

SETA Emerging Military
Technologies Series .4.

Quantum Technologies

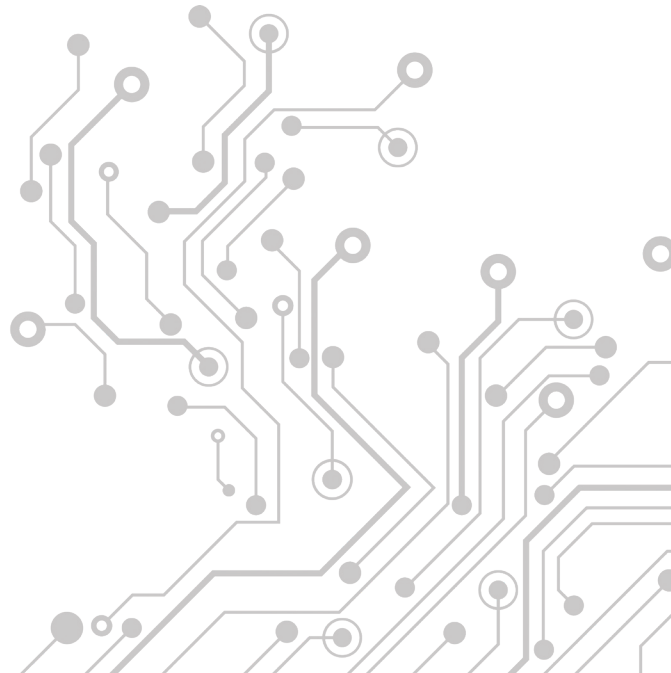
Çağrı Doğal Gül

SETA

SETA Emerging Military
Technologies Series .4.

Quantum Technologies

Çağrı Doğal Gül



ÇAĞRI DOĞAL GÜL

Machine Engineer, Ballistic Weapon and Rocket Systems Expert.

Emerging Military Technologies Series is a SETA Project aims to shed light on the key aspects of new and developing key military technologies by elaborating on global trends and Türkiye's capabilities. A part of the Project is sponsored by STM Savunma Teknolojileri, Mühendislik ve Ticaret A.Ş.

COPYRIGHT © 2022 by SETA

SETA Publications 232
First Published in 2022 by SETA
ISBN: 978-625-8322-77-4

All rights reserved.

No part of this book may be reprinted or reproduced or utilized in any form or by any electronic, mechanical or other means, without permission in writing from the publishers.

The conclusions and recommendations of any SETA Foundation publication are solely those of its author(s), and do not reflect the views of the Institution, its management, or its other scholars.

Layout: Sema Türk Bayazıt
Printed in Türkiye, Turkuvaz Haberleşme ve Yayıncılık A.Ş., İstanbul

SETA | FOUNDATION FOR POLITICAL, ECONOMIC AND SOCIAL RESEARCH

Nenehatun Cd. No: 66 GOP Çankaya 06700 Ankara TÜRKİYE
Tel: +90 312.551 21 00 | Fax: +90 312.551 21 90
www.setav.org | info@setav.org | @setavakfi

SETA | İstanbul

Defterdar Mh. Savaklar Cd. Ayvansaray Kavşağı No: 41-43
Eyüp İstanbul TÜRKİYE
Tel: +90 212 395 11 00 | Fax: +90 212 395 11 11

SETA | Washington D.C. Office

1025 Connecticut Avenue, N.W., Suite 1106
Washington, D.C., 20036 USA
Tel: 202-223-9885 | Fax: 202-223-6099
www.setadc.org | info@setadc.org | @setadc

SETA | Berlin

Kronenstraße 1, 10117 Berlin GERMANY
berlin@setav.org

SETA | Bruxelles

Avenue des Arts 6, 1000 Bruxelles BELGIUM
Tel: +32 2 313 39 41

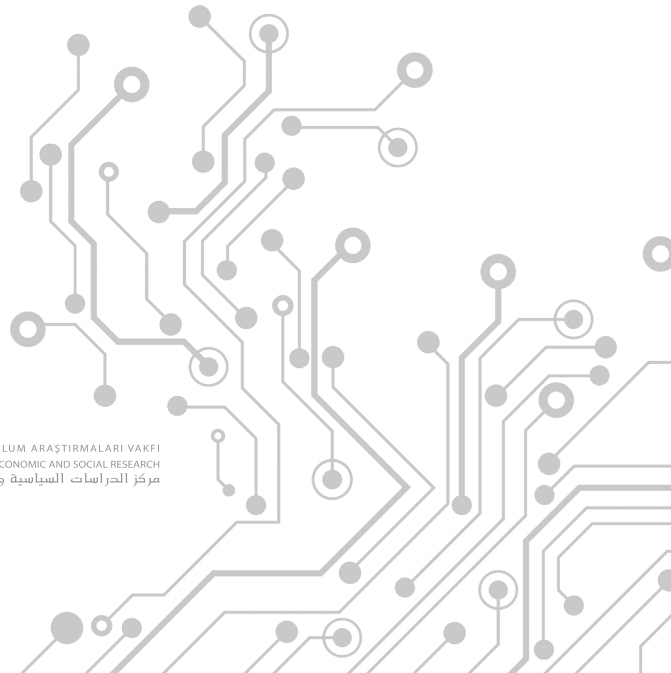
SETA Emerging Military
Technologies Series .4.

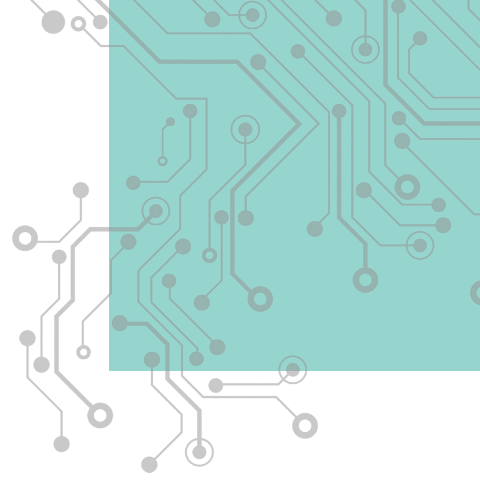
Quantum Technologies

Çağrı Doğal Gül



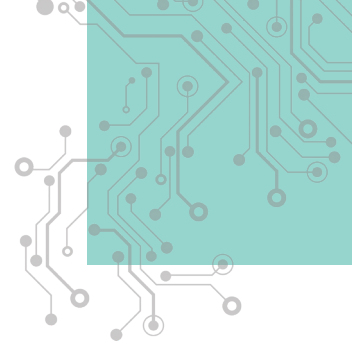
SİYASET, EKONOMİ VE TOPLUM ARAŞTIRMALARI VAKFI
FOUNDATION FOR POLITICAL, ECONOMIC AND SOCIAL RESEARCH
مركز الدراسات السياسية والاقتصادية والاجتماعية





İçindekiler

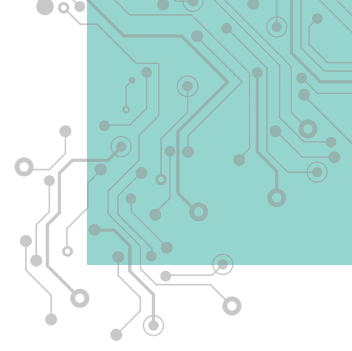
Abstract	7
Introduction	9
Quantum Theory and Quantum Technology	11
Quantum Technologies in the Military Domain	13
The Main Stakeholders Involved in Historical Development	15
Quantum Military Applications	19
Encryption and Information Security	25
Quantum Technology and Intelligence	31
Quantum Radars and Invisibility	35
Quantum Correspondence and Communication	39
Other Military Applications of Quantum Technology	43
Quantum Technology and Dual Use	47
Terrorism and the Threat of Rogue States	49
Analysis and Recommendations	51



Abstract

Quantum technology takes advantage of the fundamental laws of nature to reach the limits of detection, imaging, communication, and calculation. As such, it promises to enable mankind to gain access to certain skills that continue to seem impossible to master. Considering other emerging types of technology, including nanotechnology, biotechnology, space technology, artificial intelligence, and robotics, that point becomes clearer. At the same time, quantum technology's military and civilian applications (such as encryption, information security, communication, intelligence, radars, and stealth) continue to develop rapidly.

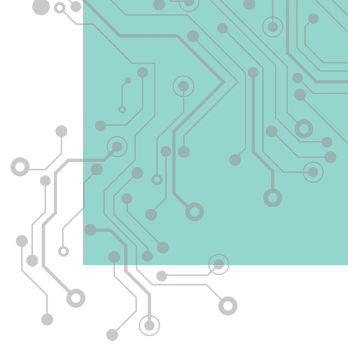
There is reason to believe that quantum technology may be used in quantum sensors, communication and computer units, fixed platforms, and autonomous aerial, naval, and land vehicles as well as within the spheres of influence of satellites for improved situational awareness. All those elements would make it possible to observe the theater of war and the enemy in a highly realistic manner. Furthermore, future armies shall be quantum armies and their commanders will be products of the quantum information generation. Accordingly, this study discusses in detail the historical development of quantum technology and its military and civilian applications as well as potential future developments.



