autonomous institute within the United Nations. One of the few policy institutes worldwide focusing on disarmament, UNIDIR generates knowledge and promotes dialogue and action on disarmament and security. Based in Geneva, UNIDIR assists the international community to develop the practical, innovative ideas needed to find solutions to critical security problems.

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Author

Wenting He is a Researcher with UNIDIR's Security and Technology Programme. Her work focuses on the intersection of international security and emerging technologies, particularly quantum technologies. She holds a master's degree in international affairs from the Graduate Institute of International and Development Studies, Geneva, and a bachelor's degree in diplomacy from China Foreign Affairs University, Beijing.

Cover image: Empty office with a quantum computer and monitors displaying complex data and AI models. Credit: Shutterstock / Gorodenkoff
Design and layout: Rick Jones, StudioExile

Abbreviations

AI	artificial intelligence
GNSS	global navigation satellite systems
QML	quantum machine learning
UAV	uncrewed aerial vehicle

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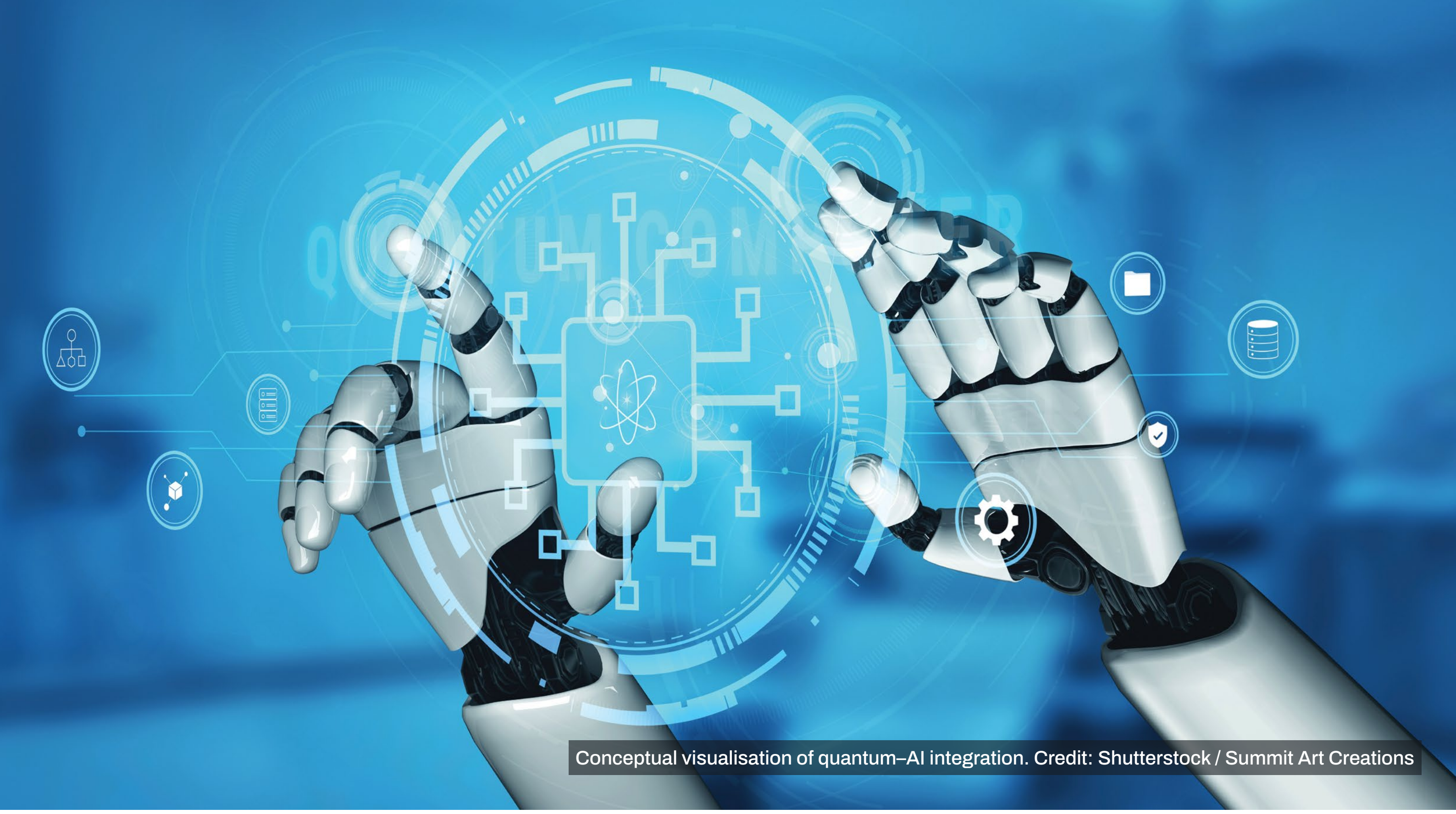

Conceptual visualisation of quantum–AI integration. Credit: Shutterstock / Summit Art Creations

Executive summary

Both quantum technologies and artificial intelligence (AI) are advancing at a rapid pace. The increasingly symbiotic relationship between these two transformative fields has sparked considerable anticipation for their convergence potential, particularly within the scientific and technical communities. AI's role is increasingly evident in quantum research and development, facilitating experimentation and system optimisation. In turn, progress in quantum technologies is also expected to enhance future AI capabilities through improved computational performance. Alongside potential opportunities, this convergence could introduce new complexities and challenges that extend beyond technical domains and into the realm of international security.

While relevant military applications of the quantum–AI convergence remain largely conceptual or in early development, examining this emerging security dimension provides an opportunity to proactively identify potential risks and inform early policy responses. Building on discussions held during UNIDIR's November 2025 webinar series on quantum–AI convergence and supplementary desk research, this primer provides a technological overview of the quantum–AI convergence, assesses emerging and future defence use cases, and examines potential international security implications.

