TECHWATCH

NOVEMBER 2023

Redefining underwater military operations

A new horizon for defence technologies

The increasing importance of the underwater domain
Next-generation technologies are a game-changer for underwater military operations

Foreseeing the future
Behind the scenes of horizon scanning and how it provides strategic foresight

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Foreword

Hello and welcome to the fourteenth edition of TechWatch.

Firstly, a huge thank you to everyone who took part in our recent TechWatch survey. It is very encouraging to hear such positive feedback and we're looking forward to putting some of your suggestions into action – more to come on that in our next edition.

Inside this issue, we take a deep dive into the depths of our oceans as we explore the underwater domain, a dangerous and unforgiving territory which brings challenges that place it within a league of its own. We discuss the increasing importance of the domain to both critical infrastructure and as a battlespace, and how its extreme environment is driving technological advancements within the offshore industry sectors that are being adapted and adopted for military use. We take a closer look at these evolving technologies including artificial intelligence (AI) and quantum and how underwater military operations are being transformed by the creation of intelligent systems, such as autonomous underwater vehicles and advanced sonar and sensor systems.

Our second deep dive goes behind the scenes of 'horizon scanning' - a process of identifying and monitoring emerging trends, challenges and opportunities that could impact an organisation's future. We take a look at the complexities of anticipating future developments and the techniques we can use to navigate them more effectively. As part of the wider process of strategic foresight, we look at the different approaches organisations can use to derive useful insights which will enable them to adjust future plans to better achieve their strategic goals.

Our very own team of expert horizon-scanners have also created a collection of news stories which highlight some of the disruptive and emerging technologies with the potential to change our world. From ceramic data storage and laser weapon technology to 'smart rust', these cutting-edge innovations give a flavour of the art of the possible.

Thank you for your interest in TechWatch and we hope that you enjoy this edition. We are always interested to hear from our readers, so if you would like to get in touch, please contact us at TechWatch@qinetiq.com.

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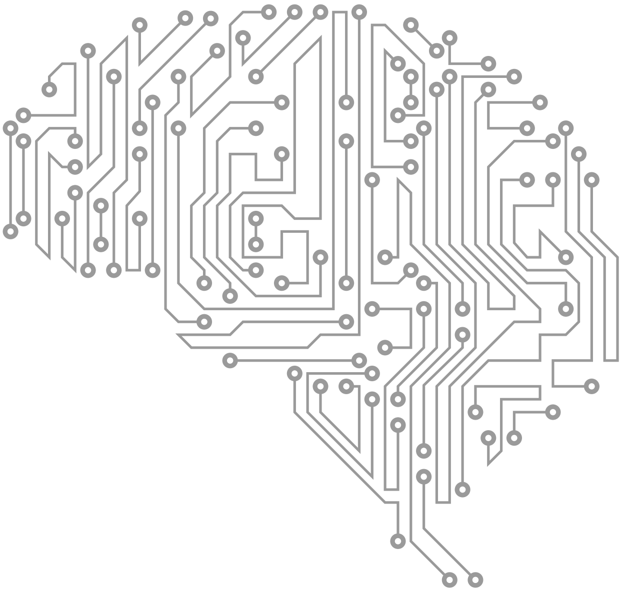

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News

Image Credit: US Marine Corps

Chinese Scientists Claim a Major Breakthrough in Laser Weapon Technology

High-energy Laser Directed Energy Weapons (LDEW) technologies are currently receiving enormous interest and investment worldwide, and the Chinese in particular are rapidly accelerating their LDEW systems development for both maritime and land applications.

A recent article in the South China Morning Post (SCMP) claims that Chinese military scientists have achieved a 'huge breakthrough' in laser weapon technology. The article reports that scientists at the National University of Defense Technology, in Changsha, Hunan province, have developed a new cooling system that allows high-energy lasers to operate continually without any build-up of waste heat.

A typical LDEW engagement of a target takes several seconds to accomplish and the conversion of electrical power into laser light (photons) is quite inefficient with a wall-plug to photon efficiency of 20-30%. The resultant build-up of excessive heat can seriously degrade the performance of the LDEW system but the integration of a cooling system, which the Chinese claim to have achieved, would enable extended engagement times and increased range and effect.

Details of the cooling technology employed in the article are not provided, so whether a real breakthrough has been achieved is moot, but the need is well understood.

Source: South China Morning Post
Estimated time to maturity: Not known

Ceramic Data Storage: Will This Eventually Address The Data Storage Demand?

As the demand for more data storage continues to increase, so has the interest in more innovative and exotic data storage solutions. Examples include optical data storage and DNA data storage, the latter of which could potentially store an unbelievable 2.2 petabytes per gram (A petabyte (PB) equates to 1,000 Terabytes, or 10^{15} bytes of digital information!)

Another contender is 'CeraMemory' which utilises inorganic nanolayers of ceramic material of 50 - 100 atoms thick to store information. Created by German storage start-up 'Cerabyte', the company has recently published an abstract for a forthcoming storage developer conference outlining how data is recorded using a laser beam and read using high resolution microscopic imaging. The company has drawn up a roadmap mentioning server racks armed with CeraMemory cartridges (in the 2025-30 timescale) that will store between 10 PB and 100 PB of data. Rather bullishly, the roadmap also sketches out its next generation 'CeraTape' (2030-35), with a five microns thick substrate and 10 nanometers thick ceramic coating that could achieve 1 exabyte (1,000 PB) capacity per tape.

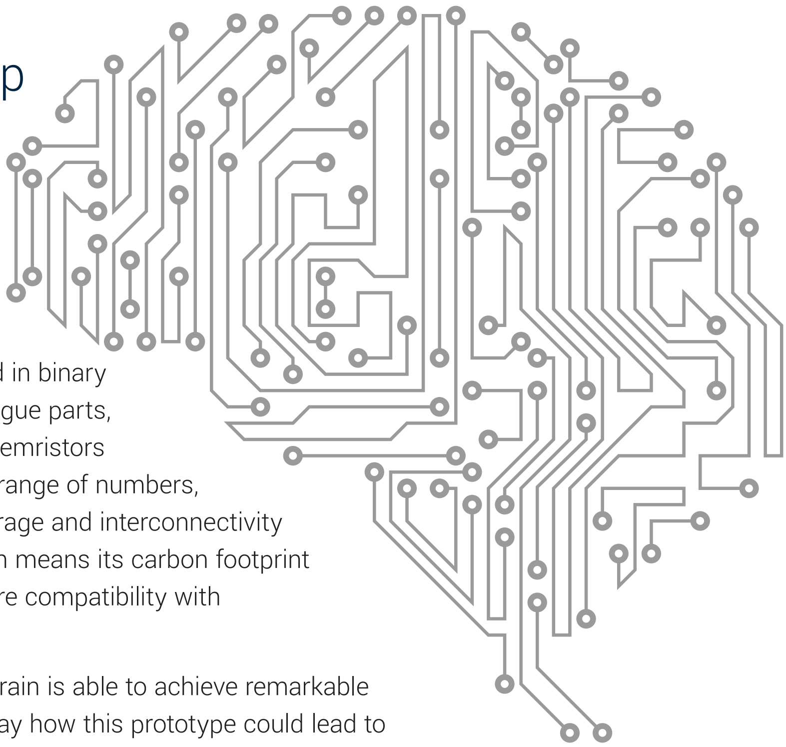
Cerabyte claims their technology has excellent media durability and longevity lasting 5,000+ years over a wide range of temperatures and adverse environments, yet it can only read and write data at modest gigabit per second speeds.

Source: tom'sHARDWARE

Estimated time to maturity:
CeraMemory: 2 to 5 years

Estimated time to maturity:
CeraTape: 5 to 10 years

Brain-Inspired Green Computer Chip



It is often said that the human brain is the best computer ever made; both fast and efficient. In this age of artificial intelligence (AI) the demand for fast and efficient computing has never been higher, so it is no surprise that researchers at IBM have turned to nature and created a brain-inspired prototype, *green* chip.

Unlike standard digital semiconductors, where data is stored in binary (0s and 1s), this chip is a hybrid using both digital and analogue parts, based on synaptic connections found in the brain. It uses memristors (memory resistors), analogue components that can store a range of numbers, that form brain-like networks when interconnected. This storage and interconnectivity is key in increasing the chip's energy efficiency, which in turn means its carbon footprint and heat emission is reduced. The digital components ensure compatibility with existing applications.

IBM scientist Thanos Vasilopoulos explained: "The human brain is able to achieve remarkable performance while consuming little power." He went on to say how this prototype could lead to "large and more complex workloads [to] be executed in low power or battery-constrained environments", for example, cars, mobile phones and cameras and it could also be used in military equipment.

Source: semanticscholar.org | bbc.co.uk
Estimated time to maturity: 5 to 10 years

Another Means of Machine Vision: Heat-Assisted Detection and Ranging

Machine vision and perception requires advanced sensors to collect information about the surrounding scene or environment to enable situational awareness. To date, lidar, radar and sonar are all means of providing such information, but now researchers from the United States have introduced a new technique known as heat-assisted detection and ranging (HADAR).

Infrared sensors for thermal vision and ranging suffer from the problem that objects and their environment constantly emit and scatter thermal radiation, leading to textureless images and resulting in the so-called 'ghosting effect'.