Introduction

By the time *The Terminator* opened in theaters in 1984, filmmakers had offered countless war-related period pieces, documentaries, and science fiction movies to moviegoers. Those works highlighted the nature of war and its impact on people and communities. None of those films, however, linked armed conflict to artificial intelligence or tackled the question of robotic technology as impressively as *The Terminator* – which combined ongoing and potential technological developments with weapons, motion systems, materials, sensors, command-and-control systems, radars, night vision systems, and unmanned aerial, land, maritime and submarine vehicles. That work of fiction stood against the backdrop of merciless and fatally quick quantum computers and other elements of quantum technology. Below the surface, it argued that technological advancements may end humanity. Some four decades after *The Terminator* conflicts around the world demonstrate how close mankind has come to accessing once-fictional technology.

As discussed below, the various armed conflicts in Türkiye's neighborhood and cyber clashes, which have occurred across cyberspace over a long period, make it possible for various countries to establish superiority over others to the extent of their ability to master technology at a higher level. Today, tomorrow, and in the distant future, that superiority shall ensure their survival and enable them to preserve their living standards. This article explains what kind of technology and which methods need to be used to get there.



Quantum Theory and Quantum Technology

Quantum refers to “the minimum amount or smallest measurable unit of an entity.” Its plural form is quanta. Specifically, it is a unit that scientists use to describe energy. In this regard, physicists define it as “the smallest amount of measurable energy.”¹

Since its development in the early 1900s, quantum theory uprooted classical perceptions of science. In modern physics, it was the German physicist Max Planck’s work on the impact of radiation on black matter in the early 20th century that led to the birth of quantum theory.

That theory analyzes matter from a different perspective than classical physics to try and account for the sub-atomic universe. In his submission to the German Physical Society (Deutsche Physikalische Gesellschaft, or DPG), Max Planck studied the reason behind color changes in radiation reflecting off a shiny surface to determine that it was necessary to assume that energy existed in each unit (as in matter) as opposed to an electromagnetic wave – which meant that it was measurable. The existence of such entities was the first assumption of quantum theory.

In 1905, Albert Einstein proceeded to demonstrate that it was possible to quantify radiation itself – in addition to energy. Moreover, Louis de Broglie stated in 1924 that there was no fundamental difference between the structure and behavior of energy and matter, adding that both could behave as if they consisted of particles or waves at the atomic and subatomic levels. This theory came to be known as the wave-particle duality principle. Accordingly, scientists accepted

¹ Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harpte Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021)

that the basic entities of energy and matter could behave like particles or waves depending on the circumstances.²

In 1927, Werner Heisenberg claimed that it was impossible to measure accurately and simultaneously two complementary values such as the location and momentum of a given subatomic particle. He argued that simultaneous measurements were inevitably flawed, unlike what the principles of classical physics dictated, as the accuracy of one value's measurement would undermine the accuracy of the measurement of another. That theory came to be known as Albert Einstein's uncertainty principle.

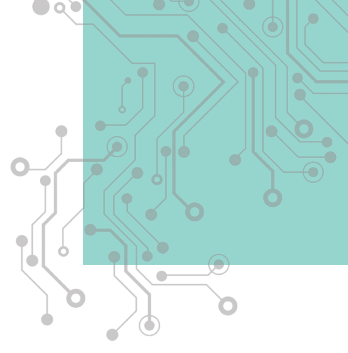
Whereas many think of quantum technology as a newly emerging field, the application of technologies, which engage with quantum in its true sense, dates back to the 1950s. Currently, popular products like quantum computers and quantum watches, which relate to quantum information technology, represent products of the second quantum revolution. As the United States Naval Research Laboratory's Dr. Marco Lanzagorta states, the development of lasers and semi-conductors in the 1950s, together with all other technological advancements that led to the discovery of modern computers, took advantage of the quantum phenomenon. Despite being used initially within the context of building machines, quantum came to be used for the gathering, processing, and analysis of information in the wake of the most recent developments.³

Today, there are many types of equipment and technology essentially resting on the impact of quantum mechanics. Some of them are as follows: laser systems, transistors, microchips, semi-conductors, and magnetic resonance imagers. According to the United Kingdom's Defence Science and Technology Laboratory, those items fall within the category of Quantum 1.0. Generally speaking, such equipment actively creates quantum versions of matter and manipulates and interprets them. They also take advantage of quantum superposition and quantum entanglement.

At the more advanced stage, which may be called Quantum 2.0, those kinds of technology can use, create, manipulate, or establish quantum matter, superposition, and correlation. Experts believe that Quantum 2.0 technology may be used for many different purposes, including imaging, timing, calculation, (gravity and magnetic field) sensors, and communication.

² Ajeay Lele, *Quantum Technology and Military Strategy*, (Springer, 2021)

³ Ajeay Lele, *Quantum Technology and Military Strategy*, (Springer, 2021)



Quantum Technologies in the Military Domain

It is necessary to analyze the development of quantum technology as a weapon technology in parallel with developments in the field of combat. Today's modern combat⁴ (network-supported combat)⁵ has reached land, sea, air, space, cyberspace and subatomic particles.⁶ Rather than firepower, it is about the optimization of firearms and various warheads and types of ammunition, increased accuracy, detecting the enemy from afar, intercepting enemy communications, preventing the enemy from intercepting our communications and extracting information, increasing radar activity, expanding the scope, capabilities, access and speed of C3I, increasing⁷ situational awareness at the level of individual soldiers and units, and the use of AI-backed autonomous main and secondary systems.

The development of quantum technology promises to exceed the existing limits imposed by the laws of nature on sensors, imaging, communication, and calculations. In particular, the activation of advanced artificial intelligence by autonomous systems and powerful quantum computers, which are secured by quantum communication, and the reinforcement of human-machine interfaces through quantum simulation, quantum imaging, and magnetoencephalography (a neuroimaging technique for recording brain activity by using extremely sensitive magnetometers) immediately come to mind.⁸

4 STM THINKTECH, *Küresel Savunma Sanayiinde 2021 Öngörülleri*, (STM Trend Analysis Feb. 2021)

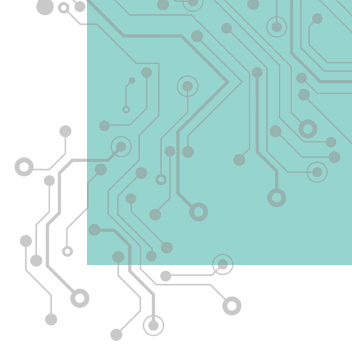
5 Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harpte Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021)

6 Michal Krelina, *Quantum Technology for Military Applications*, (EPJ Quantum Technology, Springer Open Journal, 2021)

7 Niels M.P. Neumann, Maran P.P. van Heesch, Patrick de Graaf, *Quantum Communication for Military Applications*, (The Netherlands Organization for Applied Scientific Research (TNO), The Hague, 2020)

8 Ajey Lele, *Quantum Technology and Military Strategy*, (Springer: 2021)

It is possible to argue that quantum technology may be used in quantum sensors, communication, and computer units as well as land, aerial, and naval vehicles and within the sphere of influence of satellites for advanced situational awareness toward the end of the current century. All those tools would enable an extremely realistic perception of the battlefield and enemy units. As such, quantum technology promises to emerge as a force multiplier in conventional or urban warfare against the threat of improvised explosive devices and in case of terror attacks by playing an active role in the air, on land, at sea, in space, and in cyberspace.



The Main Stakeholders Involved in Historical Development

It is possible to argue that political players have had a prominent role in the historical development of quantum technology – especially since the 1950s. Specifically, it was political stakeholders on both sides of the Cold War that made decisions and guided the relevant processes that followed the atomic bomb’s discovery. At the same time, senior and mid-level military officials as well as academics and industrialists attempted to develop the necessary technology to address emerging needs. One might add that external stakeholders caused the relevant processes to be expedited or marginally diverted at critical points in time.

The atomic bomb’s discovery and use by the United States in August 1945 encouraged the Soviet Union to respond, paving the way for a series of studies backed by quantum technology within both camps. Key political goals included nuclear armament, the use of atomic energy, accessing space, accurate calculations, accurate time measurement, the use of very small amounts of energy, the development of new materials, highly sensitive guidance systems, mass destruction, and the neutralization of enemy units from as far away as possible, as quickly as possible and in as many numbers as possible.

Another notable example, which may go down in history, was the U.S. decision to speed up its Strategic Defense Initiative, which was made possible by quantum technology, in the late 1980s. Consequently, the Soviet Union’s already fragile economy collapsed, expediting its eventual disintegration. In this sense, developing and ensuring the sustainability of quantum technology remains impossible for weak countries and systems with high levels of foreign depen-

dency. Indeed, it is possible to observe that Western countries, including the United States, found it increasingly difficult to sustain that technology, as they proved somewhat less effective against various emerging players. Such players include political stakeholders or nation-states as well as multinational corporations and technological players.