AI's role in quantum research and development. AI is increasingly instrumental in advancing quantum capabilities across computing, sensing, and communications. In quantum computing, AI-driven tools offer a promising pathway to address persistent technical challenges — including quantum error correction — efficiently and at scale. In quantum sensing, AI algorithms can be integrated into data processing pipelines to help filter background noise, enhance signal clarity, and facilitate data analysis, as illustrated by AI-enhanced quantum magnetic navigation. In quantum communications, AI could improve the performance and reliability of quantum networks, including by mitigating signal loss over long distances and supporting network optimisation.

Quantum's role in AI research and development. Quantum technologies could, in turn, enhance AI itself. Through the emerging field of quantum machine learning (QML) and other quantum-enabled enhancements, AI models may be able to tackle more complex problems, increase operational efficiency, and expand the range of feasible applications. While QML is expected to offer potential advantages for certain machine learning tasks, it is not expected to replace classical machine learning in the future. Quantum systems are anticipated to be most effective for specific computationally intensive problems and in settings involving relatively small datasets, as opposed to large-scale, data-heavy applications where classical systems already perform efficiently.

Potential applications in the military domain. Technologies emerging at the intersection of quantum science and AI are largely in the early stages of development, making their military implications highly speculative. This primer examines three application areas of high potential: 1) satellite-independent navigation, likely among the earliest military applications given the relative maturity of AI-enhanced quantum navigation; 2) cyber operations, where QML could potentially strengthen both cyber offense and defence capabilities; and 3) uncrewed aerial vehicles, where quantum-enhanced algorithms may improve flight path modelling and swarm coordination.

Emerging implications for international security. As both quantum technologies and AI continue to mature, their convergence may give rise to a new class of capabilities that neither technology could achieve alone, with implications for future battlefield capabilities and strategic competition. At the same time, quantum–AI systems could generate challenges that compound existing concerns surrounding the military use of AI, such as heightened unpredictability, opaque decision-making, and structural difficulties related to accountability and legal compliance. As a result, continuous monitoring and risk assessment efforts — supported by interdisciplinary expertise across the technical, policy, military, and legal domains — will be essential to anticipate emerging risks, guide responsible development, and ensure that the integration of quantum technologies and AI contributes positively to international security.

1. Introduction

Both quantum technologies and artificial intelligence (AI) are advancing at a rapid pace. The increasingly symbiotic relationship between these two transformative fields has sparked considerable anticipation for their convergence potential, particularly within the scientific and technical communities. AI's role is increasingly evident in quantum research and development, facilitating experimentation and system optimisation. In turn, progress in quantum technologies is also expected to enhance future AI capabilities through improved computational performance.

At the same time, quantum–AI convergence[1] could introduce new complexities and challenges that extend beyond technical domains and into the realm of international security. The Secretary-General's 2024 report on current developments in science and technology and their potential impact on international security and disarmament efforts underscores that the integration of quantum technologies and AI presents both opportunities and risks for international peace and security.[2] While relevant military applications and capabilities remain largely conceptual or in early development, examining the emerging security dimension of the quantum–AI convergence provides an opportunity to proactively identify potential risks and inform early policy responses.

Against this backdrop, and in light of the United Nations designating 2025 as the International Year of Quantum Science and Technology, UNIDIR organised a dedicated webinar series in November 2025,[3] building on the momentum of its 2024 Innovations Dialogue on quantum technologies.[4] This series focused on the intersection of quantum technologies and AI and its implications for international peace and security. Experts from the scientific, technical, military, and policy communities collectively explored the evolving technology landscape and considered the novel challenges this convergence may present.

Building on these discussions and supplementary desk research, this primer provides a technological overview of the quantum–AI convergence, assesses emerging and future defence use cases, and examines potential international security implications. It does not, however, aim to offer a technical primer on either quantum technologies or AI alone, as these topics have been addressed extensively in previous UNIDIR publications,[5] nor does it propose specific governance pathways, given the early stage of technological development and limited policy discussions around the quantum–AI convergence. Rather,

1 This report uses both 'quantum–AI convergence' and 'quantum-AI integration' to refer to the mutually reinforcing relationship between quantum technologies and AI, in which progress in one field helps accelerate development in the other, and their integration could give rise to capabilities that neither could achieve alone.

2 United Nations General Assembly (2024).

3 Further details of the webinar series are available at https://unidir.org/event/quantum-ai-dialogue-a-two-part-webinar-series/

4 The full details of UNIDIR's 2024 Innovations Dialogue on quantum technologies and their implications for international peace and security are available at https://unidir.org/ID24

5 On quantum technologies, UNIDIR has published *Quantum Technology, Peace and Security: A Primer*, available at https://unidir.org/publication/quantum-technology-peace-and-security-a-primer/; On artificial intelligence, related UNIDIR work can be found at https://unidir.org/work/ai-autonomy/

this primer seeks to contribute to ongoing dialogue by outlining emerging trends and anticipated capabilities, identifying key risks and challenges, and highlighting areas where international engagement may be needed.

The report is mainly intended for international security researchers and practitioners seeking to better understand the emerging quantum–AI convergence, as well as technologists interested in the defence and international security implications of these developments.

The primer is composed of five further sections. Section 2 examines the role of AI in advancing quantum research and development, including applications in computing, sensing, and communications. Section 3 explores how quantum technologies may in turn enhance AI, particularly through the emerging field of quantum machine learning and other quantum-enabled AI enhancements. Section 4 discusses potential military applications of the quantum–AI convergence, including satellite-independent navigation, cyber operations, and uncrewed aerial vehicles. Section 5 considers the broader implications that this convergence holds for international security, including its potential impact on future warfare, challenges related to explainability and accountability, and the need for monitoring and risk assessment. Finally, Section 6 concludes with a summary of the report's key findings and reflections.