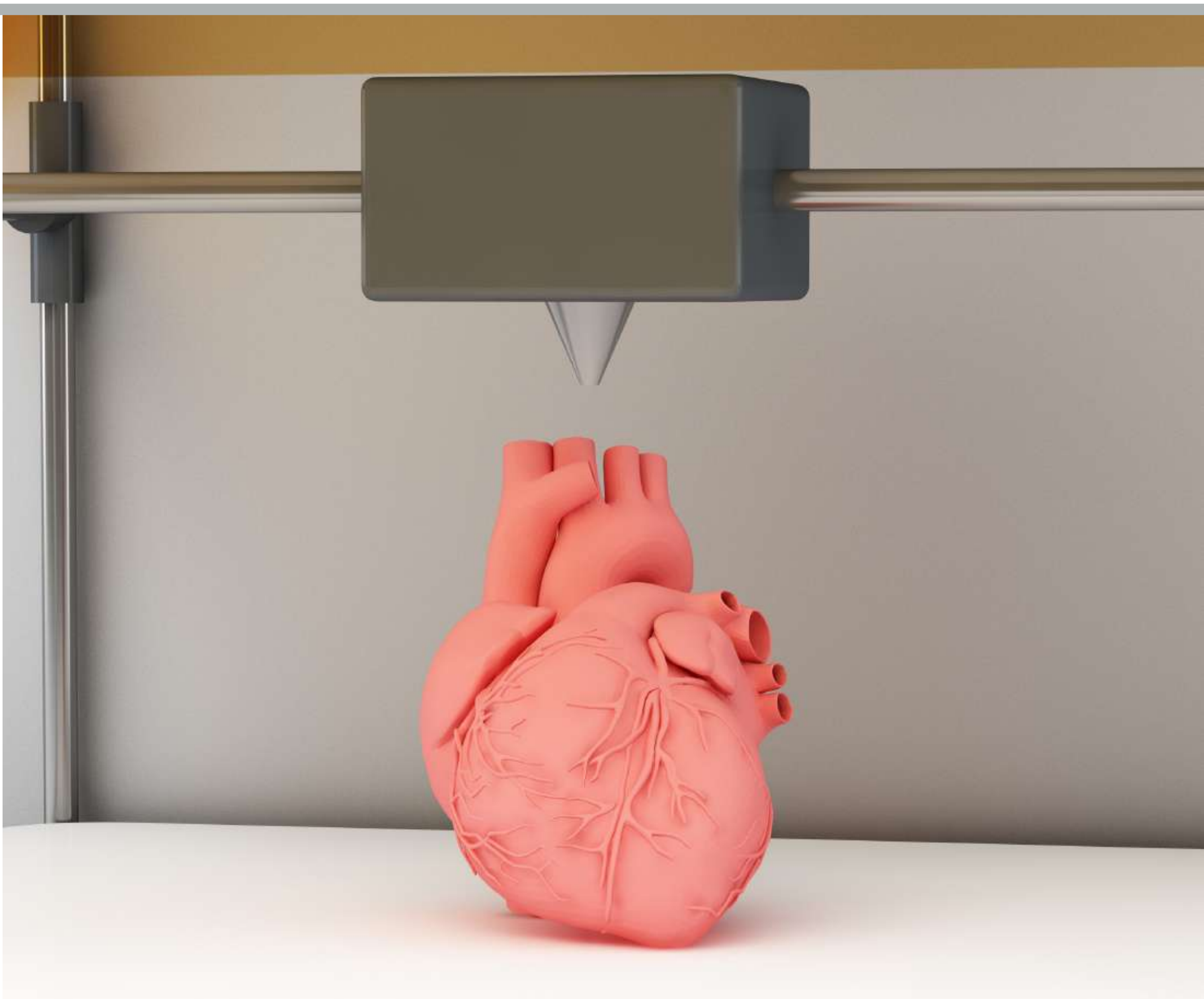
However, researchers from Purdue and Michigan State Universities reported to have resolved this problem through their innovative AI-assisted HADAR technique. They claim that "HADAR not only sees texture and depth through the darkness as if it were day, but also perceives decluttered physical attributes beyond Red-Green-Blue (RGB) or thermal vision, paving the way to fully passive and physics-aware machine perception".

Indeed, they go as far as to say that HADAR ranging at night beats thermal ranging and shows an accuracy comparable with RGB stereovision in daylight.

This technology could provide autonomous vehicles with a clear view of their surroundings and also potentially benefit other unmanned machines to better perceive their environment in night-time conditions. The researchers hope their work will lead to a technology that can accelerate the Fourth Industrial Revolution (Industry 4.0) with HADAR-based autonomous navigation and human-robot social interactions.

Source: Human Analysis Lab
Michigan State University
Estimated time to maturity: 5 to 10 years

Image Credit: Bao F. et al.: Heat-assisted detection and ranging, Nature, 619, pages 743–748.



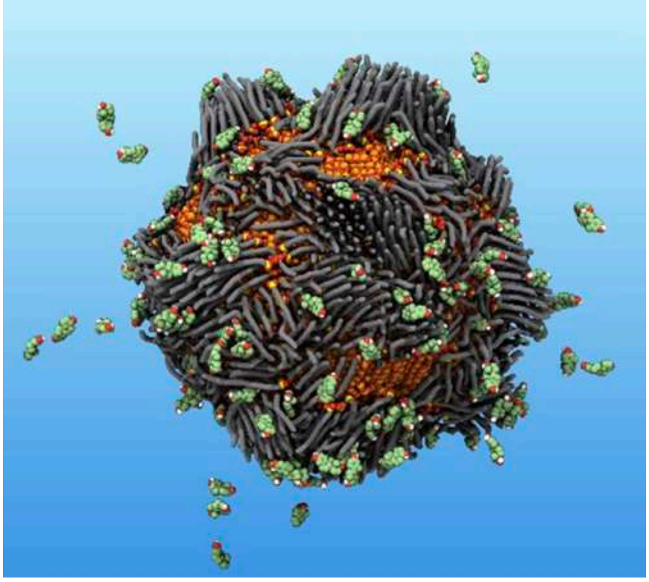
Improved 3D Printing of Human Tissue

Whilst 3D printers can quickly produce complex and high quality parts from plastics and even metals, one of the next areas of development is aiming to print human cells. The ambition is to create engineered tissues with sufficiently high numbers of cells, while maintaining high resolution detail in the print.

One promising approach to achieving this is known as digital light processing, which involves shining light onto a light-sensitive biologically compatible “ink” in the shape of the desired structure. The ink, which contains the cells, then solidifies, with following layers then printed on top, eventually forming the final 3D structure. Once printed, the cells are left to mature, where they form the desired tissue. This layer by layer approach is similar to how many resin-based 3D printers work, but it has previously proven problematic when trying to print a high density of cells, as the cells themselves scatter the light required, reducing the printing resolution. However, researchers from the University of California San Diego have found a way around this issue, reducing the problem tenfold, by adding an extra component named iodixanol, to the ink. This allows them to print at higher cell densities and maintain high resolution, improving the quality of the tissues produced.

Once established, it is hoped that this technology will support areas such as organ transplants, drug testing, disease modelling and more. Could we eventually print replacement organs for soldiers wounded on the battlefield?

Source: science.org
Estimated time to maturity: 5 to 10 years



Smart Rust

Researchers at the University of Erlangen-Nuremberg have created a novel way of cleaning water – just add rust! It may sound odd or even counterintuitive, but adding specially designed iron oxide nanoparticles, termed 'smart rust', to dirty water, could help filter it clean. Moreover smart rust is cheap, recyclable and non-toxic.

Iron is magnetic, but smart rust nanoparticles are designed to be superparamagnetic, meaning that while still being magnetic, they are not attracted to each other, preventing them from clumping together. Additionally, the particles are coated in pollutant-specific compounds which means they are designed to attract specific pollutants.

Once released into contaminated water, the smart rust attracts, encapsulates and embeds itself into the desired pollutant to form a pollutant-rust amalgamation. This mixture can then be filtered out using a simple magnet, leaving the water pollutant-free.

So far, smart rust has been shown to be effective at removing oil, nano and micro plastics, as well as harmful organic compounds including herbicides and, most recently, the hormone oestrogen, all of which have a devastating effect on ecological landscapes through modern day polluting. As the list of removable pollutants grows, smart rust may prove to be a useful tool in providing clean, safe water in remote, undeveloped lands in the future.

Source: phys.org
Estimated time to maturity: 5 to 10 years

Space Age Semiconductors

Space, the ultimate inhospitable environment, has long posed difficulties for any missions looking to explore its deep secrets. Of the many risks associated, cosmic radiation damage features among the top. But this could be a thing of the past for at least one crucial component: the humble semiconductor.

Radiation damage occurs when a material is bombarded by highly charged particles, dislodging the atoms in the material, causing its structure to be compromised. These highly charged particles are typically emitted by cosmic rays as well as earth-based nuclear reactors, making it difficult for any exposed electronic components to function effectively.

Using layers of crystalline molecules, an international group of scientists have created a new semiconductor chip which is impervious to radiation damage. The molecule, gallium oxide, comes in five different crystal forms, all known to be somewhat robust to radiative particles. However, the team found that by using two specific forms of the crystal, beta and gamma, the semiconductor created became almost completely resistant to radiation. As Andrej Kuznetsov, lead scientist, remarked: "What we discovered is really a new sort of material that tolerates unprecedented amounts of radiation damage". So, by recrystallising, the semiconductor, in effect, 'heals' itself of any dislodged atoms.

Exactly why this self-healing occurs is unclear, but it is hoped that the product can be utilised for space missions and terrestrial nuclear applications, including Defence.

Source: arxiv.org
Estimated time to maturity: 5 to 10 years

Image Credit: Text-to-image by Paragraphica. Credit: Bjoern Karmann

This Camera Requires No Light to Create a “Photo”

Generative artificial intelligence (AI) is widely talked about at the moment and it continues to inspire new applications. One of its more unusual applications is a ‘camera’ that uses AI and data from the Internet to visualise a selected place and time.

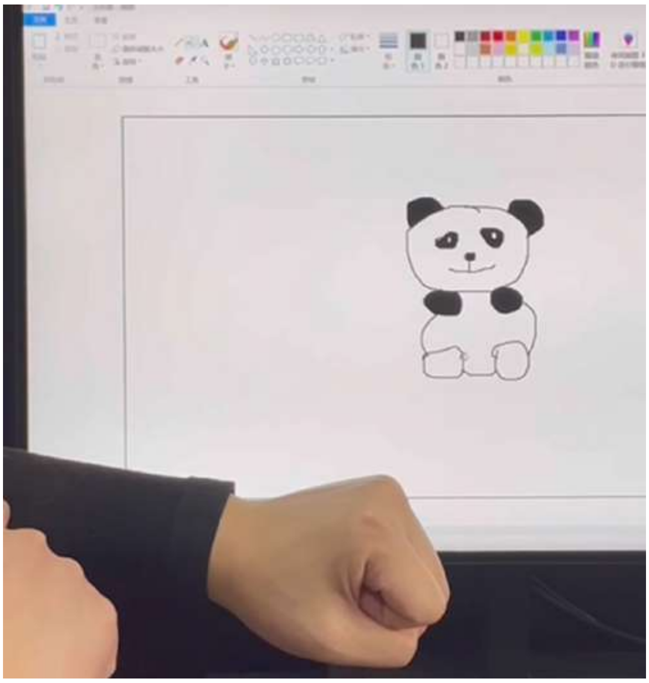
The camera, known as Paragraphica, is the brainchild of Bjorn Karmann, a designer and developer from Amsterdam in the Netherlands. It operates by first collecting data, including the desired location and orientation, to create a descriptive paragraph of text which it then converts, through text-to-image AI into a “photo”.