Under the current international circumstances, any given country's survival depends on its ability to quickly recognize nearby threats, monitor all kinds of traffic (including human movement, trade routes, natural resources, and energy reserves), ensure the distribution of and access to communication, products, energy, and other resources, and its mastery over geography and natural resources. It is equally important to have the skills to make them sustainable and protect them.⁹

In this sense, the ability to see, hear, detect, and strike one's adversary as swiftly as possible is key to success. Indeed, all kinds of quantum technology –quantum calculations, quantum sensors, quantum communications, quantum computers, quantum encryption, and quantum decryption— and their subcategories are intended to address such needs. That is the point of origin for all forms of technology that are essentially linked to conventional or high-tech arms races today.¹⁰

It is absolutely necessary for any state that wants to ensure its survival to invest in quantum technology and treat it as an area in need of constant progress and updating. After all, claiming second place in that race may mean losing regional or global competitions even before the starting gun.

A given country's quantum technology capabilities relate to its access to technology and economic power, which is necessary to perpetuate that access, as opposed to its geographical or demographic size. Furthermore, the availability, kind, and amount of energy reserves needed to develop such technology may play a defining role on that front. In other words, it is almost required for that country to have (or have access to) the kind of resources needed to generate very large sums of energy via various methods. It is also important to gain access to certain extremely rare minerals – as has been the case since the dawn of history.

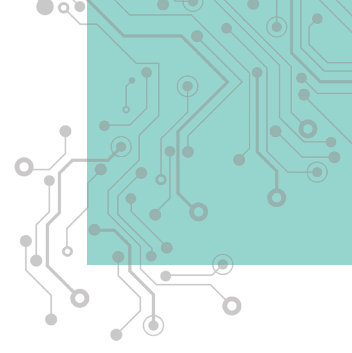
9 İbrahim Semih Akçomak and Zeki Can Seskir, "Türkiye'de ve dünyada kuantum teknolojilerinin mevcut durumu: Toplumsal çerçeveden bir bakış", *Toplum ve Bilim*, No: 157, (2021), pp. 159-187.

10 Burak Bozkurtlar, "Ulus Devletlerin Güvenlik Stratejileri ve Siber Vatan Kavramıyla Bir Değerlendirme", *ACADEMIA*, (2021).

In the absence of economic power and access to energy and minerals, the sustainability of quantum technology is bound to be subject to debate.

Today, conventional forces largely continue to operate according to the paradigm developed in the Second World War – which involves automatic weapons, armored vehicles, guided missiles, and bomb-carrying aircraft. Moreover, the world entered the latter half of the 1960s, a new period of military revolution, with warheads able to hit multiple targets independently, laser-guided missiles, infrared and visual imaging, and missile defense tools and anti-satellite weapons. Following the revolution in space information technology, which occurred in the 1970s, other states took steps to technically perfect their traditional weapon platforms like aircraft carriers, submarines, tanks, and bombers. At the same time, precision-guided munition technology emerged to increase the shelf life of weapons and counter threats. Fire control systems, which made it possible to strike targets from a greater distance and more accurately than possible with the naked eye, also signaled a military technical revolution.¹¹

11 Sait Yılmaz, “Teknoloji ve Savaş”, *Sosyal Bilimler Araştırmaları Dergisi*, SBAD, 1(1), (2021), pp. 51-66.



Quantum Military Applications

Quantum technology takes advantage of nature's basic laws to reach the ultimate limits of perception, imaging, communication, and calculation, and promises to make available new capabilities that seem impossible to attain today. At this point, the possibility of making such progress is no longer scientific speculation. Accordingly, notable public and private institutions worldwide have been taking such technology outside their laboratories to turn them into reality. At this rate, one would think that quantum technology may seriously change people's lives within the next two decades. Together with other kinds of emerging technology, including nanotechnology, biotechnology, space technology, artificial intelligence, and robotics, that point can become clearer. Meanwhile, decision-makers have the responsibility of taking and preserving their lead in quantum technology by taking the time to understand, discover and utilize quantum technology during their operations.¹²

It is important to note that quantum technology refers to a heterogenous technological mixture whose components require different amounts of preparation and have different multi-year development timelines. Their applications continue to expand and diversify at an extremely rapid pace.

Quantum simulations, quantum imaging, wearable quantum sensors strengthening the human-machine interface through magnetoencephalography, secure networks for autonomous systems secured by quantum communication, and the activation of advanced artificial intelligence developed by powerful quantum computers immediately come to mind when considering hope-inspiring military applications.

¹² Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harp'te Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021)

According to a military research institution linked to the Australian army, a quantum defense concept shall emerge by the 2040s, covering all areas (land, sea, air, and space) and featuring distributed networks of quantum sensors, quantum computers, and communication connections across the defense industry, strategic organizations and deployed operational and tactical units. In other words, all relevant structures will assume a hybrid character and power shall emerge out of that combination. Some applications of that technology develop independently but many applications shall progress together with other types of technology and platforms.¹³

Quantum image processing and quantum sensors may be stationed on stationary platforms, land/aerial/naval drones, or manned vehicles and within the spheres of influence of satellites for advanced situational awareness. Among the relevant examples are the imaging of underground or submerged structures or vehicles, geospatial mapping (e.g. magnetic and gravitational anomalies), advanced radars, and other kinds of electromagnetic imaging and sensing. Such imaging and sensory systems may make it possible for the combat theater to be perceived much more realistically within the framework of the Joint Intelligence Preparation of the Operational Environment, the Strategic Intelligence Preparation of the Operational Environment, the Joint Intelligence Preparation of the Operational Region and the Intelligence Preparation of the Combat Zone. Such advanced practices would, among other things, further facilitate the neutralization of IED/landmine threats as well as the detection of ground structures that are crucial to tracked vehicles.

Quantum computers may be distributed across platforms and networks for faster and higher-resolution signal and image processing, correlation, and definition as well as to meet the calculation demands of ever-larger groups of sensors. Furthermore, quantum communication over landlines or satellites would link quantum sensors with each other to improve detection with the help of spatial-temporal correlations. That, in turn, would create opportunities for perfect timing and combinations in detection and identification.

In terms of command and control, combat, and cyber capabilities, quantum computers stationed at headquarters would, at the strategic and operational levels, improve the speed and accuracy of decision-making by expediting op-

13 Ajey Lele, *Quantum Technology and Military Strategy*, (Springer: 2021)

erational simulation and optimization processes, geophysical modeling (e.g. the meteorology of the battlefield), data mining and artificial intelligence. Moreover, quantum computers would make important contributions to the development of new electronic warfare tools. Specifically, quantum communication links may promote the physical safety of combat electronic information systems between the operational and strategic levels. Quantum sensors, in turn, may reduce errors affecting traditional communication networks and increase their speed as an advanced time-management tool.

In terms of maneuvers and combat support systems, quantum inertial sensors would enable the precision tracking of unit progress and logistical flows without global positioning system (GPS). It is possible that armies, which regularly operate in nearby places or within their own country's borders, may not immediately appreciate the importance of that development. However, such capabilities would be extremely significant in a largely unknown location. It would be possible to optimize the control of autonomous robotic devices and machine learning as well as reach targets more quickly by handing out quantum computers to military units.¹⁴

In terms of logistics and combat service support, quantum nanosensors and microscopes may be stationed on the battlefield and, with the help of chemical and biological analysis tools as well as precise engineering, environmental and medical monitoring, and other new methods, perform various medical treatments. Quantum computers may also serve to improve medical imaging techniques (e.g. computed tomography) and optimize complex logistical systems.

Last but not least, quantum nanosensors and microscopes may contribute to the emergence of new approaches that might further the progress of advanced materials, biochemical processes, and nanotechnologies such as atomic-sensitive electronic devices. National quantum calculation facilities could expedite engineering projects through advanced simulations and optimization and enable countries to gain access to certain long-term capabilities.

Furthermore, the additional benefits of advanced quantum information technology may have an impact on key national security tools and missions like intelligence collection, solution optimization, encryption, secret technologies,

¹⁴ Michal Krelina, "Quantum Technology for Military Applications", *EPJ Quantum Technology*, Vol:8, No:24, (2021).

information technology, and communications. Indeed, the diversity of quantum applications in the field of national security warrants certain concerns over the potential benefits of quantum systems as well as the security of quantum systems. In truth, this technology simultaneously represents an opportunity and a threat. Nonetheless, having access to quantum systems shall require the creation of an ecosystem with quantum software, hardware, and algorithms – which will entail all kinds of scientific, operational, and engineering challenges.

