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Quantum Technology and Submarine Near-Invulnerability

GLOBAL SECURITY

POLICY BRIEF

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Introduction

This paper looks at how quantum technology applications might affect nuclear weapon capable submarines (SSBN) near-invulnerability. Could sophisticated means of surveillance detect and track submarines in an unprecedented manner and diminish their status as nearly invisible and thus invulnerable in the open ocean?

For most of us, quantum technology is a spooky matter. “Schroedinger’s” cat, dead and alive at the same time, is merely a native of science fiction with no resemblance to the kitten purring on our couch. Impossible to hack, quantum communication or quantum computers that could solve problems traditional devices cannot, are only few of the many applications quantum technology promises. This fantasy-like futurism increasingly makes up for the fog of the future. In fact, the quantum race is already on,[1] but we can tell neither its consequences nor who will win it.

Although quantum technology has not made it into broad public security debates,[2] it is vital to now have a conversation on its possible impact on security and defence, especially on nuclear weapons. Such debate is imperative to designing sound nuclear deterrence doctrines and force postures, predicting possible risks and shaping risk reduction and arms control measures.

> **“Although quantum technology has not made it into broad public security debates, it is vital to now have a conversation on its possible impact on security and defence, especially on nuclear weapons.”**

The race is on

The first quantum revolution resulted from building applications that followed the rules of quantum mechanics. It brought inventions such as nuclear energy, transistors, computer chips, digital cameras, lasers or magnetic resonance, transforming entire societies, not to mention the conduct of war.

We are currently facing a second quantum revolution based on the ability to precisely control the rules governing quantum mechanics. Manipulating single quantum objects and using quantum phenomena like entanglement or superposition, quantum mechanics is finding its way into communication, computing, sensing and precision (positioning, navigating, timing).

> **“The NATO Science & Technology Organization called security and military applications of quantum technologies one of the “major strategic disruptors over the next 20-years.”**

In addition to applications in the commercial sector,[3] Quantum 2.0 also promises to become a “game-changing differentiator”[4] in defence and security.[5] For instance, the NATO Science & Technology Organization called security and military applications of quantum technologies one of the “major strategic disruptors over the next 20-years.”[6] Gary Aitkenhead, the Chief Executive of the UK’s Defence Science and Technology Laboratory, argued that quantum technology will be “a game-changer for defence and society”.[7] Finally, according to Robert Ashley, Director of the US Defense Intelligence Agency, quantum technology will “figure prominently in future warfare.”[8]

Prospective security and military advancements will likely include improved underwater detection of non-spherical submerged objects, understanding building structures from the outside, detection of underground tunnels and bunkers or even fissile materials[9] or improving navigation without GPS, to name but few. At the same time, experts suspect that quantum communication could disrupt the process of authenticating codes used to control nuclear weapons,[10] quantum computing could “render nuclear secrets un-securable,”[11] and quantum radars could discern through stealth mode.[12]

Technological readiness differs from application to application – not to mention from estimation to estimation. The biggest obstacles to the development of quantum-based applications are aligning technology with end-user needs, reducing the size, weight and power consumption of enabling technologies, reducing and surpressing hardware errors, correcting background noise, developing the quantum repeaters necessary for long-distance communication and increasing the number, quality and circuit depth of qubits in quantum computers.

Yet because quantum R&D is the new gold mine, it is only a matter of time until we overcome some of these obstacles. China has already funded multi-billion National Quantum Laboratories[13] to develop quantum-based technology applications for “immediate use to the Chinese armed forces”, possibly including targeting stealthy submarines.[14] Washington invests $1.2 billion[15] to “accelerate quantum research and development for the economic and national security of the United States.”[16] The UK invested £1 billion to “secure the UK’s status as a world leader in quantum science and technologies."[17] The EU funds the €1 billion Quantum Technologies Flagship to "place Europe at the forefront of the second quantum revolution, bringing transformative advances to science, industry and society."[18] Other precursor states include Australia, Austria, Canada, France, Germany, Israel, Japan, the Netherlands, Russia, Singapore, South Korea and Switzerland.[19] And the quantum gold rush goes well beyond governmental funding.[20]

"Recent political debates on submarine replacement, procurement and programs – especially in the UK – have reignited old concerns on the possibility of technology making oceans "transparent".

The concern of transparent oceans

Recent political debates on submarine replacement, procurement and programs – especially in the UK – have reignited old concerns on the possibility of technology making oceans "transparent".[21] Indeed, scientific advances in understanding ocean environments and the emergence of new technologies related to sensing, communication, computation, data processing etc. make the expectation of a higher degree of transparency compelling again. But whether progress in relevant areas will leave undersea deterrents relatively unchallenged,[22] lead to "selective ocean transparency"[23] or likely make them fully transparent,[24] is a highly contested debate.