2. AI's role in quantum research and development

Today, AI has become increasingly instrumental in advancing a broad range of scientific and technical fields, including quantum research and development. Its impact is evident in enhancing quantum capabilities across computing, sensing, and communications. Each of these fields exhibits distinct capabilities, matures at a different pace, and interacts with AI in unique ways. As quantum technologies continue to evolve, integrating AI will be crucial for translating emerging capabilities into practical, real-world applications.[6]

2.1. AI-enhanced quantum computing

Quantum computing has made significant strides in recent years.[7] However, practical, large-scale quantum computers remain out of reach due to persistent technical challenges, including high operational error rates and hardware limitations. Integrating AI-driven tools into quantum computing research offers a promising pathway to address such obstacles efficiently and at scale.[8] By enhancing performance across both hardware and software layers, AI could serve as a powerful catalyst for advancing today's so-called 'noisy intermediate-scale quantum'[9] machines toward more reliable and practical systems.

One of the most promising areas for AI intervention is quantum error correction. Quantum states are extremely sensitive to interactions with their environment, such as thermal fluctuations and electromagnetic noise, which can degrade quantum information and introduce computational errors. This phenomenon, known as quantum decoherence, remains a major barrier to building scalable, fault-tolerant quantum systems, along with other sources of operational errors.

Today's most advanced superconducting quantum processors exhibit two-qubit gate error rates of roughly 0.1–1.0%, yet meaningful applications in areas such as quantum chemistry and materials science will likely require reducing error rates to around 0.0001%.[10] Machine learning and deep learning models have shown considerable potential in improving quantum error correction by predicting errors and recognizing noise patterns in quantum systems more efficiently than traditional methods.[11]

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6 Bongs and Sharma (2025).

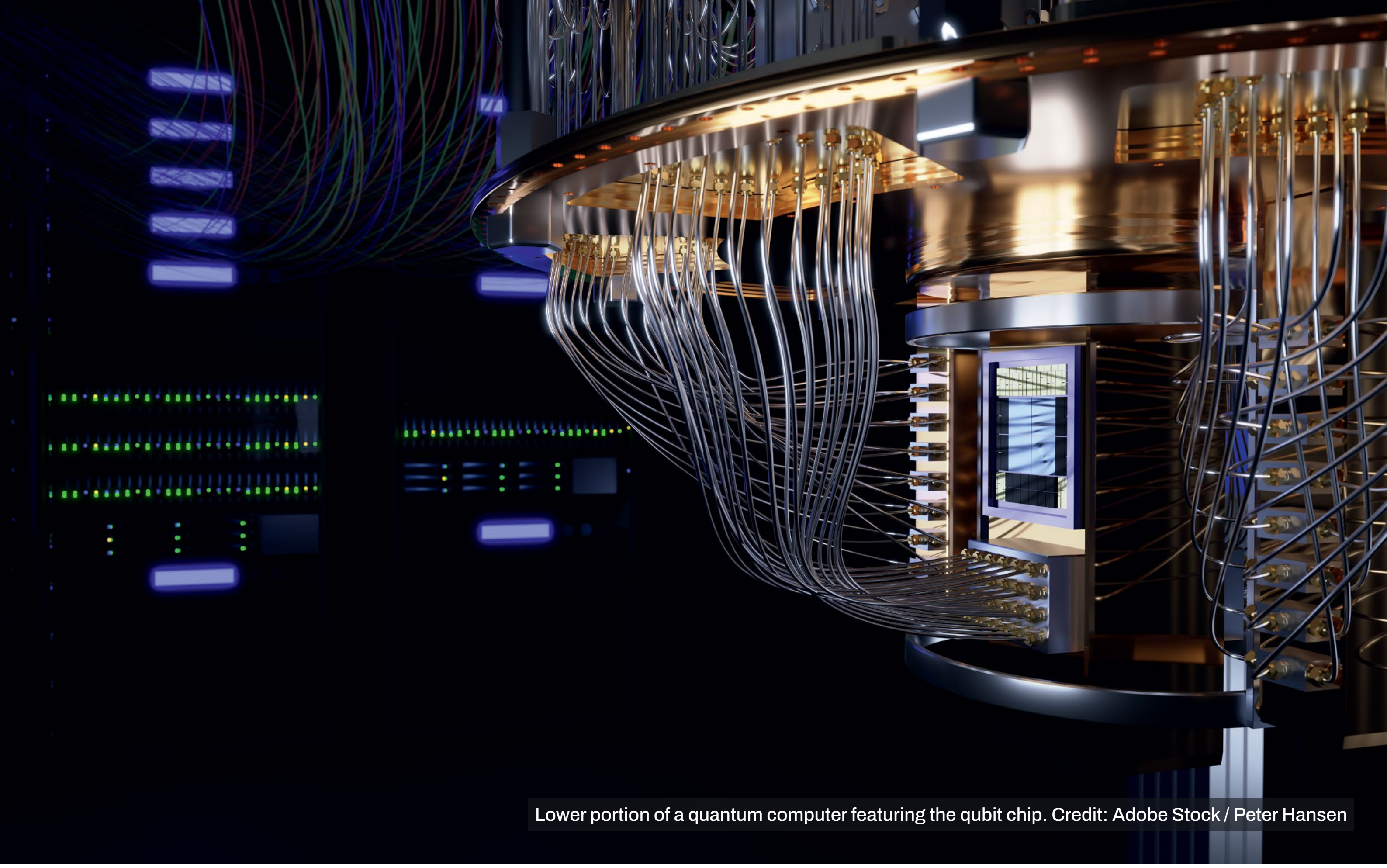
7 He (2024).