A quote from Karmann’s website states: “The camera operates by collecting data from its location using open APIs (application programming interface), utilising the address, weather, time of day, and nearby places. After combining all these data points, Paragraphica composes a paragraph that details a representation of the current place and moment”.

The Paragraphica has three main dials. The first dial controls the radius (metres) of the area where the camera searches for places and data. The second dial is comparable to film grain as the value between 0.1 and 1 produces a noise seed for the AI image diffusion process. Finally, the third dial controls the guidance scale - increasing the guidance makes the AI follow the paragraph more closely.

It is difficult to identify specific military applications for this camera, but one possible example could be generating representative Defence training environments.

Source: eeNews | Project Paragraphica
Estimated time to maturity: 0 to 2 years



Turning Your Sleeve into a Touchpad

Academics from Qingdao University in China have created an innovative way of interacting with our digital devices by turning a silk armband into a touch sensitive pad.

They did this by creating a sandwich structure, using a pressure sensitive hydrogel between layers of silk and coating the top piece of silk with graphene sheets, making it electrically conductive. By connecting this to a data collection system and incorporating it into a sleeve, the device is completely self-contained and no sticky residue is left on the wearer from the hydrogel, which has been a problem with previous similar systems.

When the armband is pressed, the touch responsive material interprets what the user draws and transmits this to the computer. The researchers demonstrated the capabilities of the sleeve by drawing a panda on their arm and believe this could inspire the next generation of flexible keyboards and wearable sketchpads.

This technology could open the door for many applications, such as allowing soldiers on the battlefield to control equipment using their clothing, helping reduce the amount of kit they need to carry, and saving weight.

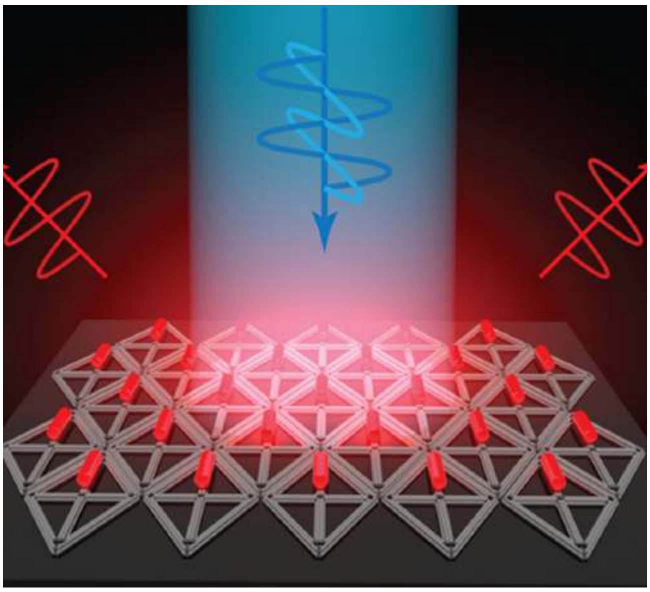
Source: acs.org
Estimated time to maturity: 2 to 5 years

Using DNA to Produce Quantum Next-Gen Displays

Quantum dots are widely used in screens today, offering improvements in areas like colour accuracy, and now researchers from Massachusetts Institute of Technology (MIT) hope to improve on this by using quantum rods instead of dots. While quantum dots are thought of as two-dimensional nano-sized spheres, quantum rods are elongated on one axis, forming a rod-like shape. This extra length brings improved properties, such as being able to control the polarisation of light as well as its colour, which could allow displays using this tech to produce 3D images. To achieve this, the researchers have used DNA to produce a nanoscale scaffold structure they call “DNA origami” to carefully control the alignment of each nano-sized rod, making sure they all face the same direction. Their process also cuts the amount of time needed to align the rods from days to only minutes, greatly reducing the cost.

The team hope that this breakthrough can be used as a stepping stone to produce next-generation displays for televisions, 3D displays, and virtual reality headsets. These displays may have significantly higher resolutions and pixel densities, thanks to nanoscale performance. There is still work to be done though, before we see this tech on the shelves, including controlling the length, shape, and overall structure of these rods.

Source: MIT News | Science.org
Estimated time to maturity: 5 to 10 years



UNDERWATER DOMAIN

DEEP DIVE

The increasing importance of the underwater domain and the technologies that are redefining it

Supporting critical infrastructure and the vital role of defence

Our oceans play a crucial part in sustaining life on earth and are vital for the wellbeing of our planet. They regulate our climate through heat and carbon absorption, host key elements of our critical infrastructure and serve as a gateway for global food supply and trade routes. According to Google data, 98% of all international internet traffic currently flows through almost 1.5 million kilometres of undersea fibre-optic cables, travelling at the speed of light, linking continents and countries and underpinning the modern digital age. Secure transmissions such as banking and e-commerce transactions, telecommunications, social media networks and the connection of global data centres for cloud computing and data storage, all depend on the integrity of these cable systems. Furthermore, thousands of kilometres of undersea pipelines transport oil and gas to different areas of the globe and maritime transport is the backbone of international trade with over 80% of its volume carried by sea.

The unique and harsh underwater environment plays a significant role in driving technological advancements and innovations that contribute to our modern world. The oil and gas sector, for example, is pioneering technologies such as remotely operated and automated underwater vehicles and the creation of novel sensors and advanced materials for deep-sea exploration and inspection programmes. The vast amount of information that can be acquired using these new technologies has also driven innovations in data analytics. This is a vital step forward in tackling data-overload and creating faster and more efficient means of interpreting data to facilitate valuable insight and decision making.

The wider influence of these technological advancements, their commercial availability and cost-effectiveness includes the impact on national security and defence. Militaries across the world are adapting and adopting new approaches to enhance their underwater capabilities.

The role of the underwater domain for militaries is both critical and multifaceted. It is home to strategic nuclear deterrence systems for those countries with nuclear capacity, providing an assured capability to deter adversaries from launching a nuclear attack. It also plays host to clandestine operations from surveillance and intelligence gathering missions and other missions such as mine laying and mine countermeasures, anti-submarine warfare and the protection of maritime assets. History also has potent reminders of the power of submarines as tools to disrupt shipping lanes and against warships, including aircraft carriers, and this potency remains undiminished.

The Indo-Pacific area, the emerging epicentre of the world's economics and geopolitics, has become an area of significant importance to defence operations due to the rising threats from potential adversaries, including China and North Korea. Greater numbers of capable ships, helicopters, aircraft and submarines are operating routinely within the region and these capabilities are only going to gain in potency. Many nations are developing their underwater capabilities, which are becoming increasingly important in terms of their overall defence strategy. NATO has recently established a new centre focused on protecting undersea pipelines and data cables following the attacks on the Nord Stream natural gas pipelines and the protection of critical infrastructure is becoming a growing priority of underwater operations. Additionally, leaders of the UK, US and Australia have created a trilateral security partnership, AUKUS, to bolster their allied deterrence and defence capabilities in the Indo-Pacific which includes increasing the number, availability and capability of submarines within the region.

A brutal and harsh environment: Challenges of the underwater environment

The expanse of our oceans is vast, covering two thirds of the Earth's surface, stretching across 361 million square kilometres and occupying 1.386 billion cubic kilometres. It is dangerous and unforgiving territory, with extreme pressures, low temperatures and limited visibility, which bring challenges that place the underwater domain within a league of its own. Navigation and maintaining situational awareness are exceptionally difficult, with depth, currents and underwater terrain creating significant complexities, requiring highly specialised training and equipment and a deep understanding of the dynamics of the underwater environment.

Variations in temperature and salinity, wind and tide affect the accuracy of operations requiring the use of complex calibration techniques to provide precise measurements. Surface disturbances and turbulence contribute to ever more complex navigation requirements, salt corrosion presents a very serious threat to the structural integrity of underwater vessels and marine life can compromise operational capabilities and stealth.

Furthermore, submarines and underwater vessels are required to travel long distances without the need to replenish fuel and supplies, to allow them to prolong stealthy operations. Range and endurance therefore contribute significantly to mission success, yet the harsh underwater environment makes no allowances.

Physics plays a defiant role below the water's surface and communications are particularly inhibited. Indeed the underwater domain is the last bastion of opaqueness in the battlespace arena. Satellite and radar systems on which land, sea and air domains depend are ineffectual below our seas. Radio waves are absorbed and scattered by water molecules, only serving to compound the isolating effects of this murky domain and in order to establish communication links with these platforms, submarines must move near the water's surface, thereby potentially giving away their position.

Restricted access to satellite and radar presents yet further difficulties for determining position, navigation and timing (PNT) underwater, nor are there an abundance of mapped reference points within our vast seas, making the task of identifying and monitoring positioning exceptionally tough. Accurate PNT is critical throughout underwater missions for precise course keeping, maintaining a position of stealth and the avoidance of collisions with other vessels including ships, other submarines, marine life and other underwater obstacles. It is also essential for receiving mission updates, co-ordinating tactics and requesting support such as in emergency situations. Weaponry, such as missiles and torpedoes, depend on precision targeting and guidance from PNT and loss of this information or marginal errors encountered during a mission could have catastrophic consequences.

The Silent Service: Warfare in the underwater domain

Submarine and anti-submarine warfare

Submarine warfare involves the use of submarines as offensive platforms to attack enemy ships, submarines or land targets. Equipped with torpedoes, missiles or other weaponry to engage and neutralise enemy vessels, tactics include manoeuvres, ambushes and strategic positioning to launch surprise attacks.