Understanding whether and how advancements will impact nuclear submarines is important for two reasons. First, submarines serve as the epitome of strategic stability.[25] They are meant to be a relatively undetectable, near-invulnerable capability with little potential for escalation. Although submarine survivability was never universal,[26] because of how hard it is to detect, track and target them, enemies are considered less likely to strike a nuclear attack first knowing that they would suffer retaliation from a hidden submarine.

Second, the United States, Russia, the UK, China and India currently spend high amounts of money modernizing old or building new nuclear weapon capable submarines to serve them for decades ahead.[27] They need to ensure that developments in new technologies will not endanger their investments and the status quo of SSBN near-invulnerability.

It is worth examining some of the terms and concepts at the heart of this debate; notably, the term "transparent oceans". It indicates that oceans are either transparent or not. In reality, they

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are a mix of opaque and translucent depending on location and resources available.

Transparency and opacity are neither positive nor negative in themselves. Their value shifts depending on the perspective and objectives pursued. For those operating the SSBN, opacity is beneficial. For enemy force location and targeting, transparency is of advantage.

A higher degree of transparency might be destabilising if it would undermine the foundations of contemporary nuclear force postures. That could happen if new technologies make submarines more detectable, locatable, and targetable. This would leave nations vulnerable to the first strike or give the impression that this is the case. In response, SSBN possessors would improve hiding capacities, decoys and countermeasures. That is because SSBN-operating nations constantly develop measures to counter novel technologies.[28] But they may also, however, perceive a loss of this particular nuclear capability and try to counter it.

Whilst opacity is a significant advantage of the SSBN for the nations that operate these vessels, it is not necessary for second-strike confidence. Losing it, however, could likely prompt higher alert states and a more “trigger”-centric doctrine. Minutemen ICBMs are a case in point. Their locations are well known to adversaries, so the missiles remain on high-alert. In a real or perceived “worst-case” scenario, states like the UK could consider a “launch on warning” posture. States like the US may feel prompted to “restore opacity”[29] through the introduction of a completely survivable force or to decentralise launch authority.

At the same time, having a capability and using it are two different things. Pursuing SSBNs outside of active conflict was more common in the Cold War than it is today. Today, however, SSBN’s are more likely to realise they are being pursued and perceive this as a threat. The signal one sends with a search activity is therefore likely to have larger consequences. Especially in a crisis, tracing could potentially undermine deterrence and risk unacceptable escalation.

Where quantum technology and submarines meet

Anti-submarine warfare is all about search and location. So far, it remains inefficient to search entire oceans for submarines. Paramount is the sheer scale of the problem. The world's oceans are "wide, deep, noisy, irregular and cluttered".[30] With relatively long and accurate missile ranges, SSBNs have the freedom to deploy in vast areas of the sea. Shielded in stealth and cramped with silencing technologies, finding them often turns impossible.[31]

To what degree could quantum technology applications render oceans transparent, allowing for ocean-wide surveillance? How will quantum technology applications affect the credibility of submarine-based deterrence? Will they increase submarine vulnerability to detection and destruction and limit their range and effectiveness? How could quantum technology surpass the capabilities of existing capabilities?

Several quantum technology applications could aid detection of submarines. These include magnetometers, gravity gradiometers and quantum clocks. Simultanously, quantum navigation could aid the submarine to hide better. Each of these will be explored below.

> **"To what degree could quantum technology applications render oceans transparent, allowing for ocean-wide surveillance?"**

Magnetometers

Magnetometers detect anomalies in magnetic fields, such as those caused by a massive piece of metal. Militaries have been using conventional magnetometers to detect magnetic signatures of submarines for decades. Despite continuous efforts towards miniaturisation and cost-effectiveness,[32] however, these remain heavy, expensive and effective only at a relatively short range of less than 10 kilometres. As such, militaries usually pair them with other sensors, like sonars, which "offer longer detection ranges".[33] Magnetic anomaly detection also requires environmental mapping of the Earth's magnetic field, especially where "variations in seabed magnetism and the presence of sunken ships generate many false alarms."[34]

A quantum magnetometer promises an increase in sensitivity over traditional devices by several orders of magnitude.[35] Sensitivity defines the detection range. The higher the sensitivity of the quantum magnetometer, the further it can reach into the ocean or the larger its search area can be.[36] Among the many quantum magnetometers,[37] the so called superconducting quantum interference device (SQUID) is most advanced and matured, and promises groundbreaking ultra-sensitivity.