8 Alexeev et al. (2025).

9 The term 'noisy intermediate-scale quantum' is often used to describe the current generation of quantum computers, characterised by a moderate number of qubits and significant susceptibility to noise. These systems are not capable of full quantum error correction, which limits the complexity and reliability of computations they can execute. Despite these constraints, such devices enable early exploration of quantum algorithms and hybrid quantum–classical methods, ahead of future large-scale, fault-tolerant quantum computers.

10 Bongs and Sharma (2025).

11 Swayne (2024b).



Lower portion of a quantum computer featuring the qubit chip. Credit: Adobe Stock / Peter Hansen

Beyond quantum error correction, AI can support many other crucial aspects of quantum computing, including qubit design, quantum algorithm development, device control and optimisation, as well as interpretation of quantum outputs.[12] AI-assisted simulation processes may also shorten experimental iteration cycles to lower costs and accelerate hardware development.[13] While most of these applications still rely on further scientific and engineering breakthroughs, early experiments have demonstrated promising results of AI enhancements in areas such as system control and optimisation.[14]

2.2. AI-enhanced quantum sensing[15]

Unlike quantum computing, quantum sensing already has real-world applications. By exploiting highly sensitive quantum states, quantum sensors offer significantly higher sensitivity and precision than their classical counterparts.[16] This enables applications across high-precision navigation, medical imaging, environmental monitoring, material analysis, as well as defence and security.

12 Alexeev et al. (2025).

13 Mohan (2025).

14 Thomas-Raynaud and Barreneche (2025).

15 This section is primarily based on the presentation delivered by Stefan Leichenauer (Vice President of Engineering, SandboxAQ) during Part 1 of the UNIDIR webinar series on quantum–AI convergence, supplemented by desk research conducted by the author. Further details of the webinar series are available at https://unidir.org/event/quantum-ai-dialogue-a-two-part-webinar-series/

16 For a full overview of quantum sensing, see UNIDIR's publication *Quantum Technology, Peace and Security: A Primer*, https://unidir.org/publication/quantum-technology-peace-and-security-a-primer/

A central challenge for quantum sensing lies in managing background noise. Due to their extreme sensitivity, quantum sensors often capture large volumes of irrelevant or interfering signals, particularly outside of controlled laboratory environments. Traditional solutions rely on physical isolation or shielding, which can be difficult to deploy and scale in complex, real-world settings.

To mitigate this, AI offers a powerful software-based alternative to physical isolation. Once data are collected from quantum sensors, advanced AI algorithms can be integrated into data processing pipelines to help filter background noise, enhance signal clarity, and transform quantum sensors' complex data into useful insights.[17] This approach may improve measurement accuracy, reliability, and efficiency, with great promise for enabling quantum sensors to operate effectively in noisy and dynamic environments that would otherwise degrade performance.

Magnetic navigation, a specialised branch of quantum sensing, illustrates the potential of AI-enhanced capabilities. Using highly sensitive quantum magnetometers, this technology detects subtle variations in Earth's magnetic field to determine position and orientation without relying on global navigation satellite systems (GNSS). This capability is particularly valuable in environments where GNSS signals may be jammed, spoofed, or unavailable, such as conflict zones. In practical use, quantum magnetometers generate data streams dominated by noise and other irrelevant signals; AI algorithms could play a crucial role in filtering this data and converting clean signals into actionable navigation outputs. Such systems are already beginning to enter the commercial market.[18]

Beyond navigation, quantum magnetic sensing technologies can also be applied in healthcare, where they enable the detection of electromagnetic signals produced by the human body and support more accurate disease diagnosis, as well as in identifying potential hardware manipulation and vulnerabilities in microchips.[19] The integration of AI could enhance signal processing and data interpretation. For example, AI may be leveraged to analyse highly detailed brain scans from quantum sensors, helping to detect early signs of neurological conditions.[20]

2.3. AI-enhanced quantum communications

Quantum communications is a rapidly advancing field that leverages quantum properties to encode and transmit information, with promising applications in securing sensitive data and systems against both traditional and quantum-enabled cyberattacks. A key technology of quantum communications is quantum key distribution, which applies the principles of quantum mechanics to generate and share encryption keys and can, in theory, reveal any eavesdropping attempts.[21]

AI could play an important role in advancing quantum communications by improving the design, performance, security, and reliability of quantum networks. One of the primary challenges in this field is mitigating

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17 Bongs and Sharma (2025).

18 This assessment is based on technical input provided by Stefan Leichenauer.

19 Ibid.; Choi (2025).

20 Bongs and Sharma (2025).

21 For a full overview of quantum key distribution, see UNIDIR's publication *Quantum Technology, Peace and Security: A Primer*, available at: https://unidir.org/publication/quantum-technology-peace-and-security-a-primer/

Abstract representation of secure networks (generated with AI). Credit: Adobe Stock / ModernFiles

anomalies and signal loss over long distances. AI models could be leveraged to enhance signal fidelity by identifying patterns in transmission errors and applying real-time corrections, thereby increasing the overall efficiency of quantum links.[22]

Machine learning techniques could further support network optimisation and dynamic resource management for quantum communications. AI-driven monitoring systems may also facilitate the early detection of potential eavesdropping attempts or security breaches in quantum key systems, strengthening protection against unauthorised access or tampering.[23] Together, these AI-driven enhancements could help to pave the way for future large-scale deployment of quantum networks.

22 Bongs and Sharma (2025).

23 Radanliev (2024).

3. Quantum's role in AI research and development

Just as AI capabilities are transforming quantum research and development, quantum technologies could also offer opportunities to enhance AI itself. Through the emerging field of quantum machine learning and other quantum-enabled enhancements, AI models may be able to tackle more complex problems, increase operational efficiency, and expand the range of feasible applications.