According to the administrator of an office linked to the United States Department of Defense, quantum technology will be used primarily in atomic clocks and quantum sensors in the near future – which provides some insights into the immediate implications of developments in this field for the military in the foreseeable future. Judging by that statement, it is possible to conclude that super-precise quantum sensors and quantum-based sensors might contribute to military missions in navigation and timing.

Accordingly, it may be possible for military units to operate in future battlefields without having to rely on GPS. At the same time, Pentagon officials continue to look for alternative navigation methods for space exploration – among other fields. In this regard, it is possible to predict that quantum applications shall be adopted by Türkiye, which charted a new course for space studies, by launching an integrated R&D effort.

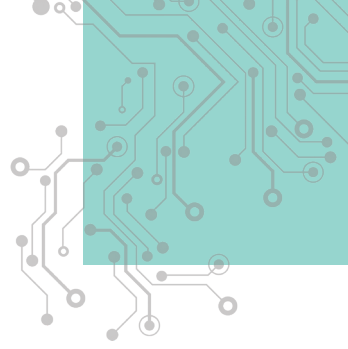
Despite various political, economic, and technological concerns, it seems highly unlikely that any country will make a great breakthrough in quantum studies soon. Still, all states must be aware of the potential opportunities and risks that quantum technology shall entail and take the necessary steps to prepare for the quantum revolution. In this sense, it would make more sense to focus on areas that quantum will directly and immediately impact.

The second quantum revolution is not limited to information technology and communication. One of the most significant transformations, which quantum will entail, shall occur in the field of measurement. To be clear, most of our daily activities depend on such calculations whether we know it or not. Finding the right exposure to take a picture, navigating with the help of GPS, and being able to know exactly what time it is to calibrate various devices are among some of those activities. In this regard, quantum might prove to be a game-changer with its level of precision. In traditional science, measurements are not taken below a certain level of tolerance. In other words, even science has admitted that it

cannot deal with certain amounts. In contrast, the world of quantum is about the micro level and focuses on studying matter and phenomena with the greatest possible detail.

Such abilities of quantum mechanics, just like information technology and communication, stem from quantum physics. For example, in terms of the detection and long-range capabilities of quantum radars and classical radars, the latter disseminates light particles and makes measurements based on their reflections. As such, classical radars compare actual findings with expected results to guess the target object's velocity and location. In contrast, a double-entangled quantum particle contains twice as much information as a classical particle. In other words, quantum correlations are stronger than classical correlations. Furthermore, they have other superiorities like operating with less emission and maintaining the same level of accuracy during low-power operations.

Such attributes may improve images as well. Many kinds of quantum imaging take advantage of quantum entanglement to measure anything from photons to magnetic or gravity anomalies. It may be possible to detect underground shelters or submarines in the deepest parts of oceans based on information obtained through quantum entanglement. The principles of gravity, too, may be used as quantum gyroscopes and form the basis of highly sensitive inertial navigation systems that do not require external signals. As a matter of fact, classic physics continues to utilize such technology at this time. Yet the quantum transformation promises to improve accuracy and make certain information available that remains out of reach. To sum up, quantum technology will enable the surveillance of stealth submarines, ghost planes, and even the most remote parts of the Earth's surface and oceans by expediting the development of new cameras, radars, and other relevant systems. By reducing our dependence on GPS technology, quantum technology may create new ways of positioning and timing to address pressing defense issues.



Encryption and Information Security

Information security represents an important goal for all stakeholders, including states and companies that use technology intensely. Military plans, defense projects, personal and institutional data, and critical information regarding state security are processed with the help of public or private networks. Protecting such information bears vital importance and experts believe that quantum encryption may be one of the few solutions available.

Cryptography uses various complex mathematical data to render digital information incomprehensible and indecipherable. Cracking that code requires so many mathematical calculations that it is nearly impossible to perform such tasks with the computers at humanity's disposal today. That system effectively puts in place a mechanism that undermines itself since quantum computers, which shall be equipped with such advanced technology, will be able to make extremely complex calculations and crack the most challenging codes. With the help of quantum entanglement and quantum superposition, even the simplest quantum computer shall be able to perform such tasks within several hours – provided, of course, that one would have to ignore the level of technological complexity required for quantum computers to exist in the first place. That development, in turn, would create a serious security problem for states and corporations. Continuing to store data attackers wish to access in existing computers until the development of quantum IT capabilities, in turn, would further aggravate the problem.

At this time, quantum computers remain unable to easily overcome any type of encryption. The majority of sensitive official secrets are protected by symmetrical encryption systems that are quantum-immune. Engineers continue to work on quantum-resilient encryption algorithms.

Under the current circumstances, expecting mathematicians to develop quantum-resilient encryption solutions is not the only solution. For states that have access to most existing systems, adapting to the post-quantum era and overcoming future problems with patches for existing systems will require hard work over a lengthy period. Moreover, reinforcing existing security systems and integrating quantum technology into them will prove difficult. In truth, the security concept, which shall emerge in the wake of the quantum transformation, will not lead to abandoning existing tools. Instead, it will be necessary to integrate quantum algorithms into existing systems. Accordingly, experts note that hiring software developers and engineers (or, broadly speaking, highly-qualified staff) that can harmonize and integrate such systems will prove to be the real challenge. Under the new system, which decision-makers will have to shape by taking into account price points, the amount of data, and distances, there is the possibility that an optimal solution shall prove elusive altogether. Notwithstanding, it is necessary to consider that political, military and technical stakeholders may have to make concessions based on their analysis of a tradeoff between the most optimal components.

The possibility of hostile states gaining access to sensitive information alone would arguably demonstrate why such an ecosystem may be absolutely necessary for any country. Observers explain the nature of this new system with reference to qubits carrying information with the help of quantum key distribution as part of quantum encryption crashing following the completion of such transfers. In other words, the data disappears permanently once the task is performed. That arrangement, in turn, would eliminate the problem of storing information – which remains one of the main vulnerabilities. Whereas hardly anyone expects quantum communication to replace the internet or cell phones in the medium term, there is reason to believe that it could prove incredibly useful in certain settings like communicating with submarines. Furthermore, quantum radars may create significant opportunities in underwater warfare. That is because submarines currently rely on sonar to detect obstacles and other underwater vehicles. Whereas the active sonar device represents the most advanced technology at this time, it also reveals the exact location of the submarine itself. In contrast, quantum radars might allow submarines to accurately detect naval mines and obstacles and to pass by them silently, making it harder for other submarines to detect or follow them.

Whereas quantum communication and radar technology would make it harder to find submarines, gravimetry stands to make it easier. Experts maintain that

those two technologies may be used against each other (as in the present) and the technological race shall continue without interruption. In this case, the decision-maker's responsibility is to identify the most optimal methods, create the necessary conditions for obtaining such technology and oversee a balanced supply process.

Quantum encryption represents a sub-category of quantum data processing that covers quantum calculus, quantum measurement, and quantum teleportation. Quantum calculations and quantum processing refer to performing IT tasks by using quantum mechanical systems. Quantum mechanics offers us a mathematical framework for developing physical theories. Its rules are fairly simple, but even experts see them as illogical. Physicists have been working on the principle of quantum entanglement for a long time to develop a better understanding of quantum mechanics. No complete theory of quantum entanglement has emerged yet, but scientists made some progress to grasp that aspect of quantum mechanics. Indeed, many researchers believe that additional research on quantum entanglement is likely to offer insights with the potential to facilitate the development of new applications for quantum communication and quantum processing. Quantum encryption is an important component of cybersecurity and it continues to gain importance in the age of information.

The majority of cryptography algorithms in classical encryption systems rest on typical challenging problems in number theory. Notwithstanding, the emergence of quantum computers and Shor's algorithm—a 1994 quantum computer algorithm developed by the American mathematician Peter W. Shor for finding the prime factors of an integer, which represented a turning point in the history of cryptography—facilitated the solving of difficult problems in number theory to pose a serious threat to the safety of crypto systems. That is why quantum encryption, which is effective against quantum and classical computers, has become a significant need. Once quantum computers go online, some widespread and major encryption methods will become obsolete.

Quantum computers shall be able to take advantage of natural laws governing subatomic particles to easily overcome existing encryption methods. Chris Monroe, an experimental quantum physicist at the Quantum Institute in the U.S. state of Maryland, recently highlighted the importance of quantum by saying that "information security is guaranteed by the fundamental laws of physics." Today, cryptography plays an important role in all electronic communication systems. For example, the safety of emails, passwords, financial transactions, and

even electronic voting machines depends on secrecy and reliability. Cryptography merely enables parties that have exchanged keys to read each other's encrypted messages. Since quantum computers can make calculations that classical computers cannot, they pose a threat to secure communications. Consequently, quantum computers would be able to crack any cryptographic code by scanning or searching all hidden keys and cutting communications between the sender and recipient of each message. Such actions require greater complexity than the capabilities of classical computers.

Modern science develops certain new materials known as quantum materials. Materials like graphene and topological insulators, which have quantum mechanical attributes, are used in this field.