Submarines can remain submerged for weeks and even months without surfacing and whilst on patrol they largely remain undetected, giving them a high degree of survivability, global reach and the ability to strategically position themselves to respond to emerging threats. Their stealth, combined with their mobility makes them the ideal platform for the delivery of nuclear weapons. The UK, US, Russia, China, North Korea, India, Pakistan and France either already have or are developing submarines capable of carrying nuclear weapons. While most countries have these programmes as deterrents and to maintain peace, it can cause tensions such as that between the US, its NATO allies and Russia in the Arctic Ocean.

Anti-submarine warfare (ASW), defined by military tactics, strategies and technologies designed to detect, track and counter enemy submarines, can be carried out by surface warships, aircraft, submarines or other platforms. Besides the threat of other submarines, there is a need to remain undetected and invisible to aircraft with passive and active sonars and magnetic anomaly detection[1] (MAD), ships with sonar and towed sonar arrays[2] and more recently, autonomous air vehicles and underwater submersibles.

Mine warfare, a longstanding feature of naval operations is again a major concern. It can be used to influence or deny the use of areas of the sea to an adversary, including against submarines, or to protect naval forces and maritime structure and coastlines.

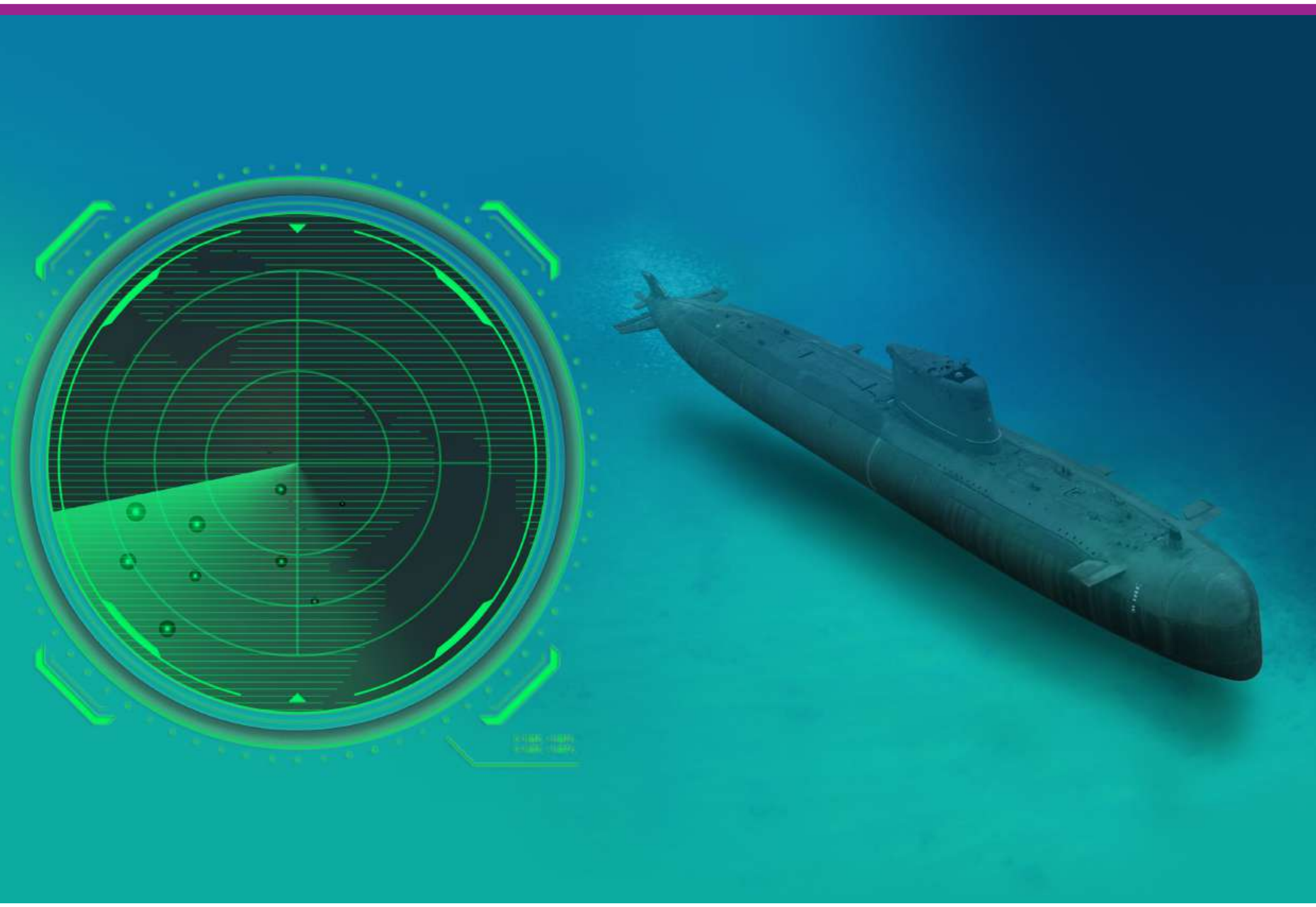
Mines can be detonated through physical contact and through much more subtle means such as magnetic, acoustic or pressure changes to their environment and they can also be operated remotely. The mines themselves are relatively inexpensive and can be integrated with progressively more advanced sensors, giving them selective targeting abilities and making the threat they pose increasingly significant.

Evading detection: A game of hide and seek

Evading detection is paramount to covert military operations in the underwater domain and the tactical and strategic nature of submarine warfare can be likened to a perpetual game of hide and seek.

Sound plays a crucial role in the underwater technologies used for the detection of military vessels. Sound waves can travel very long distances through water making sonar (SOund Navigation And Ranging) technology an ideal means to detect, locate, identify and track objects, vessels and threats in the surrounding area. Active sonar transducers emit an acoustic signal or pulse of sound into the water and any objects in the path of the sound pulse will cause it to bounce off the object and return an "echo" to the sonar transducer. The echo is used to measure the signal strength, and the time between the emission of the sound pulse and its reception is used to determine the range and orientation of the object. Understanding whether the target is moving toward or away from the sonar transducer can be revealed through the Doppler effect[3].

1. MAD detects minute variations in the Earth's magnetic field caused by the ferromagnetic component of submarines.
2. Towed sonar arrays are underwater microphones (hydrophones) or sensors arranged on a cable that is connected to a ship or submarine.
3. Doppler effect refers to an increase (or decrease) in frequency of sound, light or other waves as the source and observer move towards (or away from) each other.



All submarines have a unique 'signature' that can be used for detection and identification by experienced operators. For example, engine noise, on board machinery and the sound of the formation of bubbles produced by propellers (cavitation) all contribute to the signature of a vessel, making it vulnerable to detection by adversaries. Traditionally, militaries employed a combination of tools to detect adversaries. These included magnetic anomaly detectors (MAD) which detect tiny disturbances to the Earth's magnetic field caused by ferromagnetic components of submarines; passive and active sonar sensors that detect sound; and in the case of surfaced submarines, radar and satellite imagery. New technologies that increase the ability for a submarine or underwater vehicle to be detected, threaten covert operations and survivability. This is particularly acute for submarines acting as a nuclear delivery platform, so it is imperative that submarines employ a dynamic range of tactics and technologies to evade this threat.

An interesting phenomena of the oceans is the presence of sound channels. Temperature and salinity varies with depth (pressure), creating layers of water with varying acoustic properties. One such layer known as the 'Sound Fixing and Ranging' channel acts as a waveguide for sound, allowing it to travel vast distances with minimal loss of energy. It acts as a natural acoustic duct and is therefore of particular interest to militaries. It is believed that whales can communicate over 6,000km in this deep sound channel and military scientists in the US, Russia, Iran and the Ukraine have all worked with dolphins to study how they echolocate (create sound vibrations to locate fish or objects and analyse the return echo) in the hopes of designing better submarines and sonar detectors. Dolphins and other mammals have also been trained to listen for approaching submarines, identify the location of buried explosive devices underwater and reveal the identity of suspicious objects. The American military still has a dolphin unit, currently spending about $20m a year on more than 100 animals at the Point Loma submarine base near San Diego. In April 2022, US Naval Institute News reported that Russia's military are using specially trained dolphins to defend a critical naval base close to Crimea. Satellite imagery shows two dolphin pens at the entrance to Sevastopol's harbour in the Black Sea.

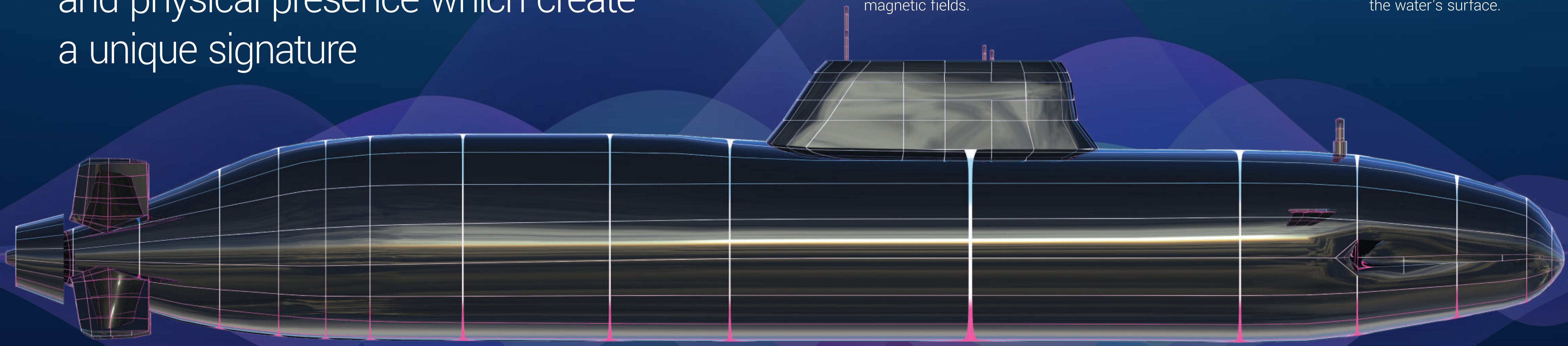
Signatures

Submarines and underwater vehicles risk detection as a result of their emissions and physical presence which create a unique signature

Magnetic signature
Metallic hulls and equipment produce a magnetic signature detectable by magnetic anomaly detectors (MAD) that sense disruptions in the Earth's magnetic fields.

Hydrodynamic signatures
These are created by the wakes produced by movement underwater and can be tracked by sensors that measure water pressure and flow.