3.1. Quantum machine learning[24]

The computational power of quantum computing is believed to offer new possibilities for AI improvement. By leveraging quantum properties such as superposition (the ability of a quantum system to exist in multiple states simultaneously, rather than being strictly limited to 0 or 1 as in a binary system) and entanglement (a phenomenon in which the states of two or more quantum particles are intrinsically linked, regardless of the distance between them), quantum computers may enable substantial performance gains in certain machine learning workflows, potentially allowing AI systems to address complex problems beyond the reach of today's classical machines.

These prospects have given rise to quantum machine learning (QML), an interdisciplinary field that integrates quantum information science with machine learning techniques. QML is expected to contribute to future advances in AI by offering potential advantages for specific tasks, including the following.[25]

- **Probability distribution modelling.** Because quantum systems are inherently probabilistic, experimental evidence shows that quantum computers may efficiently represent and process complex probability distributions that tend to be challenging for classical systems to capture.
- **Generalisation.** Generalisation refers to a model's ability to perform well on previously unseen data. For certain QML approaches, there has already been mathematical proof of models' generalisability, providing confidence that trained models could potentially maintain reliability beyond their training datasets.
- **Model compression.** Quantum machine learning may achieve higher expressiveness[26] by exploiting quantum properties to process multiple computational paths simultaneously. In principle, this could allow quantum models to match the performance of classical methods while using fewer parameters.

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24 This section is primarily based on the presentation delivered by Caitlin Jones (Senior Researcher, Quantum Software Lab, University of Edinburgh) during Part 1 of the UNIDIR webinar series on quantum–AI convergence, supplemented by desk research conducted by the author. Further details of the webinar series are available at https://unidir.org/event/quantum-ai-dialogue-a-two-part-webinar-series/

25 These examples of potential QML advantages were noted by Caitlin Jones.

26 Expressivity measures how capable a machine learning model with a fixed number of parameters is of learning a wide range of possible dynamics.

Abstract visualisation of AI data processing. Credit: Shutterstock / KanawatTH

Despite these potential advantages, QML is not expected to replace classical machine learning in the future. Instead, quantum systems are anticipated to be most effective for specific computationally intensive problems (such as dimensionality reduction[27]) and in settings involving relatively small datasets, as opposed to large-scale, data-heavy applications where classical systems already perform efficiently.[28] In addition, while QML models may appear to be more data-efficient than their classical counterparts in experimental settings, operational reliability would still require extensive validation against real-world and adversarial data. To date, no real-world demonstration has shown a QML model outperforming state-of-the-art classical AI, whose capabilities continue to advance rapidly.

Current quantum hardware remains noisy and error-prone, making fully quantum machine learning systems still infeasible and largely a long-term research direction. As a result, hybrid quantum–classical architectures have emerged as a practical path forward within existing technological capabilities. Empirical research suggests that such hybrid models can already enhance certain aspects of machine learning training.[29] In these systems, quantum processors are used to address computational bottlenecks that challenge classical hardware, while the latter continue to dominate tasks such as data handling, pre-processing, and model orchestration.[30] However, leveraging quantum hardware for classical AI tasks remains slow and cumbersome due to the difficulty of transferring large AI datasets — often terabytes in size — into and out of quantum memory.[31]

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27 Dimensionality reduction refers to the transformation of data from a high-dimensional space into a lower-dimensional representation in a manner that preserves meaningful properties of the original data.

28 Mohan (2025).

29 Xu (2023).

30 Mangram (2025).

31 Thomas-Raynaud and Barreneche (2025).

Although QML remains an early-stage field facing substantial hardware and algorithmic challenges, it is widely viewed as having transformative potential across multiple domains, including biomedicine, materials science, cybersecurity, and logistics. Quantum computers possess inherent strengths in simulating quantum-mechanical processes — such as molecular interactions — because they operate according to the same physical principles as the systems being modelled. In biomedicine, QML has been explored for applications such as drug discovery and personalised cancer treatment,[32] with hybrid quantum–classical models already demonstrating advantages in experimental settings.[33] In cybersecurity, the integration of quantum technologies may further augment machine learning capabilities for both defensive and offensive purposes, including potential applications in spam filtering, malware detection, and intrusion detection.[34]

3.2. Other quantum-enabled enhancements

Beyond quantum-driven machine learning, other quantum applications also have the potential to enhance AI capabilities. Quantum sensors, for example, can offer exceptional sensitivity and capture high-quality data, including signals that were previously difficult or impossible to measure with classical sensors. Such datasets obtained through quantum sensing could provide novel opportunities to train AI algorithms across a wide range of applications.[35]

Additionally, the nature of quantum computing may support more accurate simulations and modelling of complex physical systems, with the potential to generate large volumes of synthetic data that closely approximate real-world phenomena, down to the molecular and subatomic levels.[36] Such data could be highly beneficial for AI systems, particularly in domains where real-world data is scarce or costly to obtain. For instance, quantum computers could generate highly accurate data to train AI models for simulating chemical systems more efficiently, with the potential to accelerate materials and drug discovery.[37]

In the realm of secure communications, quantum-enabled networks such as those using quantum key distribution offer the promise of highly secure, tamper-detectable data transmission, to eventually support AI deployments and preserve data integrity.[38]

However, some of these areas remain largely hypothetical, given the experimental stage of most current quantum technologies and the challenges associated with efficiently encoding classical data into and out of quantum systems. The box below highlights the distinctions between classical and quantum data and algorithm types, providing a framework for understanding different modes of interaction between quantum technologies and AI, many of which have been discussed in this and the preceding sections.

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32 Mangram (2025).