Quantum computers can simulate the electronic structure of materials and enable the development of integrated superconductors and long-lasting batteries. The above-mentioned simulation technologies and electronic check-up processes are facilitated by quantum particles called qubits. Qubits represent basic points of departure, which provide extraordinary data storage, and interact with each other. With the help of this new application, future soldiers will wear electronic assault vests that will truly be quantum products. It will be possible to further develop armor technologies and all-season field gear with the help of methods based on the laws of quantum mechanics.

Quantum electronic warfare consists of quantum-enhanced classical electronic warfare and quantum electronic warfare. Whereas electronic warfare concentrates on counter-measures, counter-counter-measures and supporting quantum channels, classical electronic warfare systems may take advantage of quantum antennas to take electronic support measures. Specifically, Rydberg atom-based quantum antennas would take up very little space and offer various solutions for range and quality independent of signal frequency. Indeed, a quantum antenna, which is just several micrometers long, would suffice to intercept low-frequency signals.

Dynamic band-switching quantum antennas can operate precisely at different frequencies and may serve as a major force multiplier by disseminating jamming waves that are difficult to detect toward enemy lines. Furthermore, such Rydberg atom-based antennas may capture signals on AM and FM bands, self-calibrate, and measure both strong and weak signals to identify their arrival angles. Experts believe that future quantum antennas may look like a series of

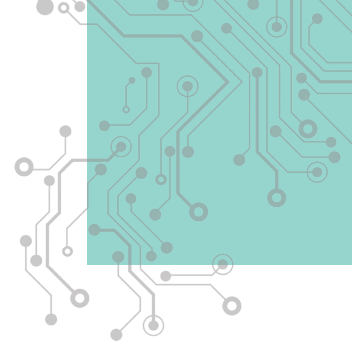
matrixes consisting of Rydberg atom cells. In that case, it would be possible for different cells to measure different signals and allow the calculation of arrival angles through the cooperation of two or more cells. That application's softest spot, however, will be to reduce the size of cryogenics needed to cool down Rydberg atoms.¹⁵

Classical EW takes advantage of QEW to offer advanced radio frequency spectrum analyzers. It is believed that processing data here directly would lead to a significant increase in efficiency.

Quantum electronic warfare would also have certain applications in signals intelligence (SIGINT), combat intelligence (e.g. identification, detection, definition, positioning), and quantum electronic assault. Since classical electronic warfare experiences certain problems due to the physical environment (through which data is transmitted), background noise, and other technical downsides, QEW would offer more reliable solutions in this area. As mentioned above, however, a quantum-based attack might cut quantum channels and entail significant vulnerabilities for the entire system. Another important problem relates to the possibility of noise pollution and the use of directed energy weapons and other platforms that may prevent the movement of photons.¹⁶

¹⁵ Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harpte Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021).

¹⁶ Niels M.P. Neumann, Maran P.P. van Heesch, Patrick de Graaf, *Quantum Communication for Military Applications*, (The Netherlands Organization for Applied Scientific Research (TNO), The Hague, 2020)



Quantum Technology and Intelligence

Quantum applications may trigger the single greatest progress for armies by facilitating certain changes within the field of intelligence. Collecting information by using advanced technology and with precision and perfect timing shall be an extremely important force multiplier for military forces around the world.

It is important to recall that U.S. military planners had started worrying about the threat posed by new radar-guided missile systems operated by the USSR and others against American aircraft by the 1970s – at the height of the Cold War. In response, engineers at the U.S. defense giant Lockheed Martin, who worked on renowned platforms like Skunk Works, expedited their work on stealth – technology that could hide American planes from the prying eyes of enemy radars.

Among the innovations that came out of that research was the ‘flying wing’ of the B-2 bomber, which could distort radar waves, had an unusual shape, and consisted of carbon-based material and new kinds of paint. Although stealth did not make military aircraft completely invisible or undetectable, significant progress has been made since the above-mentioned concerns emerged. Indeed, even the most advanced warplanes continue to reflect some radar waves today. Still, those signals are so weak and marginal that they practically disappear against background noise, enabling the aircraft to operate without detection.

Although China and Russia have been developing their own stealth aircraft since that period, it is possible to observe that the United States remains significantly ahead of its competitors. Furthermore, that advanced technology has proved itself in battles, like the 2003 invasion of Iraq.

Nonetheless, one might argue that the U.S. superiority has been challenged. In November 2018, the China Electronics Technology Group Corporation (CETC), the

country's largest defense and electronics company, announced that it had developed a radar prototype that could detect stealth aircraft mid-air. That radar reportedly uses some phenomena linked to quantum physics to reveal the location of such planes. Inspired by quantum technology, this application—which represents one of several ways in which quantum may change the face of war—could make stealth aircraft visible as well as increase the security of wartime communications and limit the ability of submarines from roaming the oceans without being detected. It is important to note that detecting such war machines, which represent one of the main challenges encountered in reconnaissance, monitoring, and detection missions from an intelligence standpoint, from a great distance remains nearly impossible with classical technology.

In contrast, it is possible to make significant advances with the help of quantum entanglement. As mentioned above, quantum entanglement refers to a situation where several particles remain interlinked and share physical attributes regardless of the space between them. Scientists at the Institute of Science and Technology Austria (ISTA), together with their colleagues at the Massachusetts Institute of Technology (MIT), the University of York (UK), and the University of Camerino (Italy), have discovered a new detection capability to showcase what quantum radars could accomplish in an intelligence sense. This new detection method, microwave quantum illumination, uses entangled microwave photons. Known as quantum radar (Q-Rad), that prototype crossed an extraordinary threshold by successfully detecting objects in noisy and extremely thermal environments where classical radar systems often fail.

As a matter of fact, this new equipment operates based on an extremely simple principle. Instead of using traditional microwaves, those researchers created a mixture of two kinds of photons: signal photons and idler photons. As signals are delivered to the target object, idler photons undergo relative isolation to be measured devoid of statics and noise. As the signal is reflected back, the true entanglement between signal and idler photons disappears. Yet a limited amount of correlation remains intact and, irrespective of noise, creates a signature or model that establishes the existence or absence of the target object.

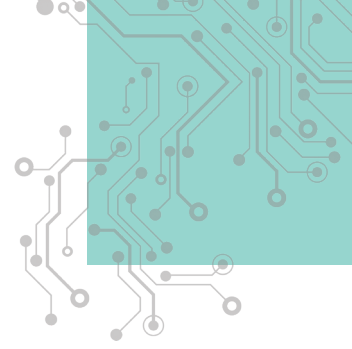
Shabir Banzanjeh, a senior researcher and associate professor at the University of Calgary whose past research helped advance the theory behind quantum-enhanced radar technology, recently stated, “What we have demonstrated is a proof of concept for microwave quantum radar.” He added that “using entanglement generated at a few thousandths of a degree above absolute zero, we have

been able to detect low reflectivity objects at room temperature.” Those statements are largely seen as a precursor of the impending revolution in quantum radar technology. Indeed, what is most needed in urban combat warfare is to gather accurate information about buildings and streets. This new application, in turn, shall be able to provide information about shapes and entry points from any room by taking advantage of ordinary objects. Furthermore, it will be possible to even determine where individuals are standing and what they are doing within a building—even behind concrete walls—with the help of reflectivity.

Whereas quantum entanglement is naturally fragile, such devices have certain advantages over traditional and classical radars. For example, traditional radar systems tend to have difficulties distinguishing radiation reflected by objects from the naturally emerging background noise at low levels of power. As such, they have a problem of low precision.

Since the similarities between signals generated with quantum entanglement and idler photons make it harder to distinguish signals (from the target object) from background noise, experts believe that quantum illumination may be used to address that particular problem.

Barzanjeh notes that “the main message behind our research is that quantum radar or quantum microwave illumination is not only possible in theory but also in practice” to suggest that this new technology may be ready to move to the next stage. He also says that “when benchmarked against classical low-power detectors in the same conditions we already see, at very low-signal photon numbers, that quantum-enhanced detection can be superior” to reiterate that quantum radars might entail certain advantages in practice over classical radars.



Quantum Radars and Invisibility

Throughout history, fundamental sciences have been the driving force behind innovation, paradigm shifts and technological advancement. Despite being perceived as conceptual proof still, this latest study revealed the possibility of developing a new perception method that could be superior to classical radars in certain situations.

As an example, the F-35 joint strike fighter remains one of the most expensive military projects of all time with its \$1.5 trillion price tag. That aircraft derives most of its value from its stealth capabilities. Lockheed Martin, the F-35's manufacturer, allocated significant financial resources to the development of new materials, techniques, and design attributes that enabled this extraordinary jet plane to fly through the coverage area of enemy radars.