Thermal signature
Engines and machinery produce heat which infrared imaging devices and thermal sensors can detect, especially when the submarine is near the water's surface.



Radar cross-section (RCS)
The reflection of radar signals can reveal an underwater vessel's presence.

Chemical signature
Gases and waste discharged into the water leave a chemical trail which can be analysed.

Biological signature
Disturbances to marine life in local underwater ecosystems can be monitored for signs of underwater activity.

Pressure signature*
Water pressure changes caused by a submarine's depth changes can be tracked both visually and through remote sensing technologies.

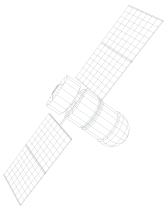
Wake signature
Submarines moving close to the surface can leave a wake on the water's surface which can be detected visually and by sensing technologies.

Visual signature
Periscope or antenna masts can be visually seen when a submarine moves close to the water's surface.

***The Bernoulli hump:** When submarines travel through the water, displacement effects can cause pressure waves that can be visible from the surface in the form of a 'Bernoulli hump'. Other distinctive patterns known as Kelvin wakes can also be formed. The magnitude of these effects is determined by the size, shape, speed and depth of the submerged object. These features can be detected by sensors on satellites and aircraft.

Advantages and threats of open source tools and technologies

Advancements in submarine detection could potentially affect the survivability of submarines as nuclear delivery platforms and therefore understanding the technologies available for submarine detection and monitoring is strategically very important. Traditionally, the systems employed such as magnetic anomaly detection (MAD), were exclusive to militaries but recent advances in commercial tools and technology now enable open source researchers to analyse the information available. Commercial satellite imagery, synthetic aperture radar (SAR), hydro-acoustic sensors and even social media analysis, are all examples which open source researchers can use to gain information. Such information could give away details of the size, location and composition of countries' submarine fleets, enable them to monitor submarine construction and that of their bases, as well as the potential to learn about patrol patterns and behaviours.

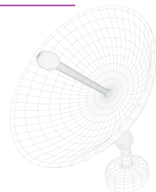


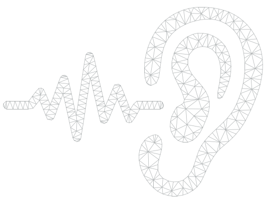
Commercial satellite imagery

Google Earth imagery has been used to gain important information about China's efforts to expand and modernise its fleet of nuclear submarines. For example, images allowed researchers to observe the installation of China's first submarine demagnetisation facility which strips submarine hulls of residual magnetic fields, which would make them less detectable.

Synthetic Aperture Radar (SAR)

SAR is a space or aircraft based radar that uses radar echoes to create high resolution imagery. SAR sensors are routinely used for environmental, scientific and law enforcement applications but they can detect the wakes of large ships and can be used for reconnaissance and surveillance. Although their ability to detect submarine wakes is as yet inconclusive, they could potentially be used for monitoring submarine construction at naval shipyards.





Hydro-acoustic sensors

The noise produced by a submarine's propulsion system is significant in exposing its position and hydro-acoustic sensors use sonar technology to detect submarines that move close to coastal borders and military locations. Data produced by hydro-acoustic monitoring stations is available for research purposes, such as tracking whale migration patterns and developing tsunami warning systems and open source researchers could use similar data to isolate the acoustic signatures of submarines allowing them to track their movements.

Social media

The explosion of social media through platforms such as Facebook, X (formally Twitter), Snapchat and Instagram as well as crowd sourcing sites and fitness trackers (eg Strava) has created significant security concerns for militaries in recent years. A number of seemingly harmless Tweets and Instagram pictures have revealed themselves as major security breaches. In January 2018, a student at the Australian National University discovered that user activity posted on Strava, a fitness app that allows individuals to map their running and biking routes, had unwittingly exposed the locations and perimeters of sensitive military facilities around the world, as well as so-called "patterns of life" of military personnel stationed at these facilities. Among the facilities profiled was HM Naval Base Clyde in Faslane, Scotland, where the United Kingdom's nuclear submarine force is berthed. Pictures posted on Twitter show clear heat signatures around the base's perimeter, indicating either a running route or perimeter patrol.

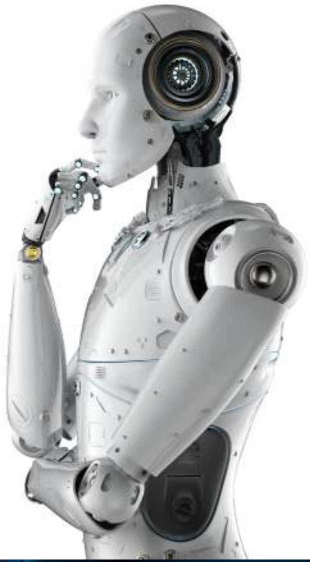
Open Source Intelligence

A large number of individuals on social media are known to 'sub spot' as a hobby, monitoring the movement of military vessels including submarines using Open Source Intelligence (OSINT) and posting their movements online.

One open source author, going by the name of H I Sutton, has created a dedicated website 'Covert Shores' and uses OSINT to track developments in the maritime domain and particularly underwater warfare. Recent posts include details of Russia's underwater activities in respect of the Russo-Ukranian war.

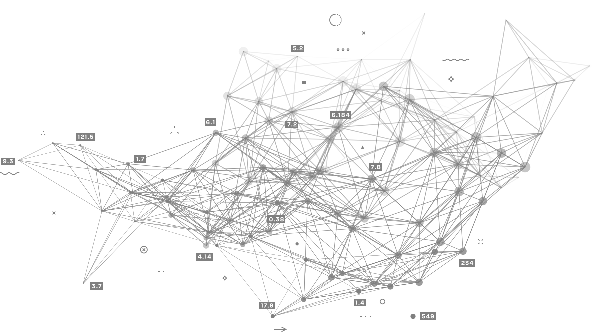
Emerging technologies and next-generation underwater warfare

Artificial intelligence and quantum technology



Artificial intelligence and machine learning are revolutionising underwater military operations, playing a major role across many new advancements. AI powered sonar systems can process vast amounts of acoustic data for more efficient and accurate detection of adversaries. AI driven autonomous vehicles equipped with advanced navigation and sensor systems are set to make dramatic improvements to the safety and effectiveness of underwater search and survey operations, with AI algorithms being used to detect and classify underwater mines quickly and effectively. AI's ability to rapidly process information and adapt to changing conditions will increasingly impact the speed and accuracy of decision making.

AI assurance is equally important to the advancements driven by AI, and involves the development of AI assurance techniques for the ongoing process of testing, verification, validation and risk assessment of AI systems. This ensures that AI systems operate safely, reliably and predictably, mitigate bias and comply with regulatory standards. AI assurance is fundamental to the integrity, transparency and accountability of AI systems and as AI becomes more prevalent and sophisticated, the role of AI assurance becomes ever more crucial.



Quantum technology is a field of major interest to militaries and offers the potential for significantly enhanced underwater capabilities in areas such as communications, data processing, navigation and sensing. Quantum encompasses the realm that exists at the atomic and sub-atomic level which is extremely sensitive to minute changes in the environment. It allows measurements that are far more precise than what is possible through conventional approaches and can introduce critically important improvements to the accuracy of different systems. In addition, certain types of calculations can be carried out exponentially faster using quantum technology and quantum cryptography introduces new ways of securing the transmission of data, potentially offering more secure communications than currently possible.

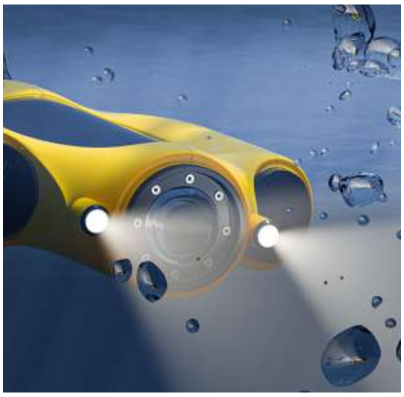
How emerging technologies will shape the underwater domain

Three of the most important factors that inspire new technologies for advancing underwater military capabilities are navigational accuracy and the enhancement of stealth and lethality. Additionally, increasing and improving the availability of underwater defence systems is a major priority. Submarines are extremely expensive, costing billions of pounds to build and tens of millions of pounds per year to operate and the astronomical costs associated with their repair and maintenance are a major incentive to maximise their availability for service.

As oil and gas exploration and production, offshore renewable energy and deep water surveying programmes drive the advancement of technologies in the underwater domain, militaries continue to harness these to create next-generation capabilities. From cutting-edge stealth and sensor technologies, remotely operated and unmanned vehicles, to superior position, navigation and timing (PNT) capabilities, these sectors are shaping the future for underwater defence.

Position, navigation and timing

While submerged beneath the ocean, submarines rely on their inertial navigation system (INS), together with traditional manual navigation techniques, to identify and monitor their location. Comprising of measurement components such as accelerometers, gyroscopes and a clock, they continuously measure and integrate accelerations and changes in rotation over time to track position, velocity and orientation. Due to imperfections in the components however, gyroscopes and accelerometers drift with time, and integration inaccuracies accumulate and ultimately produce a less than accurate PNT reading. The use of quantum accelerators, gyroscopes and clocks could provide much more accurate location data for a longer amount of time. Engineering a fused system that combines both classical and quantum technologies, could provide a superior hybrid INS.



Positioning system for deep ocean navigation

The US Defense Advanced Research Projects Agency (DARPA) has partnered with multiple organisations to develop an undersea system called POSYDON (Positioning System for Deep Ocean Navigation) which uses acoustic technology. The technology will provide continuous, accurate positioning across ocean basins without the underwater vehicle needing to resurface for a GPS fix, which would leave them vulnerable to detection and susceptible to attack. The system will consist of a network of sound emitting devices, which are resistant to spoofing and jamming, placed underwater to cover wide areas of the sea. Using underwater acoustic signals, a surface buoy, beacon or “node,” and GPS signals in a coordinated fashion, POSYDON will be able to quickly relay location coordinates from undersea drones on patrol to command and control systems on board a ship or submarine.