33 Vakili et al. (2024).

34 Bauckhage et al. (n.d.).

35 Soller and Gschwendtner (2024).

36 Marr (2025).

37 Chen and Troyer (2026).

38 Mohan (2025).

BOX 3.1

Four types of quantum–AI interactions

From a technical standpoint, interactions between quantum and AI technologies can be categorised into four types based on the nature of the data and the algorithms involved.[39] Understanding these categories could provide further insight into the structural complexity of quantum–AI interactions and help to clarify the varying maturity levels of the technologies situated within this convergence. Interaction 1 represents the current capabilities that underpin modern digital systems, interactions 2 and 3 are emerging with mostly near- to mid-term applications, and interaction 4 constitutes a promising yet longer-term vision.

Interaction 1: Classical algorithms with classical datasets. This refers to today's classical AI and computing capabilities on classical systems. Because both the algorithms and the data are binary (i.e. expressed as 0s and 1s), information can be easily stored, transferred, and processed without the need for complex data conversion.

Interaction 2: Classical algorithms with quantum datasets. In this scenario, data generated or transmitted by quantum systems must first be measured and converted into classical form before classical algorithms can process it. However, this conversion is complex and computationally expensive — a challenge that the scientific community is actively seeking to address. This interaction could allow classical AI to control and optimise quantum hardware (as discussed in section 2.1) and quantum communication networks (as discussed in section 2.3), while also analysing data generated by quantum sensors in real time (as discussed in section 2.2).

Interaction 3: Quantum algorithms with classical datasets. Here, classical data is encoded into quantum states for processing on quantum hardware, with results then converted back into classical form. This type of interaction could be observed in hybrid classical–quantum machine learning models (as discussed in section 3.1) where quantum hardware handles data originating from classical sources. As in interaction 2, the process of data conversion poses a major challenge that largely limits efficiency and scalability for today's applications.

Interaction 4: Quantum algorithms with quantum datasets. This represents a long-term vision in which data remains fully quantum throughout the processing chain, eliminating the need for any conversion to and from classical form. In future applications, data from quantum sensors could be transmitted via quantum-secured communication channels to quantum computing hardware for processing through fully quantum machine learning. While this approach could unlock powerful new capabilities, its realisation depends on the development of quantum capabilities that are not yet available.

39 Ranga et al. (2024).

4. Potential applications in the military domain[40]

Technologies emerging at the intersection of quantum science and AI are largely in their early stages of development, making their military implications largely speculative and only partially explored in the literature. Different quantum technologies — including quantum computing, quantum sensing, and quantum communications — possess distinct technical characteristics and offer varying forms of utility across defence contexts.[41] Integrating AI into their research, development, and deployment could accelerate technological maturation and unlock enhanced military capabilities. However, given the current technological readiness, near- to mid-term impacts are more likely to be incremental rather than revolutionary.

In the context of QML, near- and mid-term military applications are expected to rely primarily on hybrid quantum–classical systems due to the limitations of current quantum hardware. In the longer term, QML is also unlikely to replace classical AI entirely but could complement it by addressing particularly complex problem sets that challenge conventional approaches. In this capacity, QML has the potential to act as a future force multiplier across strategic, operational, and tactical military domains.[42]

By leveraging quantum-enhanced algorithms and models, QML may deliver substantial improvements in computational speed, information processing, and analytical capacity relevant to defence applications. These enhancements may, in the long term, strengthen military functions currently assisted by classical AI, such as intelligence analysis, modelling and simulation, training and operational planning, multi-agent coordination, and logistics management.[43] For example, quantum-enhanced modelling could accelerate the processing of intelligence data and enable planners to simulate operational scenarios and outcomes more efficiently, supporting more informed and timely decision-making.[44]

As both quantum technologies and AI mature, their convergence may gradually translate into tangible operational advantages on the battlefield. The following subsections examine three application areas of quantum–AI integration in greater detail, selected based on their high potential in defence contexts and current research traction.

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40 This section is based on the panel discussion during Part 2 of the UNIDIR webinar series on quantum–AI convergence with Michal Krelina (CTO and Co-founder, QuDef; Associate Senior Researcher, Armament and Disarmament, Stockholm International Peace Research Institute), Taniel Yusef (Research Affiliate, Centre for the Study on Existential Risk, University of Cambridge), and Elie Alhajjar (Senior Information Scientist, RAND; Professor of Policy Analysis, RAND School of Public Policy), supplemented by desk research conducted by the author. Further details of the webinar series are available at https://unidir.org/event/quantum-ai-dialogue-a-two-part-webinar-series/

41 Malekos Smith and Persi Paoli (2024); Krelina (2025).

42 Stone and Stone (2025).

43 Bureš and Františ (2025).

44 Malekos Smith and Persi Paoli (2024).

Maritime deployment of a GNSS-independent quantum navigation system. Credit: Q-CTRL

4.1. GNSS-independent navigation

AI-enhanced quantum sensing enables navigation in GNSS-denied or -degraded environments and is already commercially available (see section 2.2). Given the relative maturity of this technology, this capability is likely to be among the earliest military applications of quantum–AI integration. In particular, it holds significant potential to strengthen the resilience of positioning, navigation, and timing in defence operations.

In contested environments where GNSS signals are routinely jammed, spoofed, or unavailable, quantum-enabled navigation could allow military platforms to determine their position without relying on satellite signals. This approach typically leverages onboard quantum sensors capable of measuring subtle variations in the Earth's magnetic or gravitational fields along a platform's trajectory. AI algorithms could play a critical role in processing these measurements by filtering background noise, extracting relevant geomagnetic features, and matching them against high-resolution reference maps to enable accurate GNSS-independent positioning.

Such capabilities could be applied across multiple operational domains, enabling navigation in the air, over open water, on remote terrain, and even underwater or underground where GNSS signals are jammed or unavailable. By providing reliable positioning in previously inaccessible or high-risk environments, navigation enabled by quantum–AI integration could expand the operational reach, endurance, and flexibility of military forces.