It is important to note, however, that some researchers affiliated with the China Electronics Technology Group Corporation (CETC) developed the world's first long-range quantum radar (Q-Rad) in mid-September 2016. Each particle fired by this experimental system has an enclosure with quantum entanglement that is stored in its sensor. Thanks to the unusual ways of quantum entanglement, each object (including the F-35 aircraft) that those particles encounter creates an instant reaction within the sensor. As such, quantum entanglement may be capable of detecting the world's most expensive stealth fighter. This, in turn, is asymmetry *par excellence*, as a perfectly simple quantum device may be enough to cope with an extraordinary war machine within a limited time – as opposed to trying to develop counter-measures possibly over multiple decades.

China's technological breakthrough sent shockwaves through the defense community. Research groups worldwide, including Lockheed Martin, had been con-

ducting quantum radar experiments for a decade without taking such a major step forward. Indeed, just one year before the Chinese study, experts established that the quantum radar's effective range was less than 7 miles. In contrast, the Chinese team claimed that their product could operate from a distance of 61 miles – a hard-to-believe discovery.¹⁷ Keeping in mind the capabilities of the Turkish Air Force, it is not at all difficult how significantly that breakthrough could strengthen Türkiye's hand in the Mediterranean. After all, it is possible to conclude that some products, which have been hailed as stealth, could become history in light of the latest discovery, which might start new chapters in warfare.

Another area in which quantum radars may prove useful corresponds to active protection systems that are used to defend armored vehicles, main battle tanks, and similar military vehicles or platforms against kinetic and chemical armor-piercing ammunition during combat as well as target detection and tracking radar systems.¹⁸ The aforementioned systems are expected to identify and track the target with very high reaction times and address the launch control issues of protection systems to neutralize the threat with active or passive systems. Despite the lack of a known study in that field, ongoing developments suggest that a prototype may emerge in the near future.

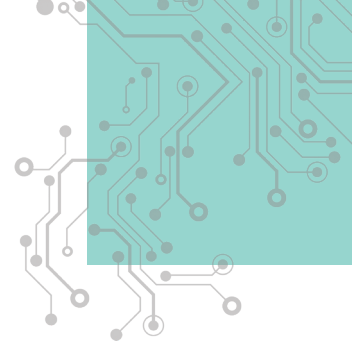
At the same time, precision nanosensors continue to play a more important role in the generation and dissemination of operational intelligence in a timely manner. Sensor systems represent one of the points of emphasis for studies in military nanotechnology. The production of precise nanosensors with the help of nanotechnology would not only help detect mines but also identify terrorists illegally crossing national borders. Sensors with high visual sensitivity play a crucial role in intelligence production for missions like assessing the enemy's settlements, the nature of terrorist activity, and combat damage. Accordingly, the quality and resolution of images impact the overall accuracy of collected intelligence. At the same time, the measurement of CBRN leaks may be performed more accurately with the help of nano-level sensors – which would facilitate the more effective combating of bioterrorism. Equipped with nanosensors, au-

17 Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harpte Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021).

18 "Aselsan Tarafından Altay Tankı İçin Aktif Koruma Sistemi Akkor Geliştirilecek" [Aselsan to develop the active protection system Akkor for the Altay tank], ASELSAN, <https://www.aselsan.com.tr/tr/basin-odasi/haber-detay/aselsan-tarafindan-altay-tanki-icin-aktif-koruma-sistemi-akkor-gelistirilecek>, (Accessed: 22.10.2022).

onomous aerial and land vehicles can perform important tasks for monitoring the theater, ensuring the safety of friendly units, and providing early warnings. Nanosensors are smaller, cheaper, and stronger than traditional sensors and they will come to play a more prominent role in our daily lives together with smart systems.

It is highly likely that terrorist organizations, not just states, could produce nanotechnological materials. Accurate and timely intelligence will be needed more than ever to counter state actors and terrorist entities with such capabilities. Whereas traditional weapon systems are easily detected and countered with precautions, the detection of weapons, which are produced at the nano level, shall prove difficult.



Quantum Correspondence and Communication

Storing and transferring information possibly represent the most serious challenge for any intelligence organization. It is extremely difficult to carry sensitive and valuable information from one platform to another without experiencing negative side effects. The increased importance of that issue has become easily observable in the current atmosphere of widespread cyberattacks and cyberbullying. Against that backdrop, quantum computers may create unparalleled opportunities for the storage and transfer of sensitive information thanks to their quantum encryption capabilities. Furthermore, data processing and analysis may become significantly easier with quantum communications. That, in turn, would represent a breakthrough for officials involved in the intelligence production process, which requires hard work and the questioning of many different relationships. Despite the disadvantages of completely quantifying the decision-making process, making known the unknown and making decisions in a deterministic manner represent an inherently mathematical process. That is how quantum computers could generate optimal solutions in challenging areas like intelligence.

Notwithstanding the above benefits, the system may become vulnerable as countermeasures are taken with the help of artificial intelligence and quantum technology. Still, that is a basic problem encountered all the time. As war changes, methods change and the tools and technology utilized move forward in an attempt to cancel each other out.

At the same time, experts believe that quantum communications shall improve cryptography and security solutions. Quantum computers, which can run Shor's algorithm with the help of quantum attributes, are expected to be available within the next decade.¹⁹

¹⁹ Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harpte Yeni Kavramlar*,

Such algorithms may be used to crack traditional digital signature schemes commonly used in embedded systems today. The security issues in this field are not as obvious as the armor/anti-armor paradox, but there is a progressive process between defensive and offensive applications. On the defense side, there is an emphasis on quantum systems for encrypted communication purposes. For example, experts stress that China has been focusing on quantum communications for years in an attempt to counter the progress that the United States has made in quantum communications. Although such studies are undertaken independently of each other, those systems tend to emerge as each other's antidotes.

Google's theory of quantum superiority encouraged the development of urgent solutions for finding solid algorithms that can withstand quantum attacks. In terms of quantum communications, the development of such attacks has been underway for years, as defining and taking advantage of quantum attacks continue to create a major research field.

Quantum communication may also contribute to the development of revolutionary artificial intelligence systems. We have discussed the benefits of that development above. In addition, the most recent efforts led to the conclusion that there were strong and unexpected links between quantum communication and artificial neural networks, potentially giving rise to new approaches to machine learning. Experts maintain that such advancements may lead to significantly improved pattern recognition and, by extension, improve machine-based target definition. For example, quantum computers, supported by artificial intelligence, may collectively analyze massive data collected by quantum sensors and robots to make it significantly more likely to detect stealth submarines operating in massive places like oceans.

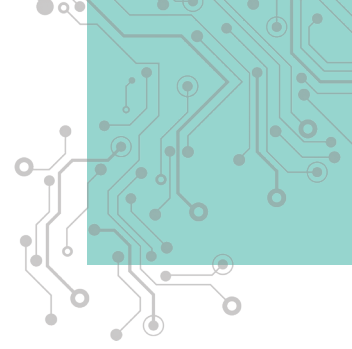
Quantum communication could also influence quantum image processing to address logistical problems more quickly. Still, most of those issues remain the subject of basic research.

It is believed that various combinations of quantum sensors shall enable significantly improved detection on the ground. Current applications rely on satellites and GPS systems to generate location data. Quantum communication, in contrast, may take advantage of quantum entanglement and superpositions to

generate more precise location data (even without GPS or satellite support) and improve the detection rate and quality of sensors.

C5ISR is absolutely necessary for any army to perform sensitive tasks. Quantum systems, in turn, have significant potential in terms of battlefield awareness. In this sense, experts believe that quantum communication is likely to make the greatest impact on this field. Storing, sorting and making sense of large amounts of data under complex and uncertain battlefield conditions represent a serious problem for planners. In contrast, decision support systems that rely on quantum communication might make very serious contributions to gaining the upper hand in decision-making.

With the help of quantum perception, it will be possible to complete information-gathering missions with more diverse and optimal combinations, as such systems are easily integrated into land, naval, and aerial platforms. As a matter of fact, even low-orbit satellites shall become available to armed forces and be operated independently.



Other Military Applications of Quantum Technology

In the field of quantum detection, gravimeters and gravity gradiometers may prove useful in precise underground imaging and detection, providing precise location data and navigation.

The quantum magnetometer represents another important sort of detection. Quantum magnetometry applications overlap with quantum gravimetry applications to some degree, encouraging new applications. Quantum magnetometers can generate high-quality and precise data for practical reasons, including the detection of underwater mines and the study of ground metals (mainly as a precaution against lightning strikes) near military bases in eastern Türkiye. Last but not least, one of the main breakthroughs in this field is expected to take place vis-à-vis imaging (e.g. radars and three-dimensional cameras) as such devices shall produce high-quality and high-definition images that require less storage space.

Magnetic anomaly and gravity-based sensing may enable the production of a new picture of the Earth's surface. The aforementioned quantum perception technologies, magnetometry, gravimetry, and gravity gradiometry may achieve high levels of sensitivity – at least in the laboratory. It is believed that quantum formulas may make a real difference in perception, despite many challenges involved in the process, with the help of precise data interpretation and calculation skills.