Improving communications

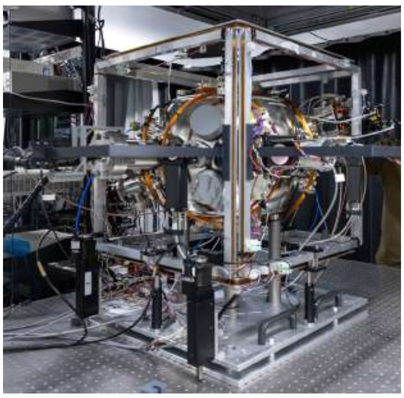
Emerging light technologies are poised to revolutionise underwater military operations. Light can travel faster and further through water than radio waves and is less susceptible to interference making it a more reliable method for underwater communications. Optical communications using lasers or LEDs allow for high speed, secure data transfer, which are ideal for sharing information. Quantum technology also holds great promise for improving underwater communications as, in addition to providing watertight security, it could overcome challenges of the underwater environment to enable long distance communication with minimal interference, providing much clearer and more robust channels.

Laser communications

DARPA are working with partners to develop a blue-spectrum submarine laser communications system which will enable submarines to communicate at depth and with nearby aircraft for anti-submarine warfare. This will reduce the reliance on towed buoy receivers and increase the reliability of communications for better co-ordination between aircraft and fast-attack submarines.

Advanced underwater sensors

Sensor technologies, including nanotechnology, that detect changes in water temperature, pressure, salinity, turbidity, oxygen levels and chemical contaminants and the presence of hydrocarbons have been adapted for militaries, giving them access to important data for risk analysis and threat assessment. Devices integrated with more precise underwater measurement, for example using quantum technology, will enable superior navigation, sensing and detection of underwater threats including mines.



Quantum sensor prototype undergoes trials

A prototype quantum sensor, developed by academics at Imperial College London, has been undergoing trials conducted by The UK Royal Navy. The technology has the potential to help enable GPS free navigation, making it ideal for use in areas with poor or no satellite coverage. The sensor is a new type of accelerometer which measures how an object's speed changes over time. By combining this information with rotation measurements and the initial position of the object, the current location can be calculated.

Robotics

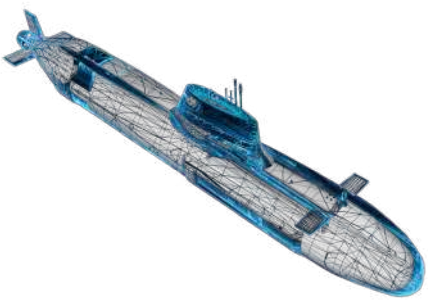
Remotely operated vehicles (ROVs) and autonomous unmanned vehicles (AUVs) used in the oil and gas sector for underwater search and exploration, inspect and survey subsea infrastructure to assess condition and maintenance requirements. ROVs are typically tethered to a cable that provides power and communications whereas AUVs operate independently without the need for real-time human control and they can be equipped with cameras, lights and robotic arms. Militaries have been increasingly using these vehicles integrated with sensors, for a wide range of data gathering operations, including reconnaissance and intelligence gathering missions, tracking underwater adversaries, mine detection and underwater mapping.

UK Royal Navy orders first crewless submarine

Cetus is the name being given to a £15.4million crewless submarine which will become The Royal Navy's largest and most complex crewless submersible. Named after a mythological sea monster, it will move stealthily through the oceans to monitor hostile activity and listen for ships and submarines that may pose a threat to the Fleet or to key national infrastructure such as deep-sea cables and pipelines. Twelve metres long and 2.2 metres wide, the 17-tonne submarine can fit inside a shipping container and be transported around the world to wherever the Fleet needs it. The unarmed battery-powered craft will be able to dive deeper than any vessel in the current submarine fleet and cover up to 1,000 miles in a single mission.

Gravitometry

A technique used to measure variations in the Earth's gravitational field can aid the detection of submarines, mines or other threats or geological formations, by detecting anomalies in underwater gravity caused by their presence. This technology provides crucial information for ASW and for maintaining situational awareness. By utilising quantum sensors, quantum gravimetry could introduce much greater accuracy in the information gathered for ASW and in navigational abilities.



Hunt for the Red October film exposes state secrets

According to a number of sources, the film 'Hunt for the Red October' revealed classified information about the use of gravitometers for submarine navigation.

Retired CIA officer Bill Hadley, describes in the journal 'Studies in Intelligence' how some senior U.S. naval officers were "convinced the movie would do for submariners what Top Gun had done for U.S. Navy jet fighter pilots." The Navy even allowed the use of its submarines in the film and its movie's stars, Sean Connery, Alec Baldwin, and Scott Glenn were given unprecedented access to their submarines and even training in submarine steering. At one point in the film, a crew member mentions 'milligal anomalies', exposing the use of gravimetry in underwater operations.

Tom Clancy, author of the book on which the film is based and renowned for the technical detail of his best-selling military thrillers, originally revealed the use of gravitometers through the plot involving a Russian submarine. At the time the book was published in 1984, no Russian vessel carried such elaborate gear, but the US were using a somewhat more complex system using gravimetry.

Materials science

The development of a wide range of advanced composites and materials that are resistant to corrosion, pressure, detection and marine life (biofouling) are being leveraged for submarines and military equipment.

Biofouling mitigations

The outer protection of underwater vehicles is crucial to their safety, durability and performance and the use of advanced materials such as paints and coatings can have multiple benefits including enhancing stealth, minimising drag and preventing marine growth, while offering corrosion protection and ultimately increasing efficiency whilst reducing costs.

Biofouling, the attachment of living organisms such as algae, barnacles and tube worms to a submerged aquatic surface, is becoming an increasingly significant problem within the underwater domain for multiple reasons. Not only does it increase resistance to the underwater vehicle's motion, known as 'hydrodynamic drag', thereby reducing its speed and fuel efficiency, it can also compromise its operational capabilities and stealth as the attached organisms serve to increase its signature. In addition, stringent measures are being taken by some governments to monitor and prevent biofouling, known as antifouling, to protect their waters from invasive aquatic species. For example, the Australian and New Zealand governments have adopted regulations to control biofouling which has resulted in ships being refused entry to ports in both countries and significantly impacting ship operations and passengers.

Biofouling can also compromise the safety of submarines, as one incident in 2011 highlights, in which a submarine crew were overwhelmed by heat exhaustion, caused by barnacles blocking the vessel's air conditioning inlet pipes. Three hours after HMS Turbulent left Fujairah in the United Arab Emirates, 26 of the 130-strong crew suffered from intense heat exhaustion when temperatures inside the submarine reached 60 degrees Celsius. Once the engineers had fixed the problem, the submarine was taken to deeper depths to aid cooling in the submarine and the injured crew received treatment by medical staff.

Previous methods of biofouling prevention involved the use of toxic coatings called biocides to clear colonies of barnacles from the vessel's surface but legislation passed in 1998 seeking to better protect the environment has led to the development of more innovative approaches. Professor Anthony Brennan at the University of Florida has been investigating how the unique pattern of shark skin, for example, naturally prevents the adhesion of micro-organisms. This has led to a new biomimetic technology called 'Sharklet' (as featured in the WIRED x QinetiQ report: Transforming Defence), which has shown very positive results in inhibiting marine growth or 'antifoulant' properties.

Another approach to antifouling is the incorporation of 'zwitterionic' or mixed-charge compounds into coatings. The compounds possess both positive and negative charges and have proven very effective in preventing bacteria, algae, barnacles and tubeworms from attaching to its unique surface.

Protection from a harsh environment

Corrosion is a constant threat to the structural integrity of underwater vehicles as it can lead to cracks which can have devastating consequences, making protection against the harsh environment of the sea a safety priority. Repairs to corrosion are also extremely costly, not least of all because the platform is unavailable for use while they are carried out. With the expected lifetime of a submarine being 20 - 30 years, the need for ongoing repairs over this long period of time leads to serious inefficiencies.

Hull materials are typically constructed using high-strength alloys that resist corrosion, such as HY100 steel or titanium and anti-corrosion paints and coatings such as epoxy-based materials provide a barrier between the hull and seawater. Cathodic protection is one of the most effective methods to prevent corrosion of submerged structures. In submarines, metal 'sacrificial anodes' typically made of zinc or aluminium are installed which corrode more readily than the hull, thereby protecting it. Certain parts of the submarine such as gaskets and seals are often made from rubber or synthetic materials which are less prone to corrosion.

Emerging technologies for corrosion protection are vital to ensure the longevity and performance of submarines. Examples include advanced coatings such as graphene and nanotechnology based materials, self-healing materials which have the ability to repair minor damage and sensors that monitor corrosion.

Underwater energy storage and power generation

As nations seek to reduce their dependence on traditional fossil fuels, they are turning to cleaner, more efficient options. Hydrogen fuel cells are being explored as a power source for submarines, which, when the hydrogen is converted to electricity, only produce water as a byproduct. Air Independent Propulsion (AIP) systems also have the potential to improve the performance of conventional diesel electric submarines, enabling them to operate without surfacing for extended periods. Powered by various fuels including biofuels and liquid oxygen, they enhance stealth while being more environmentally friendly.

Environmental monitoring and impact assessment

Cutting edge technologies such as 'synthetic aperture sonars' and 'multibeam echosounders' which are equipped with thousands of individual sonar beams, can generate much higher resolution bathymetric (depth measurement) data, providing high resolution 3D maps of the seafloor. This has also led to a greater understanding of underwater topography (the shape of the seabed), greatly enhancing navigation accuracy. Mine countermeasures, identifying potential hiding places and the protection of infrastructure are all further examples of the importance of these technologies.

The need for accurate underwater navigation charts

Underwater military operations are not only reliant on accurate PNT, but also a very accurate knowledge of the physical characteristics and features of the seabed terrain. In October 2021, this was demonstrated by an incident involving a US nuclear powered fast-attack submarine when it collided with an underwater mountain in the South China Sea, injuring 11 crew members and causing in excess of $50 million of damage to its bow and rudder. Researchers believe that more than 100,000 seamounts rise more than 1,000 meters from the seafloor, most of which were formed by undersea volcanoes.