In 2017, Chinese scientists revealed a significant upgrade to their SQUID.[38] The achievement points to an airborne device that can detect submarines from several kilometres away rather than just a few hundred metres. The credibility of the Chinese revelation needs to be treated with caution, especially as the specific measurement conditions supporting this claim are unknown. Yet scientific estimations point out that SQUID-based magnetometers could detect submarines at an estimated range of six kilometres or further.[39]

SQUID-based magnetometers still suffer from major disadvantages: they require extreme cooling and can be challenging to set up.[40] Together with their detection range, this currently makes it unlikely that SQUIDs will be put on satellites anytime soon. While cryogenic cooling is already used in space for astronomy missions, it remains overly expensive. Moreover, space radiation seriously affects superconductive technology-generated signals.[41] Another problem is the lack of market proof processing solutions to image and identify findings. Furthermore, submarines can apply magnetic shielding. Similarly to preventing acoustic detection, stealth technology can minimise their magnetic signature.

"Quantum magnetometers will unlikely be a game-changer for now."

Deploying magnetometers on planes, ships or unmanned aerial, surface or underwater vehicles (UAV, UUS, UUV, respectively) could provide more of a step-development in anti-submarine warfare. But these platforms also pose some constraints. UAVs require lightweight, small volume and very low power consumption devices.[42] UUVs' limiting factor is its battery life, determined by the power demands of the propulsion and onboard systems.[43] As one sensor produces too much noise, it requires spatial correlation of a signal from more detectors. An array of detectors is necessary. Yet networked UAVs or UUV's covering a specific area to find a submarine could prove too costly, especially if they turn easy to defeat.

As such, quantum magnetometers will unlikely be a game-changer for now. Even if they improve the location range to, say, 100 kilometres, this remains a location which requires prior knowledge of the submarine's rough position.

Gravity gradiometers

Gravity gradiometers can detect anything with a mass that distorts gravitational fields specific to any location on Earth. Taking several minutes to filter out local vibrations, existing tools make surveys extremely slow and expensive.

However, future quantum gravity gradiometers have the potential to "cut down the impact of vibration, enabling quicker measurements – potentially in no more than a second."[44] This would allow stability under dynamic conditions and enable scanning the ground from a moving vehicle, a very limited capability by existing technology standards.[45]

Quantum gravity gradiometers will be very sensitive. That creates two problems. First, although putting them in space would solve the issue of their subsequent sensitivity to ground noise, space-based quantum gravity sensing or mapping is unlikely to detect submarines. Due to a combination of instrument sensitivity and satellite altitude, satellite gravity sensing will have a limited spatial resolution on the ground. Even if the currently estimated achievable resolution of around 100 km could be reduced up to 10 km, it would still be a few orders of magnitude the size of a submarine.[46] Whether further improvements will be possible remains to be seen after the first quantum gravity gradiometers are put into space. Second, even if the spatial resolution would improve, gravity gradiometers would see a lot from space as a lot is happening in and above waters – think, for instance, of commercial underwater infrastructure, surface ships, planes etc. Even if a gravity gradiometer would be able to detect and distinguish a submarine, further intelligence will need to determine whose and what type of submarine it sees. Yet classification is tough. Like with birdwatching, one needs to know very well what to look for. Next to SSBNs waters are crowded with commercial, research and conventional military submarines. In 2019, militaries of 40 states operated 491 conventional and nuclear subs.[47] That number excludes those owned privately or by research institutions. Distinguishing a strategic nuclear submarine would thus most likely make only sense through continuous tracking, so tracing nuclear submarines down from their known ports/bastions.

While submarines can shield themselves from magnetic or acoustic detection, there are no methods to shield from gravity gradiometers. Simply because such methods have not been necessary so far. Should this change, however, in the first instance decision-makers will likely do all possible to hide their submarines better. One could design ways to decrease the detectable gravity signature by improving mass distribution on a submarines' hull. That would need to happen at the already

> **“While potentially enhancing submarine detection, quantum gravity gradiometers will not make oceans fully transparent or seriously endanger submarine near-invulnerability.”**

overly complex design stage of a submarine. Correcting mass distribution in hindsight could turn out very tricky. Moving masses in a significant way on a vessel is not easy in itself and might upset other optimisation efforts. States building new SSBNs today would need to consider this in advance.

Like magnetometers, quantum gravity gradiometers will most likely first be mounted on moving platforms like planes, ships or drones. While potentially enhancing submarine detection, they will not make oceans fully transparent or seriously endanger submarine near-invulnerability.