Furthermore, observers believe that Türkiye may attach gravimeters to drones and other platforms to accurately identify trenches, tunnels, and underground paths in terms of depth and width. Ongoing efforts in this field, which requires advanced engineering projects for more advanced purposes on naval platforms,

could spearhead unprecedented progress in search-and-rescue operations, rubble detection, counter-mine measures, and offensive missions. Last but not least, the integration of precise magnetometers and gravimeters into floating platforms would arguably contribute to the discovery of petroleum and other hydrocarbons as well as the demarcation of maritime jurisdictions.

In addition to quantum radars, there have been certain developments in the field of imaging. The emergence of tactical passive sensors, active/passive imaging systems with the ability to operate secretly, precision detectors for various noise levels, cutting-edge technology for the detection of stealth vehicles, quantum illumination systems, and quantum 3D cameras immediately come to mind.

It is possible to reach quick 3D imaging performance with low-noise and unprecedented wide focus depth that aims for low background noise and long range. The development of that capability may give rise to jets, satellites, and other sensitive military technology for inspecting and identifying deviation or structural cracks. It will also be possible to perform detailed reconnaissance of enemy facilities and equipment with the help of long-range 3D imaging via unmanned aerial vehicles.

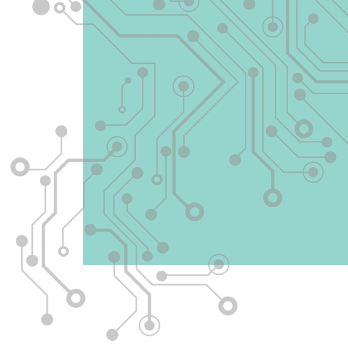
Thanks to its specific short-range capabilities, this imaging system makes it possible for operators to look around corners and beyond their line of sight – which could make it useful in urban warfare, hostage situations, and the detection of vehicles approaching from un surveilled places. Such devices may also be operated in low-visibility and low-illumination settings. Furthermore, they promise to create significant advantages against certain obstacles and restrictions like clouds, rain, fog, dust, smoke, trees and nighttime conditions that are part and parcel of military operations. What distinguished those new systems from their classical counterparts is their ability to detect, categorize and define targets with low signal noise. For example, such systems shall be very helpful to helicopter pilots trying to land on a dusty surface. Moreover, they won't be easily detected due to their low noise level – significantly reducing the time, energy and capital to be invested in counter-measures.

Space continues to gain importance from the perspective of states. Especially technology-oriented developed nations may start using space as a battlefield. Despite being primarily used for navigation, communication, and mapping to date, space has come to be utilized for military surveillance purposes in the recent past. Furthermore, countries are likely to adopt a more active approach

to double down on an arms race in space. Although there are no weapons or launch pads directed from space, satellites, and lasers in the Earth's orbit can be used for such purposes. In truth, the great powers continue to launch their own platforms and vehicles into space. Such satellites, whose stated purpose is to increase the Internet's speed and pursue other peaceful goals, may transform into kamikaze tools at some point. At this time, an estimated 2,200 systems are orbiting the planet.²⁰

At the same time, space will be key to equipping satellites with quantum sensors and communication technology. To use various kinds of quantum technology, which we have discussed above, it will be possible to integrate quantum gravimeters, gravity gradiometers, or magnetometers (and other quantum sensor technologies) into low-orbit satellites. Such applications remain under development today. For example, a lower-strength quantum gravity sensor being attached to a minor satellite may be used to accurately map resources or assess the impact of natural disasters. The obvious next step would be to detect such devices and monitor space as a countermeasure. It is possible to argue that quantum radar applications may create very different solutions at advanced stages here. In this regard, space quantum radars being able to track and detect small, dark, and fast objects in a complex atmosphere may make huge contributions to future space wars.

²⁰ Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harp'te Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021).



Quantum Technology and Dual Use

Following the Second World War, two separate R&D and manufacturing industries emerged for military and civilian markets in line with changes and the need for new technology to ensure the sustainability of armed forces. Especially during the Cold War, the increased demand for new technology spurred R&D projects. Since the mid-1990s, however, there have been cuts in defense and weapon development budgets – which led to the rise of “dual use” at the intersection of military and civilian domains. Experts argued that this new concept would reduce the cost of meeting the military’s demand for high-performance weapon systems.²¹

It is important to note that all sorts of quantum technology, including calculations, sensors, communications, and encryption, have many civilian applications in fields like medicine, electronics, optics, space, and aviation.

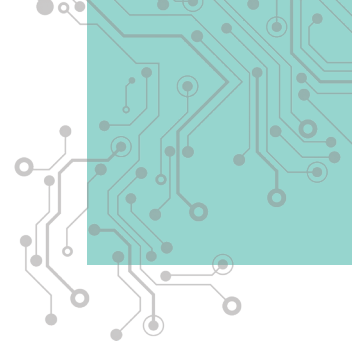
The idea of dual use does not benefit the armed forces just by expediting supply processes and reducing costs. At the same time, dual use may increase the operational capacity of weapons until their expiration, expediting technological development processes and facilitating the development of more reliable and easily-maintained technology.

Nonetheless, dual use faces some level of criticism. In addition to concerns over the scarcity of technology with military and civilian applications, some observers warn that it would be impossible to reduce high-performance weapon production costs as drastically as intended no matter how low the cost of commercial products may be. Experts, who criticize the idea of dual use in such ways, instead

21 STM THINKTECH, *Teknolojide Çift Kullanım ve COVID-19 İlişkisi*, (STM Trend Analysis, July 2020).

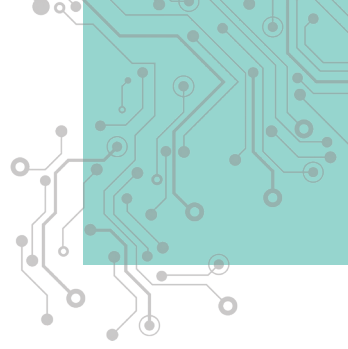
recommend that companies, which exclusively focus on the defense industry, operate under the strict supervision of national governments. Another concern is that military personnel would not be able to distinguish between “mandatory” and “optional” products if some activities continue to be carried out with commercial products and, by extension, cannot reduce costs continuously. Last but not least, there are concerns that opting for commercial products would require the sharing of sensitive information about the production of weapon systems with non-military companies – which might outweigh the potential benefits of dual-use.²²

22 STM THINKTECH, *Teknolojide Çift Kullanım ve COVID-19 İlişkisi*, (STM Trend Analysis, July 2020).



Terrorism and the Threat of Rogue States

Judging by the current level of quantum technology and the resources needed to sustain it, it seems extremely unlikely for the average terrorist organization to obtain and use it. The only exception would be terrorist entities backed by so-called rogue states, which might utilize weapons that incorporate quantum technology by receiving logistical support from such countries – no matter how unlikely that may be. Obviously, that unlikely scenario would be extremely destructive to all infrastructure and superstructure in the target country or region if it were to become a reality. One might assume that such a development could be prevented through strict adherence to existing international protocols designed to stop terrorist organizations from getting their hands on nuclear and radiological agents. Likewise, it seems extremely unlikely that any terrorist entity could pose a threat, which would be made possible by expensive and advanced nano-level quantum technology, without outside support.



Analysis and Recommendations

Studying quantum technology is necessary for gaining access to its military applications as well as appreciating the issues, conclusions, threats, and choices rooted in its development. Above all else, this emerging field deserves to be fully grasped and carefully studied with a diverse and interdisciplinary approach. Instead of bringing about the quantum revolution without making due calculations, it would be best to be aware of the potential problems that such applications may create. Together with those issues, their future result shall be analyzed from military, ethical, and technical standpoints.

Within the context of military practices, quantum technology shall preserve existing capabilities to make available more precise cruise, ultra-secure communications, advanced C5ISR (command and control, reconnaissance/surveillance, communications-electronic and information systems, and intelligence), and quantum IT capabilities. In the intelligence field, that technology will diversify technology-intensive collection tools.

Generally speaking, the term *quantum warfare* requires the overhaul, replacement, or reorganization of military doctrine. At this time, it is necessary for doctrine and training planners to carefully analyze changes on the ground with plenty of foresight. In this sense, experts maintain that updating the Joint Doctrine for Intelligence by incorporating this field's intelligence applications and with a scientific approach or launching a more comprehensive effort to export them to the principles of intelligence for an overhaul. They add that placing greater emphasis on technical intelligence in this new volume would be suitable.

Planners need to immediately start creating military scenarios and making plans for developing new techniques and acquiring new weapons for the quantum age.

More importantly, assuming a strategically important position and responding to changes in due time requires the development of technology policy and strategy. Likewise, intelligence units should undergo on-the-job training in physics and engineering to develop some level of expertise and study the relevant fields in greater detail. Officials pursuing graduate and doctoral degrees, in turn, need to study more practical applications as opposed to theoretical approaches.