However, the same quantum-sensing technologies could also be exploited by adversaries to detect the very systems they are designed to protect. Technologies such as quantum magnetometers and gravimeters could improve the detection of stealthy or low-observable assets, with AI further amplifying these capabilities through advanced signal processing, sensor fusion, and pattern recognition. As a result, innovation in this domain is likely to evolve as a dynamic competition between increasingly sophisticated quantum–AI navigation systems and countermeasures designed to detect, degrade, and defeat them.

4.2. Cyber operations

Once reliable, large-scale quantum computers become available, they are widely expected to introduce profound changes to the cybersecurity landscape, particularly because of their potential to compromise widely used public-key encryption schemes. In defence contexts, dominance in quantum technologies could ultimately determine who is able to exploit adversarial encryption systems and who remains vulnerable to such exploitation.[45]

The integration of AI could facilitate the development of practical quantum computers (see section 2.1) while also advancing quantum communication capabilities that are critical for protecting digital infrastructure against quantum-enabled cyberattacks (see section 2.3). In parallel, AI-driven tools are already being used to identify cryptographic weaknesses and to test and validate emerging post-quantum cryptographic standards,[46] thereby helping to accelerate their development in response to quantum cyber threats.[47]

Furthermore, the pairing of AI and quantum information processing — specifically through the development of quantum machine learning — could potentially alter the balance between cyber offense and defence. On the offensive side, AI systems operating on sufficiently powerful quantum hardware could be used to identify vulnerabilities, optimise attack strategies, and exploit system weaknesses. Compared to classical machine learning, QML models could enable attackers to generate more powerful, harder-to-detect attacks more quickly and with less prior knowledge of target systems, increasing the difficulty of defending against them.[48] This potential has already been considered in the ongoing development of post-quantum cryptography.[49]

Meanwhile, current research also points to the great promise of applying QML for cyber defence. Quantum-enhanced machine learning models may strengthen pattern recognition, improve anomaly detection,

45 Ryan and Singer (2025).

46 Post-quantum cryptography refers to algorithms that are designed to remain secure against both classical and quantum cyberattacks and that can already be implemented in existing systems. A notable example is the set of relevant standards released in 2024 by the US National Institute of Standards and Technology; https://www.nist.gov/news-events/news/2024/08/nist-releases-first-3-finalized-post-quantum-encryption-standards

47 Cyber London (2025).

48 Bauckhage et al. (n.d.).

49 Swayne (2026).

and support more effective threat mitigation. Early tests of quantum–AI approaches suggest possible advantages over traditional detection techniques, with the promise of improving detection efficiency.[50]

Nevertheless, given the current limitations of quantum hardware and algorithms, it remains premature to determine how QML will ultimately shift the balance between attackers and defenders. Future advances in quantum machine learning will need to be closely monitored to assess its long-term implications for cyber operations.[51]

4.3. Uncrewed aerial vehicles

Research on the combined application of quantum technologies and AI to uncrewed aerial vehicles (UAVs) is beginning to emerge, with early experimentation taking place in defence settings.[52] The development of quantum-enhanced algorithms may enable more accurate and timely flight path modelling while improving the decision-making capabilities of UAV flight management systems.[53] Experimental studies indicate that integrating quantum optimisation techniques with AI-driven error correction can improve fault tolerance and scalability in UAV path planning, highlighting its potential to support autonomous operations in complex and dynamic environments.[54]

In parallel, militaries are also exploring more effective approaches for managing large-scale UAV swarms. Coordinating numerous autonomous platforms could quickly become a high-dimensional optimisation problem that may overwhelm traditional AI models as swarm size increases.[55] A recent study suggested that quantum-assisted reinforcement learning could, in the longer term, contribute to more efficient swarm coordination strategies.[56] Emerging QML techniques have also been examined for their effectiveness in detecting cyber intrusions within UAV swarms, with findings indicating measurable benefits in analysing complex network data, although technical limitations and performance trade-offs remain.[57]

50 Swayne (2024a).

51 Bauckhage et al. (n.d.).

52 Stone and Stone (2025).

53 Robles et al. (2024).

54 Bandyopadhyay et al. (2025).

55 Bureš and František (2025).

56 Ibid.

57 Chen et al. (2025).

5. Emerging implications for international security[58]

As both quantum technologies and AI mature, their convergence may give rise to a new class of capabilities that neither technology could achieve on its own. Although most prospective applications and their military relevance remain speculative at this stage (as outlined in the previous section), current technological trajectories already suggest several issues that the international security community should begin to consider. The following subsections outline some emerging areas of concern and potential impact.

5.1. Impact on the future battlefield and strategic competition

The growing interaction between quantum technologies and AI could potentially enhance future battlefield capabilities while also influencing the pace and character of warfare. Even before applications at this critical convergence become fully deployable in combat environments, their impact may first be felt in military planning, training, and scenario development.

Modern military planning depends on complex simulations that model force movements, terrain constraints, logistics networks, and adversary behaviour. As these scenarios grow in scale and complexity, the number of possible outcomes expands dramatically, therefore placing substantial computational demands on existing systems.[59] Quantum–AI systems could potentially accelerate specific optimisation processes within such simulations, enabling planners to assess a wider range of courses of action and explore operational trade-offs more rapidly and effectively.[60]

In a future, long-term scenario, distributed quantum sensor networks might detect extremely faint signals across multiple domains and transmit this data via secure quantum communication links to command-and-control systems, where quantum-accelerated AI processing could analyse the information, model adversary behaviour, and task autonomous platforms to respond.[61] The integration of quantum sensing, communications, computing, and AI across an interconnected kill chain could further compress operational time frames beyond the current AI deployment in defence.