Setting the scene for the future

"It is an exciting time in the underwater environment, we are now seeing the potential of advanced sensors, uncrewed systems and large-scale data exploitation starting to yield significant benefits. Much of this technology is widely available and speed of adoption and adaption are a key priority to retain operational advantage. For the foreseeable future the focus is on the teaming of crewed and uncrewed systems, leveraging already capable ships, submarines and aircraft. Enabling increasingly skilled operators to deliver greater mass and operational pace (or tempo); i.e. doing more and doing it faster and better, and with lower operational risk – that's the goal. To this end, submarine and mine warfare are seeing very significant investment globally, and defence of Critical Undersea Infrastructure (CUI) is another area very much in the spotlight."

Bill Biggs

Senior Consultant on Robotics and Autonomous Systems, QinetiQ

HORIZON SCANNING

DEEP DIVE

Foreseeing the Future: An Insider Look Into Horizon Scanning and Its Use in Strategic Foresight

"We watch the horizon to catch a glimpse of those things that are going to affect us so that we can plan, prepare and act in response. The modern, data rich world offers unprecedented opportunities to do this in ways that a generation ago could only be imagined. Defence is intent on exploiting this situation and relies on its partners in industry, academia and society at large to do this, to anticipate and respond to the emerging threats of the 21st Century."

Major S Imran Ahmed

UK Ministry of Defence

In recent years the global explosion of innovation, information, and the uncertainty and opportunity that they bring, has brought horizon scanning back into vogue. Organisations and governments alike are seeking to shine a steady light through a dense mist of uncertainty to make better technological and strategic bets.

The richness and complexity of data and expertise available, coupled with an increasingly fluid and shifting ground beneath our feet, has created a seemingly paradoxical situation; it's getting harder to accurately model potential futures, yet it's never been more important to do so. In this insider look into horizon scanning, we give you our take on the complexities of anticipating future developments, and how to navigate them more effectively.

What Is Horizon Scanning?

Horizon scanning fits into the wider process of strategic foresight, where organisations attempt to derive useful insights from a range of existing data sources, and use them to adjust their future plans and actions to better achieve their strategic goals.

Because the context of horizon scanning is always evolving, the definition of the term and the actual things that 'horizon' and 'scanning' refers to, can take on many different practical meanings. What constitutes viable horizons and appropriate scanning methods, varies by topic, industry, context, technologies, purpose, stakeholders, and more.

With the crucial qualification that horizon scanning is in practice an amorphous and dynamic concept, a methodical review on horizon scanning methodologies has boiled down most definitions of it to: "a systematic examination of information sources to detect early signs of important developments."

These signs, or signals, can be strategically significant when they are linked to other economic, social, legal and commercial developments. For this reason, horizon scanning needs to be holistic, continuous, multidisciplinary, and encourage fresh thinking and creativity.

The information can be taken from a wide range of sources, including experts, journals, patents, news articles, and databases. The pieces of information from these sources are known as signals, most of which will have a low-level of validity and significance. To separate the wheat from the chaff, the signals are filtered, prioritised, and then assessed by their potential impacts to create strategically meaningful insights and models of how the future could play out.

QinetiQ's horizon scanning typically focuses on the early lifecycle of technologies ahead of their potential adoption in the market, but can also be used to examine broader trends, challenges and opportunities. The signals derived from horizon scanning can be used to anticipate and navigate potential bottlenecks to the adoption of new technologies, as well as for uncovering strategic insights that help to minimise risks and maximise opportunities.

Horizon scanning reports are not comprehensive studies, nor are they crystal balls. Rather, they provide qualified and digestible insights that help organisations to make more comprehensive strategic assessments that inform their decisions and actions.

The Dawn of Horizon Scanning and Scenario Modelling

In the decades following World War II, modelling how the future could play out became an increasingly important focus for government bodies and corporations alike. This was done largely through forecasting developments using existing data and trends, but the linearity of this approach exposed its own limitations, which drove a growing adoption of scenario modelling and horizon scanning for strategic foresight.

Forecasting proved useful insofar as an existing trend could be verified to continue at a certain pace, but proved far less useful for longer time horizons, and relatedly, anticipating the disruptive shifts that arise from the lateral and subtle coalescence of new developments from a range of different areas.

Forecasting methods did, and still do, create many erroneous predictions, which led Shell to abandon its Unified Planning Machinery (UPM) program in the early 1970s. In a 1991 forecasting report, the Japanese government failed to predict and leverage what would become the exponential growth of the domestic mobile phone market. By 2005, it was five times higher than forecasted.

The issues of linear forecasting continued to encourage a more non-linear approach. After abandoning its UPM program, Shell pioneered a more expertise and creativity driven approach to potential futures. This led to Shell pioneering its scenario planning technique, which enabled the company to enjoy considerable success in anticipating the 1973 and 1981 oil crises.

First developed in the 1960s within the Stanford Research Institute, horizon scanning was originally used to create scenarios of future social change by finding weak but significant emerging signals lying outside of the scope of mainstream perspectives and trends. In combination with scenario modelling, it enables organisations to leverage these signals to envision a wider array of potential scenarios, assess their time to impact, probability, significance, and desirability. In turn, this enables them to alter their strategic roadmaps accordingly.

As the world became more complex, dynamic and unpredictable, using horizon scans to scout for potential trajectory-changers lying beyond the territory of the known, became increasingly essential for strategic foresight. Since then, a greater number of actors and information sources has driven a more widespread and diverse adoption of horizon scanning in the strategic foresight process, including by governments, corporations and regulatory bodies.

Approaches To Horizon Scanning

Previously, scans relied on networks of experts and traditional literature review methods such as academic journals and research. However, the development of technology has created new methods for undertaking scans, such as the deployment of large language models for analysing sentiments at scale online.

Some organisations such as Shaping Tomorrow, focus more on using AI and data-driven methods across a wide range of sources to deliver their horizon scanning services. While others such as Forrester, focus more on leveraging and engaging with networks of experts and stakeholders and using a smaller pool of trusted information sources, to find, prioritise and assess signals.

Different approaches to horizon scanning have been devised for finding the ripples that could become waves in the future. Although each follows the same fundamental process, they use different methods that can be more or less effective, depending on the context.

The process begins with scoping the scan's purpose, time horizon and information sources, and assembling a scanning team. This is followed by the collection, filtration, and prioritisation of signals, which are then organised into a report and distributed to decision makers and stakeholders for assessment and actioning. Experts are typically engaged throughout the process to verify and assess the quality and importance of the signals.

Although in reality there are as many approaches as there are horizon scans, the diverse methods employed by organisations can be grouped into three approaches. These can be labelled the traditional, data-driven, and stakeholder-oriented approaches, with the latter two being more recent developments. In reality, most organisations use a blend of the three in different mixes to gather, filter and prioritise signals.

"A bracingly informed, evidence-led look at 'possible futures' based on thorough, dispassionate research about what's happening in the here and now and the trends that are emerging. For WIRED Consulting, most projects we are involved in require us to undertake some version of that process.
We use a range of sources - qualitative, quantitative, public domain, private - but one thing that I think can often be vital is speaking to a range of experts in the relevant field across academic, commercial and public organisations."

Charlie Burton

Head of Editorial Content at WIRED's UK Consulting division

Approaches to Horizon Scanning in the Strategic Foresight Process:

	Horizon Scanning			Engagement and Consideration	
	Scoping	**Collection**	**Filtration**	**Prioritisation**	**Assessment**
	Assemble scanning team, determine where to look and how	Identifying and collecting weak signals	Discarding irrelevant signals	Choosing which signals to prioritise based on probability and impacts.	Determining the potential material impacts and implications of prioritised signals, and appropriate responses to them
Traditional	- Academic papers - Industry reports - News articles - Patents - Expert networks - Specialised institutions - Regulatory frameworks and organisations	- Insights - Statistics - New events - Expert interviews - Quantitative data	- Peer review - Classification - Criterion - Manual filtration	- Rating and ranking - Risk analysis - Delphi approach	- Driver modelling - Scenario modelling
Data Driven	- Social media platforms - Websites and documents - Databases	- Web crawling and scraping - Text scanning and processing	- Sentiment analysis - Data mining	- Natural Language Processing - Predictive modelling (machine learning)	- AI-driven scenario modelling (statistical)
Crowd-sourced	- Social media platforms - Research organisations - Crowdsourcing platforms - Forums and expert communities	- Expert panels/ workshops - Surveys - Focus groups - Stakeholder interviews	- Pre-screening contributions - Peer validation - Expert validation	- Expert impact assessment - Weighted crowd insight scoring	- Driver modelling - Crowd-sourced scenario modelling

Note: Experts are best involved in each step of the process for creating valid and meaningful scans.

"Prediction is very difficult, especially about the future"

This quote from Niels Bohr points to the key crux of leveraging horizon scanning effectively for strategic foresight; we need to seriously consider the validity of our existing data, assumptions and insights before we can viably piece them into trajectories of potential futures.

Mistaking the map for the territory and settling with a fixed set of tools and assumptions for mapping it, can lead to errors such as missing key signals, falling for the false hype surrounding many new technologies, and mischaracterising the nature and impact of emerging trends.

At its best, horizon scanning is a continual practice that questions assumptions, triangulates perspectives and knowledge, and contributes to robust yet open-ended strategic frameworks that are amenable to creative insights.

Even visionaries make inaccurate predictions. Famously, Steve Jobs predicted that the live streaming of music could never take off. While back in 2004, Bill Gates predicted that spam would cease to be a problem within two years.

For this reason, constantly sharing intelligence, collaborating, and tapping into expert knowledge, is crucial for attaining effective strategic foresight from horizon scanning. By embedding these practices into horizon scanning, organisations will be better placed to enrich their strategies by asking their unasked questions and identifying their unknown unknowns.

Valuable Horizon Scans Need Validity

Fundamentally, the value that horizon scanning provides to an organisation's strategic posture is probability-based. Its purpose is to maximise opportunities and minimise risks by providing continually curated insights from a range of sources, disciplines and sectors.

Although the strategic benefits of horizon scanning are anchored in probabilities, one thing is guaranteed – organisations that do not use horizon scanning will be comparative net losers, as they will inevitably become laggards and victims of blind spots. That said, poorly conducted horizon scanning can be just as damaging; a bad bet made confidently, is still a bad bet.

A key reason for the recent uptake in horizon scanning services is that organisations of all sizes are becoming aware of their relative unawareness in a faster, more interconnected and information-saturated environment. They need a way to filter valuable signals from a cacophony of noise.