In this regard, the following recommendations can be made to decision-makers:²³

1. Studying national resources of quantum technology (e.g. universities, laboratories, and private companies), forming strategic partnerships with the relevant sectors, monitoring developments in real time through staff exchanges, and conducting internal threat assessments and feasibility studies represent a starting point. This field is most likely to impact intelligence units which must develop the capabilities to monitor global quantum trends very closely from their unique perspective.
2. Tracking the evolution and adaptation of quantum technology is key to monitoring technological advancements. Putting in place the relevant institutions and R&D processes represents a problem area that already deserves attention. In this regard, intelligence units must create realistic and achievable lists of their needs and aim to reach specific goals by directing the upper echelons in that direction.
3. Another important task intelligence services must complete relates to keeping track of the advancements of neighboring countries and potential threats and recording the relevant developments in strategic documents. Instead of relying on classical formats and collection tools, it would be suitable for them to develop a systematic collection strategy by taking advantage of the above-mentioned upsides of quantum encryption.
4. Despite currently lacking the necessary financial, R&D and technological capacity, it is absolutely necessary to monitor this sector continuously and to adopt a decisive stance regarding this issue. That is why

²³ Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harpte Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021).

all modern armies must watch this space and the Turkish Armed Forces need to translate its awareness into reality. Meanwhile, intelligence units should be integrated and coordinated among themselves to try and gather more technological intelligence from isolated countries, especially China, regarding this field.

5. Governments need to shape their trade and export policies in cooperation with military decision-makers and launch strategic grant programs to seriously encourage military and civilian researchers to focus on this field. For example, the European Union already offers significant grants regarding this issue. There is also reason to believe that creating a legal framework for intelligence units within the Turkish Armed Forces to engage and enter into commercial relationships with foreign organizations and institutions would give momentum to ongoing efforts.

Among all the different applications of quantum technology, quantum computing promises to facilitate more progress and change. In truth, all other areas largely take advantage of existing capabilities in this domain. It is primarily necessary to work hard to gain access to quantum computing capabilities and to build on that with indigenous methods and studies to make progress on other fronts. As mentioned above within the context of quantum encryption and quantum computing, mastering those types of technology could enable armies to make significant progress. However, it is important to note that they shall entail certain major threats as well. The exposure of sensitive information and the risk of systemic attacks require the development of counter-countermeasures. That is why it is necessary to study this subject in a continuous and progressively developing manner instead of making momentary advancements. Specifically, intelligence units must contemplate countermeasures in addition to focusing on developing skills. It is necessary to ensure that all relevant units fully understand the importance of becoming aware of this field and maintain a high level of discipline throughout. After all, mastering such technology and developing the necessary skills shall serve as a force multiplier on a regional scale and potentially create an asymmetrical impact worldwide.

As noted above, preserving the current achievements and scope of quantum technology and building on them to reach more precise results may create major gains. Whereas this field has been studied with an emphasis on achievements and utilization, a closer look at ethics and the use of force reveals that there may be certain interdisciplinary concerns involved. That topic falls within the scope of

the law, yet I shall endeavor to briefly identify some of the potential challenges.²⁴

With the help of future quantum capabilities, it may be possible to manipulate human DNA, design weapons that could potentially create a mass effect in combat, discover sensitive yet lethal methods with artificial intelligence, and use space for combat capabilities. Those possibilities lead us to identify this field as a problem area that calls for various countermeasures. Quantum technology is bound to reduce the time needed for making decisions and executing commands once a decision is reached. Generally speaking, that shall make the use of force more likely. For the sake of the extremely sensitive balance of power and diplomacy, it would be useful to think about those issues in detail. Furthermore, it shall be necessary to rethink intelligence-gathering efforts regarding such concerns. As advanced technology makes it easier to access information, certain legal problems may arise. Therefore, it may be necessary to hire legal advisors as required by intelligence units. Considering the possible failure to stop the development and export of such technology and, by extension, to prevent certain harmful groups from getting their hands on it, one cannot rule out the need for a multidimensional approach to operations.

Last but not least, monitoring all developments in this field and obtaining the relevant technology shall prove financially challenging. As such, one would think that it would be more appropriate for governments to adopt smart policies and focus on initially needed capabilities.

Precision and resolution are among the main technical problems that may occur.

Preserving the existing infrastructure and laying the groundwork for the quantum transformation shall require significant financial resources and technical expertise. That is why the initial need for skilled labor will be extremely high. It would take some time to find, train and manage the relevant staff and it is likely for some significant challenges to be encountered during the training of personnel that shall oversee the initial transformation. To address that problem, it is important to start training physicists and engineers with doctoral degrees within government agencies and to launch partnerships with the country's leading universities. Furthermore, there is reason to believe that the technical staff,

²⁴ Burak Alp, Erol Demir, Ertuğrul Serkan Yalınpala, Alper Genar, Hasan Temel, *Harpte Yeni Kavramlar, Operatif Sanat, Teknoloji ve Harp Hakkında Yansımalar*, (Milli Savunma Üniversitesi Yayınları, Kara Harp Enstitüsü: 2021).

which will process and analyze data from quantum computers, shall require various skills and training. In this regard, it would make sense to train a small yet highly qualified labor force and adopt the same approach within the context of intelligence staff.

Furthermore, it is necessary to look for ways to keep highly qualified and specialized staff members. A highly qualified workforce may look for new jobs with material or emotional considerations and change employers as soon as their expectations are met – as was the case with pilots in the recent past. Such developments, in turn, cause public institutions to lose time and energy. To discourage such career changes, it is necessary to take precautions and aim to find solutions that strike a balance between the interests of individuals and the organization.

In terms of training and doctrine, military schools and other educational institutions must make room for this issue within their curricula to raise future generations that are highly aware of quantum technology and equipped with the right knowledge and skills.

Perhaps the main challenge that the quantum revolution entails is the extraordinary amount of data involved. It is therefore necessary to consider this technical aspect in the acquisition of any system or tool. C5ISR system designs as well as the development of imaging, processing, and communication infrastructure must consider that issue to develop comprehensive and detailed solutions in advance.

Another major issue relates to standardization. Ultimately, in imagining an ecosystem where all systems work harmoniously over a certain network, it is crucial for them to have interoperable algorithms. Various elements, including interfaces, system protocols, and security verification, must be viewed with an eye on the entire system. It is also necessary to focus on new formats that can adapt to future changes. Intelligence units, too, must adopt this inclusive approach in terms of organization and equipment, and consider related units and their surroundings as they take each step.

Following the development of core competencies, the quantum network and all relevant systems must be able to use each other's infrastructure and enable data transfers.

To conclude, I maintain that the Turkish Armed Forces needs to raise awareness about quantum technology as a first step and, subsequently, train its

staff members to monitor developments in that field as well as put in place the technical infrastructure and personnel to facilitate the quantum transformation alongside the overhaul of training and indoctrination methods. In this regard, it must facilitate that transition by initially focusing on crucial capabilities. Accordingly, all research institutes operating under the purview of the Turkish Armed Forces need to prioritize the training of more people with higher qualifications in the relevant fields. It is also necessary to take greater advantage of research opportunities at universities and other civilian institutions as well as enable faculty members to travel to countries like the United States and China to observe the most recent developments on the ground. Although this field will have applications in various civilian sectors, there is reason to believe that the greatest transformation shall take place in the sense of the military and security. As such, there should be more individuals who are interested in this field and have the necessary capacity to engage in relevant discussions within the Turkish Armed Forces. In other words, the relevant field is too broad for military engineers to cover alone and too critically important to be dealt with instant solutions and measures.

The bottom line is that future armies will be quantum armies and their commanders will be products of quantum information generation. Since serving one's country resembles a relay race, it is important to note that reason and science shall be our main guides in trying to oversee this change and transformation as well as possible. In this regard, the most important issue will be to train decisionmakers who work well with numbers but also have leadership traits like gut feelings, intuition, and perception – which is why there is a need to invest in them.

Quantum Technologies

Quantum technology takes advantage of the fundamental laws of nature to reach the limits of detection, imaging, communication, and calculation. As such, it promises to enable mankind to gain access to certain skills that continue to seem impossible to master. Considering other emerging types of technology, including nanotechnology, biotechnology, space technology, artificial intelligence, and robotics, that point becomes clearer. At the same time, quantum technology's military and civilian applications (such as encryption, information security, communication, intelligence, radars, and stealth) continue to develop rapidly.

There is reason to believe that quantum technology may be used in quantum sensors, communication and computer units, fixed platforms, and autonomous aerial, naval, and land vehicles as well as within the spheres of influence of satellites for improved situational awareness. All those elements would make it possible to observe the theater of war and the enemy in a highly realistic manner. Furthermore, future armies shall be quantum armies and their commanders will be products of the quantum information generation. Accordingly, this study discusses in detail the historical development of quantum technology and its military and civilian applications as well as potential future developments.