Quantum clocks

Next to the most precise measurement of time, scientists propose to use quantum clocks to detect tiny variations in the gravitational potential.[48] Paired with gravity gradiometers, quantum clocks could remotely detect and precisely locate small gravitational anomalies or objects, deriving shape and mass distribution. Detectors could be located on buoys across a wide area. But for this to happen, the quantum clock’s mass and price need to be significantly reduced, and prototype tests run to validate practicality. Putting them on satellites also requires miniaturisation and improved stability under dynamic conditions.[49] Thus using them to detect submarines currently seems like a far-fetched option.

Quantum navigation

Today around 50 research groups worldwide work on improving the sensitivity, stability, accuracy, and compactness of so-called quantum inertial sensors.[50] These allow to continuously estimate an objects’ position, direction, and speed of movement without a requirement for external references.

Submarines use built-in inertial navigation systems to determine their position. But these systems “drift over time due to integration error.”[51] To know with high-precision where a submarine is during a long-distance and long-period sailing, it requires recalibrations.[52] That can be done by various methods, including but not limited to cross-checking with global navigation satellite systems (GNSS) like the European Galileo, American GPS or Russian GLONASS. Yet GNSS are prone to jamming, imitation and denial by an adversary[53] or natural phenomena such as solar storms. Application of GNSS also suffers accuracy and signal continuity issues.

“While the technological importance of quantum technology applications, in general, is very high, its potential for disrupting submarine near-invulnerability in the near future remains relatively low.”

Quantum Positioning Systems promise increased accuracy, confidentiality protection, anti-interference ability and smaller energy consumptions compared with traditional devices.[54] For quantum detection in the underwater environment, scientists expect a 1000-fold improvement in performance to existing inertial navigation sensors.[55] Through “rapid re-acquisition of lost signals and the ability to keep time to an accuracy of a microsecond or less for hours or days”[56], they could provide for additional navigational redundancy. Submarines also offer a stable, quiet and controlled environment with time and space for maintenance of heavy and bulky devices. Before miniaturisation hits in, we can expect submarines to be one of the first adopters of quantum inertial navigation.

Precise quantum inertial navigation systems paired with a map matching component that does not require exchanging information with the outside world could thus elevate a submarine’s navigation to unprecedented accuracy and allow it to perform longer without the need for recalibration.[57] For submarines operating in the Arctic, quantum navigation would also mean detecting proximity to the ice shelf without using traditional navigation devices that could disclose a submarines location.[58]

Looking Ahead

While the technological importance of quantum technology applications, in general, is very high, its potential for disrupting submarine near-invulnerability in the near future remains relatively low. Despite improvements in sensitivity, quantum sensors will not make oceans fully transparent and endanger the status-quo of SSBN near-invulnerability, at least not in short to the middle timeframe.

Quantum technology applications might, at one point, aid both the pursuer and the pursued in the submarine cat and mouse game. Chokepoints and approaches to bases could become more dangerous than they are today. Submarines will have to operate more cleverly. But one can be sure of corresponding efforts to improve submarine counter detection capabilities like signature reduction, anti-detection devices and countermeasures. This is especially true because submarines could use the very systems which are being developed to detect them (quantum gravimeters, magnetometers and inertial navigation systems for underwater terrain exploration) to hide better. There is a real chance that this could provide the submarines with a strategic advantage of increased invulnerability, all to the detriment of the hunter.

Nevertheless, developing quantum technology applications warrants a discussion of consequences of their possible use, especially in a crisis. What kind of signalling would one send by chasing a sub, when the chased sub is likely to realise it is being pursued? How would the chased party likely react?

Many of the quantum technology applications are currently in the research and development phase, and of a low readiness level.[59] There are no reliable prototype demonstrations and field testing.[60] Capability development will need to prove financially sound and technically feasible to deploy and operationalise.

It is also worth putting the quantum hype in the context of other “transparency game changers” touted over the years, which have turned out unsuccesful. In the 70s and 80s, for instance, the Soviets, Americans and Brits all invested in non-acoustic submarine detection technologies. Yet magnetics, thermal imagery or wake detection proved too difficult and costly. Even if successful, they would only provide another means for location.

> **“The ramifications of quantum computing and communication are far more likely to change the strategic security landscape in ways as yet undetermined...”**

Quantum technology precursors will have a time-limited advantage over less savvy technologically and underfunded competitors. Yet because quantum technology applications will predictably also benefit economies and societies, their proliferation will be only a matter of time. Export controls on sensitive applications will, at best, slow down the spread of quantum technologies, but is unlikely to fully prevent it.

At the same time, quantum technology applications seem far more likely to shock the status quo through their effect on the ability to keep secrets in the global economic, defence and national security sectors. The ramifications of quantum computing and communication are far more likely to change the strategic security landscape in ways as yet undetermined and which could affect nuclear weapons’ deployment, posture and deterrence and hence strategic stability far sooner and more significantly.

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