Verifying Horizon Scanning Signals

The benefits of horizon scanning are founded on the scope and validity of the scans themselves, the understanding of contributors and decision makers, and the quality of knowledge sharing.

Regardless of the specific approach that is used, there are three key contributing pillars for validating the materiality and predictive significance of signals. These pillars are:

1. Confidence that as much quality information as possible has been captured.
2. An understanding of technology in general.
3. Knowledge of the specific technologies involved in the scanning topic, their use cases, and the industry context.

To derive strategic benefit from horizon scanning, all three of these pillars must be present and triangulated together, rather like the three legs of a stool. The organisations that can verify, synthesise and utilise a holistic range of signals in an agile way, will be better placed to make effective bets that empower their strategic success.

Signal Quality Contributors	**Signal Quality Risk Factors**
- Triangulation of sources and data	- Isolated data sources
- Depth and breadth of expert involvement	- Unquestioned assumptions
- Positive cross-expert appraisals	- Poor signal filtering
- Promising or solid evidence base	- Lacking evidence base
- Signal is relevant in other contexts and industries	- Over-reliance on numerical data
	- Misaligned information source motivations

Top three practices for creating valid and useful horizon scans

Charlie Burton, WIRED Consulting

1. Start with a realistic and clear-eyed sense of what horizon scanning can and can't achieve.

The main thing is that it is not about 'accurately predicting the future'. Nobody can reliably and consistently do that. It is more about taking a bracingly informed look at 'possible futures', considering the implications and desirability of those scenarios, and assessing the questions that they throw up for how we live and work today.

2. Root the future gazing in careful, evidence-led analysis that draws on multiple credible data points.

For the kind of work we do, I think it's often helpful to take a relatively far-reaching approach to sourcing insight and expertise. Clearly, traditional sources such as scientific journals, market analysis, and published expert commentary are important - but it can also be appropriate, if approached with a sufficient degree of critical thinking, to look at sources such as social media discussions (particularly on expert forums), say, or specialist newsletters. I think it's also particularly helpful to pick up the phone and speak to people working in the fields in question, to hear from the front line directly. Finally, I think it's also perfectly valid to speak to generalists whose work encompasses the field in question, because their 'outsider's perspective' can be useful for seeing the bigger picture, and is often untainted by 'insider' biases and orthodoxies.

3. Have a defined sense of your parameters.

What are you trying to achieve? What time frame do you want to look at? How do you want to use that in the here and now? For example, if you are a business operating on a 3-5 year cycle, you will want to look at a shorter timeframe than a government considering demographic trends on the generation scale.

How the horizon scanning results are processed and presented should keep those parameters and goals firmly in mind. Horizon scanning can produce reams of material, so a judicious analyst who can fillet it for information directly relevant to the questions germane to the task at hand, can explain the 'so what' of how the research relates to those questions, and can communicate all that in a succinct and accessible way is important.

Automation and AI in Horizon Scanning

The rise in generative artificial intelligence (GAI) presents opportunities and challenges for horizon scanning. In contrast to automated tools such as web crawling and explicitly programmed keyword-based filtering, GAI is a newer development for the world of horizon scanning that can bring a softer intelligence to the process.

Of course, the role of humans and experts is crucial for properly filtering and prioritising the signals and trends that emerge from AI-driven tools. A key risk in using automation and GAI is that these tools can create a lot of noise to sift through, and they can only be as good as their designers' data and thinking. For now, GAI is not able to exhibit the degree of creativity, discernment, fresh thinking, and acuity of insight that horizon scanning and strategic foresight calls for.

Separating Hype from Reality: Prioritising Signals

Identifying the significant ripples that can become waves in the future is crucial for deriving strategic benefits from horizon scanning. Due to economic, psychological and political factors, most publications, media coverage and experimental data shroud the true potential value of technological, social and strategic developments. Because of motivational drivers, the maturation and imminency of technology can be inflated and lead to unwarranted conclusions.

This is seen in many contexts where small developments within a technology such as blockchain, 3D media, and virtual reality, sparks renewed public, corporate and research interest. After a short time, the interest subsides again due to lingering inconveniences, constraints, and costs associated with the technology's development and adoption, regardless of its merits as a potential idea.

This kind of cycle resembles the humps of a camel. Amidst the ups and downs of interest, finding the true take-off point for a technology's maturity is the name of the game. By looking at previous signals and trends, an organisation can determine if a signal is just 'another one of those' or is indicative of a wider shift with strategic significance.

Good and Bad Predictions About the Future

Good: Nikola Tesla's Predictions About Wireless Connectivity and Smart Devices

Nikola Tesla was a pioneering inventor and a somewhat eclectic character who made a range of accurate long-range predictions about the future. In a 1926 interview, he described how mobile phones would work and foresaw capabilities such as video conferencing, the wireless sending of documents and videos, and how wireless connectivity could be used to power devices to work for us; in essence, the Internet of Things.

Tesla exemplifies some of the best qualities that can be brought into a horizon scanning process as well as some of the risks. By combining his deep expertise across physics and engineering, coupled with an eccentric outlook and brilliant intuition, he was able to anticipate many groundbreaking developments that would emerge from the coalescence of multiple scientific and technological disciplines.

However, there is a risk to siloed and eclectic predictions that is reflected by a higher risk-reward relationship; if organisations betted on some of Tesla's predictions, they would have won big, and likewise for some of his predictions, such as aircraft powered by on-ground stations, they would have come out empty handed as well.

Bad: Nokia's Failure to Respond to Signals in the Mobile Phone Market

Nokia is a fateful example of how a dominant player can misestimate and respond to developments within its industry. Nokia's failure to adapt to signals became obvious in 2007 with the release of Apple's iPhone, which prompted a rapid market shift to smooth touchscreen experiences, complemented by a diverse and feature-rich app ecosystem.

Initially, the company lagged behind in its response, continuing to produce phones with physical keyboards and resistive touchscreens. It acquired Symbian in 2008, an originally pioneering but increasingly outdated operating system provider, which failed to provide a developer-friendly and competitive app ecosystem compared to the Android and iOS platforms. Nokia's smartphone market share began dropping precipitously, plummeting from nearly 50% in 2007, down to 3% in 2013.

Several issues, including an ineffectual partnership with Microsoft in 2011, organisational inertia, and a lack of innovation and organisational agility, led the company to lose its market dominance. Nokia's example highlights the importance of swiftly acknowledging, understanding, and responding to emerging signals, alongside the importance of questioning assumptions, especially when it is painful to do so.

Bringing Clarity to Foresight: Applying Horizon Scanning

Done effectively, organisations can leverage and engage with insights from horizon scans to inform how and where they invest their strategic resources in the future. Horizon scans are akin to potential pieces of a wider strategic puzzle that can be fitted together for a clearer and actionable picture.

After a set of horizon scans are completed, the signals can be used to develop different scenarios of how the future will play out, the likelihood and impact of risks and opportunities involved in each scenario, as well as the concrete steps and adjustments to be taken to meet the organisation's strategic goals.

If the findings of horizon scans are harnessed effectively, organisations can become more agile, foresightful, innovative, competitive, and prepared for potential future developments. The wider field of strategic foresight, like horizon scanning, is never a silver-bullet. Organisations should remember that as essential as anticipating the future is, these insights amount to unearthing probabilities of what could be, and then acting accordingly.

For organisations seeking to leverage emerging technologies, horizon scans can be informed by and used alongside a taxonomy of technologies, identifying new areas and items, mapping the connections and dependencies between them, alongside the wider legal, social and political factors that will impact their maturity and adoption.

Applying Horizon Scanning: Leveraging Disruptive Technologies in Defence

Defence is a particularly promising area where horizon scanning can equip organisations with insights for adopting emerging technologies with more agility and effectiveness.

Many military organisations encounter inertia in their adoption of emerging technologies, which arises from using a more deliberative approach. They are more likely to procure and deploy new technologies once they have crossed the chasm towards more widespread adoption, however, this elevates the risk of being out-innovated by actors that embrace and leverage uncertainty. To unlock the full value that horizon scanning has to offer, it must work in concert within a wider culture and system that leverages a degree of risk and uncertainty.

By embracing uncertainty, change, and continual improvement, this approach alongside horizon scanning, can ensure that feedback loops for deploying an emerging technology can be more holistic, fast, thorough, and incorporate feedback from a wider array of sources, such as users, regulators, and suppliers.

One example of where this approach fruitfully meets with horizon scanning, is prototype warfare. Horizon scans can continually find and assess a range of signals that are relevant to a technology before and throughout acquisition processes, which can then be used to exploit new opportunities and mitigate risks.

In this context, it would be misleading to believe that prototypes would replace existing capabilities outright. The combination of horizon scanning with the philosophy of prototype warfare is rather about competitively realising the potential of an emerging technology, in a way that is proportionate to its existing maturity, risks and integrability. In principle, the role of horizon scanning for the adoption of maturing technologies remains the same across other domains.

Seeing Into the Technological Horizon

A key benefit of conducting horizon scanning for assessing emerging disruptive technologies, is that it helps to identify and navigate bottlenecks to adopting innovations, which are otherwise blocked by what Jeffrey Moore refers to as the 'chasm'; the interlinked technological, informational, organisational and social bottlenecks and gaps, that prevent a technology from being widely deployed and adopted.

To stay at the cutting edge today, organisations will need to pick up on the right signals and respond to them appropriately. This requires making the right investments into upcoming technologies that will have varying time horizons to maturity, taking the steps to align, test and integrate them ahead of competitors.

By leveraging horizon scans in this way, organisations can derive a range of benefits, including greater strategic responsiveness, risk minimisation, enhanced innovation, optimal resource allocation, and the faster adoption of new technologies.

The Place of Horizon Scanning Today

The seeming paradox of making effective bets on the future under mounting conditions of complex uncertainty, does not mean that organisations will be unable to detect and respond to the most impactful signals of future developments. Rather, the rising pace, complexity and interconnectedness of the world is calling for more holistic, integrated and responsive practices for deriving and leveraging strategically meaningful insights.

As long as horizon scanning practices meet the challenges of this expanding context, it will continue to add strategic value to organisations across the world. Serving as an approximative tool that empowers organisations to pick up on the most promising and underlooked ripples that could become waves in the future, enabling them to make better bets that complement their strategic success.

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