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58 This section is based on the panel discussion during Part 2 of the UNIDIR webinar series on quantum–AI convergence with Michal Krelina (CTO and Co-founder, QuDef; Associate Senior Researcher, Armament and Disarmament, Stockholm International Peace Research Institute), Taniel Yusef (Research Affiliate, Centre for the Study on Existential Risk, University of Cambridge), and Elie Alhajjar (Senior Information Scientist, RAND; Professor of Policy Analysis, RAND School of Public Policy), supplemented by desk research conducted by the author. Further details of the webinar series are available at **https://unidir.org/event/quantum-ai-dialogue-a-two-part-webinar-series/**

59 Bureš and František (2025).

60 Ibid.

61 Seraphin (2025).

While such scenarios remain largely speculative — given that most applications of quantum–AI integration are still on the horizon — their plausibility is already sufficient to drive technological competition among military powers. States that invest early and strategically in quantum–AI capabilities may gain decisive advantages in sensing, secure communications, information processing, and decision superiority. As a result, the pursuit of leadership in quantum–AI integration could become an increasingly important dimension of military technological competition and broader strategic rivalry.

5.2. Explainability and accountability challenges

The potential deployment of quantum technologies in defence and security contexts can raise ethical concerns similar to those associated with AI.[62] The complexity of quantum algorithms may render them difficult to reverse engineer, potentially creating a responsibility gap in which liability for system outcomes becomes unclear.[63] Integrating quantum technologies into military AI systems may therefore heighten existing risks, particularly with respect to explainability, accountability, and unintended consequences.

However, the implications of quantum–AI integration may extend beyond simply intensifying existing AI-related challenges. Embedding quantum processes within military decision-support or autonomous systems could introduce fundamentally new sources of uncertainty into algorithmic decision-making. In defence settings where systems should ideally meet requirements of predictability, traceability, and legal accountability, such uncertainties carry particular weight.

While classical AI systems already pose substantial explainability challenges, they still permit limited post hoc analysis through log inspection, model freezing, and scenario replay. Quantum–AI systems may pose additional challenges by constraining — or potentially eliminating — these possibilities, as quantum algorithms rely on quantum states that, once collapsed upon measurement, might not be fully recorded or reconstructed. This could potentially render the computational processes underlying their outputs irretrievable.

In addition, issues such as variance (where identical inputs yield different outputs) and behavioural drift (where system behaviour changes over time) already complicate the evaluation of classical AI systems, although they can, to some extent, be monitored and mitigated. Quantum processes, however, could amplify these effects due to their inherently probabilistic nature, while also limiting the diagnostic tools typically used to detect and correct them.

Consequently, this could complicate efforts to determine how a system classified an individual as a combatant, interpreted behaviour as hostile, or crossed a force-escalation threshold — decisions that may hinge on small variations. If system outputs and the computational processes underlying them cannot be reliably reproduced or reconstructed, it becomes considerably more difficult to establish foreseeability, conduct lawful post-incident investigations, and verify compliance with applicable legal and operational frameworks.

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62 Taddeo et al. (2024).

63 Ibid.

Quantum computing data display. Credit: Shutterstock / Gorodenkoff

Future quantum development must therefore anticipate and adequately address such challenges. Advances in quantum machine learning may offer partial avenues for risk mitigation. For instance, a recent study suggests that quantum gate-based models could encode information in ways that more closely reflect underlying problem structures; if validated, such approaches could enable quantum–AI systems to better meet military requirements for traceability, validation, and compliance with rules of engagement, areas where opaque systems often encounter institutional resistance.[64] However, such approaches remain largely experimental, and significant gaps persist in both technical tools and skilled personnel capable of evaluating such systems effectively.

5.3. Continuous monitoring and risk assessment

As the technological landscape at the quantum–AI convergence evolves, continuous monitoring and risk assessment will be essential to identify and address potential threats at an early stage, particularly given the rapid pace of innovation that may outstrip relevant normative development.

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64 Bureš and Františ (2025).

Beyond defence, emerging developments — such as the potential use of quantum machine learning for molecular modelling[65] and life sciences[66] — also warrant careful attention from the international security community, alongside risks of misuse and proliferation. Unforeseen consequences are likely to arise from deeper quantum–AI integration, which could amplify the unpredictability already associated with both fields. As new technologies and applications materialise, corresponding risks will inevitably evolve, necessitating adaptive, forward-looking approaches to governance and risk management.

Effective monitoring and risk assessment will require building expertise at this critical juncture of two frontier technologies, spanning the technical, policy, military, and legal domains. Discussions around quantum–AI convergence have only begun to gain momentum in recent years and are expected to intensify. Developing interdisciplinary capacity among relevant actors — including defence organisations, regulatory bodies, industry, civil society, and academia — will be essential to ensure informed oversight, coordinated action, and responsible innovation.

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65 Pyrkov et al. (2026).

66 Soller et al. (2025).

6. Conclusion

The ongoing development of quantum technologies and AI points to a likely synergy. Their integration, despite still being in a very early stage, may unlock capabilities that neither could achieve alone, particularly in domains that require intensive data processing and complex problem-solving.[67] Understanding the various modes of quantum–AI interaction (as outlined in section 3) will be essential as both technologies continue to evolve together across a range of applications. In defence, this convergence could represent a transformative frontier with potentially profound implications. Emerging military applications — ranging from GNSS-independent navigation, cyber operations, to UAV swarm management — illustrate the potential of quantum–AI integration to enhance operational effectiveness, accelerate decision-making, and even alter the pace of future warfare.

At the same time, these capabilities may intensify technological competition and introduce novel risks. Quantum–AI systems could generate challenges that compound existing AI-related concerns, including heightened unpredictability, opaque decision-making, and structural difficulties related to accountability and legal compliance. Given the nascent state of development in most quantum–AI applications, proactive monitoring, rigorous risk assessment, and sustained interdisciplinary coordination will be critical to anticipating emerging threats, guiding responsible development, and ensuring that the integration of quantum technologies and AI contributes positively to international security.

67 Thomas-Raynaud and Barreneche (2025).

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